SOCIAL AND SCIENTIFIC ISSUES

IN THE

ACCEPTABILITY OF RADIATION RISKS

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Ionising radiation hazards are perhaps the most documented and regulated occupational and environmental hazard. In the radiological protection field a single expert advisory organisation has held an unusually large influence on the international standard setting process. This is the International Commission on Radiological Protection (ICRP).

Two common, and opposing views, exist over the formulation of protection recommendations by the ICRP. The first, and most widely accepted, is that its recommendations are *scientifically determined.* The second view, is that its recommendations are *politically or socially determined.* Neither of these analyses adequately accounts for the complex process in which protection recommendations are formulated. A third view, provided by studies of the origins of the scientific controversy, suggests that both science and social factors are important in the assessment and limitation of risk.

The aim of this thesis is not simply to examine the origin of controversy. An issue of equal, if not more, importance is the resolution of controversy and the formation of consensus and the maintenance of expert authority and influence. This issue forms the central focus of this thesis. The aim is to assess the process through which the ICRP formulates its radiological protection recommendations and comment on the extent that these are influenced by the affiliations of its members.

This thesis concludes that the ICRP's recommendations have been shaped by a complex relationship of scientific and social considerations, in which a socio-technical commitment to nuclear energy has played a key role. The Commission has responded to new scientific data by making complex changes to its philosophy and methods of describing risk. Where reductions in numerical limits have been applied they have been accompanied by practical measures designed to limit the impact of the change and provide continuity with the old limits and flexibility in the application of the new recommendations.

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ABBREVIATIONS

AERE	Atomic Energy Research Establishment
ALARA	As Low As Reasonably Achievable
AWRE	Atomic Weapons Research Establishment
BEAR	Biological Effects of Atomic Radiation Committee, U.S National Academy of Sciences
BEIR	Biological Effects of Ionising Radiation Committee, U.S National Academy of Sciences
BNF	British Nuclear Fuels
BXRPC	British X-ray and Radium Protection Committee
CEGB	Central Electricity Generating Board
CMBANP	Committee on the Medical and Biological Applications of Nuclear Physics
FoE	Friends of the Earth
HSC	Health and Safety Commission
HSE	Health and Safety Executive
ICRP	International Commission on Radiological Protection
ICRU	International Commission on Radiation Units
IXRPC	International X-ray and Radium Protection Committee
LET	Linear Energy Transfer
MPD	Maximum Permissible Dose
MRC	Medical Research Council
mSv	Milli-sieverts
NCRP	National Council for Radiation Protection and Measurements (U.S)
NRPB	National Radiological Protection Board (U.K)
PIRC	Committee on Protection Against Ionising Radiation
PWR	Pressurised Water Reactor
r	Röntgen
RERF	Radiation Effects Research Foundation, Japan
RPS	Radiological Protection Service
Sv	Sievert
TDP	Tolerance Doses Panel
UKAEA	United Kingdom Atomic Energy Authority
UNSCEAR	United National Scientific Committee on the Effects of Atomic Radiation
USAEC	United States Atomic Energy Commission
USXCXRP	United States Advisory Committee on X-ray and Radium Protection
WHO	World Health Organisation

NOTES ON RADIATION UNITS AND RISK

1: Radiation Units

Three different units of radiation dose or exposure are used in this thesis, according to the unit in use during the period under discussion. For purposes of comparison the following conversions apply:

1 röntgen = 1 rem = 10 milli-sieverts

100 rems = 1 sievert

2: Risk Estimates

The risk from exposure to radiation can be expressed in a variety of different ways. The methods used in this thesis correspond to those used in each source document. A risk estimate is a measure of the probability that a deleterious effect, such as fatal cancer, will occur in a specified time. The two main methods used are; (i) an estimate of individual risk following exposure to a unit of radiation dose, ie the risk per Sievert (or per Rem) of radiation; and (ii) the number of predicted cancers occurring in a population exposed to radiation.

Under the first method, the current NRPB risk estimate for fatal cancer in the general population would be written as 4.5 % per Sievert. This means that every person, who receives a dose of one Sievert, faces a 4.5 % increase in their risk, or a 1 in 22 chance, of developing a fatal cancer. This could also be written as 4.5×10^{-2} Sv^{-1}, (or 4.5×10^{-4} rem^{-1} if the old radiation units are used).

Under the second method, the current NRPB risk estimate would be written as 450 fatal cancers per 10,000 person-sieverts (or 450 fatal cancers per million persons-rems). This means that if ten thousand people each received a dose of one SIEVERT (100 Rems) 450 of them could be predicted to develop a fatal cancer. Each one of them would face a 1 in 22 chance that they would develop a fatal cancer.

CHAPTER 1: INTRODUCTION

The notion of "risk" has become a central factor in the regulation of a variety of occupational and environmental hazards during the past few decades. Decision makers at all levels of Government and society have found themselves faced with choices over the risk, cost and benefits of particular policy decisions.

Until recently the identification and quantification of risk was seen as the domain of the scientific expert. Many recent debates have seen this domain challenged[1]. Analyses of risk have become central components of public policy debates over Government action in regulating risk[2]. These debates are frequently characterised by the adversary positions adopted by scientists acting in the role of industry or governmental advisers and scientists or lay persons operating outside the "official" and often closed decision making process. Each side maintains that its case is supported by the available Scientific evidence[3]. The number of such controversies has led the process of using advisory committees to secure

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[1]Cole L.A (1983) 'Changing Attitudes within the Scientific Community', Bulletin of Science and Technology in Society 3 107-117
Nelkin D (1975) 'The Political Impact of Technical Expertise', Social Studies of Science 5 35-44
Nowotny H (1981) 'Experts and their Expertise: On the Changing Relationship between Experts and their Public', Bulletin of Science and Technology in Society 1 235-241
Nowotny H (1982) 'Experts in a Participatory Experiment: The Austrian Debate on Nuclear Energy', Bulletin of Science and Technology in Society 2 109-124
Robbins D and Johnston R (1976) 'The Role of Cognitive and Occupational Differentiation in Scientific Controversies', Social Studies of Science 6 349-368

[2]Regens J.L, Dietz T.M and Rycroft R.W (1983) 'Risk Assessment in the Policy-Making Process: Environmental Health and Safety Protection', Public Adminstration Review 43 137-125

[3]Del Seato S (1983) 'Uses of Knowledge and Values in Technical Controversies: The Case of Nuclear Reactor Safety in the U.S', Social Studies of Science 13 395-416

consensus in support of policy decisions to be increasingly questioned[4]. A central issue is not "how safe is safe", but *who* decides and *how*[5].

Examples of such public controversies include: the siting of nuclear power stations or nuclear waste repositories[6]; the risks of lead in petrol[7]; the risks of smoking[8] or the use of pesticides[9].

Lowrance has argued that risk assessment involves two processes. First, the scientific quantification of the hazard under consideration. Second, the social regulation of the hazard[10]. On the other hand, in many regulatory areas it is often difficult to separate the scientific considerations of risk from the social aspects of the regulatory action. Consequently, the boundaries between science and social judgements become obscured[11].

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[4]Steward F (1982) 'Scientific Expertise, Workers Interests and Public Involvement; Industrial Risks as an Example', In Risk and Participation Proceedings of the Second Conference on Science, Society and Education, Leusden, Holland August 17-20, 1982 48-57

[5]Irwin A (1985) Risk and the Control of Technology, Manchester: Manchester University Press

[6]Bickerstaffe J and Pearce D (1980) 'Can There Be a Consensus on Nuclear Power?', Social Studies of Science 10 309-344

Mazur A and Conant B (1978) 'Controversy over a Local Nuclear Waste Repository', Social Studies of Science 8 235-243

Nelkin D (1971) 'Scientists in Environmental Controversy', Science Studies 1 245-261

[7]Collingridge D and Reeve C (1986) Science Speaks to Power The Role of Experts in Policy Making, London: Francis Pinter

[8]Reeve C (1981) Smoking and Lung Cancer An Example of Disagreement between Experts in Decision-Making about Technology, Msc Thesis Birmingham:University of Aston

[9]Gillespie B, Eva D and Johnston R (1979) 'Carcinogenic Risk Assessment in the United States and Great Britain: The Case of Aldrin/Dieldrin', Social Studies of Science 9 265-301

[10]Lowrance W. W (1976) Of Accepatable Risk Science and the Determination of Safety, California: William Kaufmann Inc

[11]Jasanoff S.S (1987) 'Contested Boundaries in Policy-Relevant Science', Social Studies of Science 17 195-230

National Research Council (1983) Risk Assessment in the Federal Government: Managing the Process Committee on the Institutional

The uncertain nature of the basic scientific information is frequently complicated by disputes between scientists over how to interpret the data. This is seen as a scientific issue, although these judgements may be shaped by non-scientific influences[12]. On the other hand, social judgements about the "acceptability" of risk are often quantified in scientific terms.

Ionising radiation hazards are perhaps the most documented and regulated occupational and environmental hazard. They are also very controversial. The establishment of radiation safety standards has been marked by considerable scientific, and often public, controversy between different scientific "experts".

This is not a recent phenomena. The first radiation safety standards were established in response to the public outcry over the death of many early radiation workers: prominent radiologists and clinicians who worked with X-ray machines and radium sources in the early years of this century.

During the 1950s attention was directed towards the genetic hazards of fall-out from atmospheric nuclear weapon tests. This debate also attracted considerable public attention.

More recently the controversy has been centred around the question of "acceptable" levels of radiation exposure for radiation workers and members of the public.

Means for Assessment of Risks to Public Health Washington D.C: National Academy Press

[12]See Section 1.3 (iii).

A central element of the radiation controversy, as with many other controversies over risk, has been the role of expert advisory groups. The recommendations of such expert groups forming the basis of regulatory action. Most expert advisory groups operate in a national political context. A unique feature of the radiation debate is the international origins of the safety standards that form the centre of the controversy. In the radiological protection field a single expert advisory organisation has held an unusually large influence on the international standard setting process. This is the International Commission on Radiological Protection (ICRP).

This is thesis is concerned with the development of the ICRP's philosophy and safety recommendations. It seeks to assess the extent of scientific, social and political considerations in the standard setting process.

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1.1: THE INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

The ICRP is a unique organisation. No parallel organisation exists for regulating other occupational or environmental hazards. It is a non-governmental organisation. It is composed of thirteen scientists, and is widely regarded as the foremost authority in the field of radiological protection.

Since 1928, its recommendations have formed the basis of both international and national radiological protection standards. Consequently, the evolution of radiological protection standards are integrally linked to the development of the ICRP.

The ICRP sees its role as considering the fundamental principles upon which appropriate radiological protection measures can be based[13]. Other organisations, in the field of radiological protection, have explained this function as:

> "The International Commission on Radiological Protection (ICRP) interprets the scientific data and develops conceptual guidance on the assessment of, and protection against, radiation risks"[14].

Since different conditions apply from one country to another, the detailed elaboration of ICRP's recommendations into laws or codes of practice is left to other national or international organisations[6]. This process is not covered by this thesis. On the other hand, this thesis does look at the influence of national thinking on the recommendations of the ICRP.

The members of the Commission are

> "selected as individuals, not as representatives"[6]

and are

> "chosen on the basis of their recognised activity in the fields of medical radiology, radiation protection, physics, health physics, biology, genetics, biochemistry and biophysics with regard to an appropriate balance of expertise rather than nationality"[15].

The ICRP is regarded as the "acknowledged authority" in the field of radiological protection[16]. The independence of the ICRP and the

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[13] Sowby F.D (1981) 'Radiation Protection and the International Commission on Radiological Protection (ICRP)', Radiation Protection Dosimetry 1 No 4 237-240

[14] OECD NEA (1984) Radiation Protection The Role of the OECD Nuclear Energy Agency (NEA) Draft Document.

[15] ICRP (1977) 'Rules governing the selection and work of the Commission', In Recommendations of the ICRP, ICRP Publication 26 Oxford: Pergamon Press

[16] OECD NEA (1984) Radiation Protection The Role of the OECD Nuclear Energy Agency (NEA) Draft Document.

expertise of its members is widely stressed in scientific literature and in publicity material or information documents issued by the Commission itself, the nuclear industry, its regulatory organisations and from governments. The following quotes are typical examples:

> "ICRP has no legislative role but its recommendations have formed the basis for regulation concerning radiation in many countries. It is independent of governments, responsible only to its peers"[17].
>
> "The ICRP is concerned with all aspects of human exposure to radiation and is an independent body made up of members elected every four years purely on the basis of their known expertise in subjects relevant to radiological protection, regardless of nationality"[18].
>
> "In 1928 the International Commission on Radiological Protection (ICRP) an independent non-governmental body, was established to recommend the maximum radiation doses to which people could be safely exposed"[19].
>
> "Permissible limits for exposure to ionising radiation are recommended internationally by the ICRP, a body of experts financially supported by groups such as the United Nations"[20].
>
> "The ICRP is an independent group of doctors and scientists established under the auspices of the International Congress of Radiology"[21].
>
> "The ICRP is a unique organisation. For the 51 years of its existence, it has been universally regarded as the prime source of authoritative advice on radiological protection. . . They represent no one but themselves - they are chosen solely for their eminence in the relevant fields of science. Thus the authority of the ICRP's recommendations depends entirely on the regard in which its members are held by their peers and, given such a high regard. . . governments frequently adopt the recommendations. Such is ICRP's reputation that some governments boast that they allow no

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[17]Wade B* (1981) 'Radiation and Nuclear Power', Atom November 301
*of the U.K Atomic Energy Research Establishment, Harwell.

[18]British Nuclear Forum (Undated) Nuclear Information - The Health Effects of Radiation No 1

[19]IAEA (1982) Radiation - A Fact of Life, Vienna: IAEA

[20]CEGB (1981) The CEGB and Nuclear Power - Questions and Answers

[21]Bonnell J.A (1982) Biological Effects of Radiation and the Medical Supervision of Radiation Workers, Sizewell 'B' Public Inquiry, CEGB P17

practice which will cause radiation doses that exceed ICRP's recommended limit irrespective of the cost"[22].

"ICRP is composed of independent members, chosen on the basis of their recognised activity in the field of medical radiology, radiation protection, physics, health physics, biology, genetics, biochemistry and biophysics, with regard to an appropriate balance of expertise rather than nationality. The Commission and its Committees are fully independent of both national governments and the nuclear industry although ICRP has maintained its close relationship with medical radiology"[23].

"Current British law on ionising radiations reflects the best and most widely accepted scientific advise, which comes from the International Commission on Radiological Protection (ICRP), an independent body of eminent scientists"[24].

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1.2: LITERATURE ON THE DEVELOPMENT OF RADIOLOGICAL PROTECTION STANDARDS AND THE ROLE OF THE ICRP

A considerable amount has been written about radiological protection standards and the risks from ionising radiation. Most writings on the

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[22]Richings D* (1979) 'Radiation Risks, Limits and ICRP', New Scientist 26 April 278-280
*Richings was the Deputy Director (Policy) of the U.K National Radiological Protection Board when he wrote this article.

[23]Berry R.J (1987) 'The International Commission on Radiological Protection - a Historical Perspective', In Radiation and Health The Biological Effects of Low Level Exposure to Ionising Radiation (Edited by Jones R.J and Southwood R) Chichester: John Wiley and Sons, 1987.
The author of this article was a member of the ICRP Main Commission between 1985-1989 and was a Professor at the Department of Oncology, Middlesex Hospital Medical School. He was also a member of the U.K National Radiological Protection Board, and of the Committee on the Medical Aspects of Radiation in the Environment (COMRAE) as well as a number of other Government Advisory Groups. In late 1987 he took up a post as Director of Health and Safety with British Nuclear Fuels at the Sellafield reprocessing plant in West Cumbria. He resigned from the advisory groups but stayed as a member of ICRP until 1989. When he left the Main Commission and became a member of ICRP Committee 4, on the Application of the Commissions Recommendations.

[24]Health and Safety Commission (1989) 'HSC to Issue Further Guidance on Radiation Protection', Press Release 15th September.

development of radiological protection standards have been written by those directly involved. They fall into one of several categories.

(I) Personal Recollections and Accounts

First, there are articles, or books that contain personal recollections, reminiscences or first hand experiences in the development of a particular recommendation, or of radiological protection standards generally[25]. Such sources of information generally only provide an account of events and does not attempt to analyse or interpret the thinking behind particular standards. Furthermore, they are often incompletely referenced, or not referenced at all. This severely limits their usefulness as it is difficult to assess the accuracy of the accounts. Others involved in the development of radiation protection standards have alleged that some of these articles contain errors of fact[26]. Nevertheless this type of first hand recollection is of use for general interest and in providing some background material.

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[25]Eisenbud M (1986) 'Highlights in the Evolution of Radiation Protection Practices', In Twenty Years Experience in Radiological Protection - A Review Outlook, Proceedings of the IVth European Congress, XIIIth Regional Congress of the International Radiation Protection Association, Salzburg, Austria 15-19th 1986

Healy J.W (1988) 'Radiation Protection Standards: A Historical Perspective', Health Physics 55 No 2 125-130

Kathren R.L and Ziemer P.L (Eds) (1980) Health Physics: A backward Glance - Thirteen Original Papers on the History of Radiation Protection, Oxford: Pergamon Press

Lindell B (1978) 'ICRP 1928-1978', Radiological Protection Bulletin No 24 5-9

Spiers F.W (1987) 'Early Protection and Radiological Physics', International Journal of Radiation Biology 51 841-854

Stone R.S (1946) 'Health Protection Activities of the Plutonium Project', Proceedings of the American Philosophical Society 90 11-19

[26]Taylor L.S (1981) 'Technical Accuracy in Historical Writing', Health Physics 40 595-599

(II) Official Histories by Official Historians

Second, there are accounts of the development of standards by official historians[27]. These records tend to be concerned with the development of atomic energy, or atomic weapons in a particular country. The development of radiological protection standards and the role of the ICRP is therefore a secondary topic. Where protection standards are discussed the analysis is generally one of standards reflecting the available scientific information of the time. The quality of this information, or the value judgements made in deriving a particular standard are generally not discussed.

Some of these histories, such as those concerning the development of nuclear energy and weapons in the United Kingdom, by convention do not contain any references to official source material. This makes it difficult to check the accuracy of their accounts. These can be contrasted with histories by American authors that are more completely referenced. Nevertheless, official histories are an important source of information that enable the researcher to view the development of radiological protection standards in a wider context.

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[27]Arnold L (1987) A Very Special Relationship British Atomic Weapon Trials in Australia London: HMSO

Gowing M (1964) Britain and Atomic Energy 1939-1945 London: Macmillan and Co Ltd

Gowing M (1974) Independence and Deterrence Britain and Atomic Energy, 1945-1952 Volume 1: Policy Making and Volume 2: Policy Execution London: Macmillan Press

Hacker B.C (1987) The Dragon's Tail Radiation Safety in the Manhattan Project 1942-1946 Berkeley: University of California Press

Mazuzan G.T and Walker J.S (1986) Controlling the Atom The Beginnings of Atomic Regulation 1946-1962 Berkeley: University of California Press

(III) Popular Accounts or Histories

A contrast to the personal recollections and official histories is provided by a variety of popular accounts on the subject of radiation hazards. As with the official histories these are often, though not all, primarily concerned with atomic energy or weapons. They frequently present a view that differs from the official account, challenging the validity of accepted safety standards[28].

From the perspective of the academic researcher aiming to analyse the basis of radiological protection standards these accounts do not represent a primary source of information. They tend to be critical rather than analytical. They often present radiation protection standards as resulting from a conspiracy designed to enable the nuclear industry to develop unhindered. While this viewpoint may, or may not be valid, it is often only supported by anecdotal evidence.

On the other hand, these accounts are of interest representing particular viewpoints. They provide a different interpretation of the social context in which radiological protection standards developed.

Additional background information can also be found in books by journalists on the radiation debate[29] and in news items from the popular science journals such as *New Scientist* and *Science*.

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[28]There are many books and popular articles that fall into this category. Examples include:
Bertell R (1985) No Immediate Danger - Prognosis for a Radioactive Earth, London: The Womens Press
Gofman J.W and Tamplin A.R (1979) Poisoned Power Emmaus Pa: Rodale Press
Pringle P and Spigelman J (1983) The Nuclear Barons, London: Sphere
Smith J (1985) Clouds of Deceit, London: Faber and Faber
Sternglass E (1981) Secret Fall-out - Low Level Radiation from Hiroshima to Three Mile Island New York: McGraw Hill

[29]Caufield C (1989) Multiple Exposures - Chronicles of the Radiation Age, London: Secker and Warburg

(IV) Reviews of the Development of Protection Standards

The fourth source of information are articles in the scientific literature, or books that review and comment on the development of radiological protection standards. Material from this category also tends to be written by those with a personal involvement in this issue. These reviews appear in several forms:

(i) historical reviews of organisational changes in bodies such as the ICRP[30], or other international or national protection institutions[31];

(ii) discussions of the changes that have occurred in progressive recommendations or regulations, either internationally or nationally[32]. (This approach may also be combined with a discussion of the organisational changes in the body making the recommendation[33]);

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[30]Taylor L.S (1958) 'History of the International Commission on Radiological Protection (ICRP)', Health Physics 1 97-104

[31]Taylor L.S (1958) 'Brief History of the National Committee on Radiation Protection and Measurements (NCRP) Covering the Period 1929-1946', Health Physics 1 3-10

Taylor L.S (1958) 'History of the International Commission on Radiological Units and Measurements (ICRU)', Health Physics 1 306-314

Silini G (1981) 'The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)', Radiation Protection Dosimetry 1 (4) 261-262

[32]Kathren R.L (1962) 'Early X-ray Protection in the United States', Health Physics 8 503-511

Smith H (1988) 'The International Commission on Radiological Protection: Historical overview', IAEA Bulletin 30 (3) 42-44

Spiers F.W (1984) '40 Years of Development in Radiation Protection', Physics in Medicine and Biology 29 145-151

Stone R.S (1952) 'The Concept of a Maximum Permissible Exposure', Radiology 58 639-660

Taylor L.S (1971) Radiation Protection Standards, London: Butterworths

Taylor L.S (1981) 'The Development of Radiation Protection Standards (1925-1940)', Health Physics 41 227-232

[33]Smith H and Thorne M.C (1987) 'The Origins and Work of the ICRP', Investigative Radiology 22 918-921

Sowby F.D (1981) 'Radiation Protection and the International Commission on Radiological Protection (ICRP) Radiation Protection Dosimetry 1 237-240

(iii) papers that discuss the philosophy behind radiation protection standards[34];

(iv) papers that discuss how standards might develop in the future[35].

Of these, the works by Lauriston S Taylor, a founder members of the ICRP and the U.S National Council on Radiation Protection and Measurements

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Taylor L.S (1979) Organisation for Radiation Protection - The Operations of the ICRP and NCRP 1928-1974, Office of Technical Information, U.S Department of Energy, U.S DOE/TIC-10124

[34]Pochin E.E (1986) 'The Evolution of Radiation Protection Criteria', Nuclear Energy 25 (1) 19-27

Pochin E.E (1989) 'Radiation Protection: Past and Future Needs', In Radiation Protection - Theory and Practice, Proceedings of the Fourth International Symposium of the Society for Radiological Protection, Malvern, 4-9 June 1989, Bristol: ICP Publishings Ltd

Taylor L.S (1957) 'Editorial: The Philosophy Underlying Radiation Protection', The American Journal of Roentgenology 77 914-919

Taylor L.S (1958) 'Radiation Exposure as a Reasonable Calculated Risk', Health Physics 1 62-70

Taylor L.S (1965) 'Philosophical Influences on Radiation Protection Standards', Health Physics 11 859-864

Taylor L.S (1988) 'Will Radiation Control be by Reason or Regulation?', Health Physics 55 133-138

[35]Clarke R.H (1989) Current Estimates of Radiation Risk and Implications for Dose Limits, In National Radiological Protection Board Update Course Notes, NRPB April 1989

Dunster H.J (1989) 'Recent Developments underlying the recommendations of the International Commission on Radiological Protection', In Radiation Protection - Theory and Practice, Proceedings of the Fourth International Symposium of the Society for Radiological Protection, Malvern, 4-9 June 1989, Bristol: ICP Publishings Ltd

Lindell B (1988) 'Radiation Protection - A Look to the Future:ICRP Perceptions', Health Physics 55 (2) 145-147

Murthy M.S.S, Madhvanath U and Soman S.D (1988) 'Some Factors that may influence future Radiation Protection Policies', In Radiation Protection in Nuclear Energy Vol 1, Proceedings of a Conference, Sydney 1988, Vienna: IAEA

Ryder E.A and Beaver P.F (1989) 'Changes in Risk Estimates and their Implications: the U.K Legislative Position', Journal of the Society of Radiation Protection 9 (3) 195-196

Taylor L.S (1988) 'Will Radiation Control be by Reason or Regulation?', Health Physics 55 (2) 133-138

Vallario E.J (1988) 'Regulatory Perceptions of the Future: A View from the United States', Health Physics 55 (2) 385-389

Wrixon A.D (1989) The Implications of Changes in Risk Estimates for Occupational Exposure, In National Radiological Protection Board Update Couse Notes, NRPB April 1989

(NCRP), are particularly worthy of note. Taylor has had access to a variety of closed information sources. His writings are important sources of information and are referred to throughout this thesis.

This category of information, with the original scientific papers and protection recommendations are a significant source of information on the development of radiological protection standards. This category gives the official, published, interpretation of how these standards developed.

(V) Papers on the Philosophy of Science

A fifth category of information, not specifically concerned with radiological protection, is the literature on the philosophy of science. This attempts to analyse and account for examples of scientific conflict and expert dispute[36]. This is a viable source of information that can be used to form a framework in which the developments in radiological protection can be assessed and interpreted.

(VI) Official Records

The final category of information are the official records of organisations involved in the standard setting process. This includes minutes of meetings, supporting papers and the personal correspondence between scientists. This category of information allows the researcher access to the actual process of standard setting and enables an assessment to be made of the main influences on the standard setting process.

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[36]See footnotes 1 - 10 and 43, 45 - 50.

1.3: A SUMMARY OF CURRENT THINKING ON RADIOLOGICAL PROTECTION PHILOSOPHY

The general framework that emerges from these sources, except for the popular critical accounts and the analyses of scientific controversy, is that the primary influence leading to changes in the philosophy or recommendations of the ICRP is scientific information and data.

(I) The Official View

Taylor considers that our entire radiological protection philosophy has evolved from the early concepts of radiological protection, namely the so-called tolerance dose. He adds

> "that we have yet to adopt a numerical permissible dose based upon any actual or even statistically identifiable injury. Our entire permissible dose structure of today is based upon our inability to observe any deleterious or other effect at the permissible dose levels which have been in vogue since 1934"[37].

By implication, safety standards err on the side of caution. They place the protection of health as the most important factor.

The suggestion that radiological protection standards have gradually evolved in response to changing scientific information is repeated by other members of the ICRP. Two recently published reviews of the ICRP's work, by the current ICRP scientific secretary, relate the evolution of dose limits with developments in the understanding of the biological effects of radiation[38]. Social considerations are not discussed.

Some authors do discuss social considerations, but only in the context of applying radiological protection standards in practice. Here social

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[37]Taylor L.S (1971) Radiation Protection Standards, London: Butterworths

[38]Smith H (1988) 'The International Commission on Radiological Protection: Historical Overview', International Atomic Energy Agency Bulletin 30 No 3 42-44

Smith H and Thorne M.C (1987) 'The Origins and Work of the International Commission on Radiological Protection', Investigative Radiology 22 918-921

considerations arise in cost-benefit analyses. These determine how much expenditure is justified to reduce exposures within the dose limits. Cost-benefit analyses are a common feature of modern regulation of environmental and occupational hazards[39].

Another former member of the ICRP has stated that the development of radiological protection standards have depended on several key scientific events. These are: (i) the early recognition of the types of biological harm that developed as a result of radiation exposure; (ii) the establishment of a reliable dosimetry system and (iii) the quantitative evaluation of the risk of exposure through the publication of key scientific papers[40]. He suggests that the approach adopted in the regulation of ionising radiation would benefit the regulation of other carcinogenic agents such as chemicals.

This observation is also supported by a recent comparison of differences in the regulatory approach to ionising radiation and chemicals[41]. Very few analyses of this kind have been undertaken. As well as illustrating the general framework in which standards for chemicals are established this review provides a valuable insight into how non-radiation specialists view radiation safety standards.

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[39]Regens J.L, Dietz T.M and Rycroft R.W (1983) 'Risk Assessment in the Policy Making Process: Environmental Health and Safety Protection', Public Administration Review 43 137-145

[40]Pochin E.E (1986) 'The Evolution of Radiation Protection Criteria', Nuclear Energy 25 (1) 19-27.

[41]Halton D.M* (1988) 'A Comparison of the Concepts Used to Develop and Apply Occupational Exposure Limits for Ionising Radiation and Hazardous Chemical Substances', Regulatory Toxicology and Pharmacology 8 343-355

* Of the Canadian Centre for Occupational Health and Safety.

This study compared the rationales used by the ICRP with those used by the American Conference of Government Industrial Hygienists (ACGIH) in their standards for ten different chemicals[42]. The ACGIH was not created as an international organisation but it is observed that its recommendations have been widely adopted elsewhere in the Western World.

This author commented that the scientific information supporting a particular recommendation was directly available from publications of the ICRP or ACGIH. Information on the underlying philosophical concepts and socioeconomic considerations was obtained in papers by key individuals in the standard setting process.

The study concluded that the philosophy of radiological protection was considerably more advanced than that of chemical protection. In areas of scientific uncertainty, exposure limits for ionising radiation were considered based upon worst case or conservative assumptions. It was argued that this approach favoured human safety. Whereas the costs of meeting the proposed standard played a more significant role in the establishment of standards for chemicals.

According to this study the approaches of the two organisations were completely different. The main focus in radiological protection was on the prevention of acute effects and the limitation of stochastic effects, such as cancer. The chemical standards were largely aimed at preventing acute effects.

Regarding the respective dose limits, the limit for radiation

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[42]Toluene-2,4-diisocyanate; Hydrogen fluoride; n-Hexane; Carbon disulfide; Cadmium; Inorganic Mercury; Cobalt; Nitroglycerol (NG) and ethylene glycerol dinitrate (EGDN); Silica and Vinyl chloride.

"appears to be based upon health considerations alone".

This statement that was supported by reference to papers by Taylor, a founder member of the ICRP, and to Evans, a member of the U.S National Council for Radiation Protection and Measurements (NCRP). The dose limit was

> "defended and explained in terms of a detailed assessment of tissues at risk from radiation exposure".

The limits for the ten chemicals were based upon a combination of human dose-response data, animal data and on "professional" judgement. It was considered

> "evident that considerations other than health effects have entered into the process for determining an exposure limit".

It terms of economic considerations the study stated:

> "the ICRP does not compromise on the question of the primary limit with respect to cost/benefit considerations".

This was supported by reference to current ICRP recommendations that say individuals shall not exceed the dose limit. In radiological protection cost/benefit considerations are used to determine the degree to which exposures are kept beneath the limit. On the other hand, the ACGIH has

> "in the past, had heavy involvements with industry, and economic considerations played an influential role in the setting of exposure standards".

As a result

> "the standard setting process of ACGIH seemed to focus on weighing the degree of risk that exposure involved with the cost to industry of introducing control procedures which would reduce the exposure levels".

This was contrasted with the approach adopted by the ICRP:

> "ICRP makes its limit recommendations on the basis of health considerations alone and does not directly consider the costs, management, or implementation of its recommendations at the industrial level".

It was argued that the ICRP was not concerned with the cost of keeping exposures within its dose limits:

> "little consideration is given to balancing the recommended limits against the economic or technical feasibility of introducing them at the practical level".

This study concluded:

> "Its seems that the concepts, philosophy, and socioeconomic considerations used in the judgement process for recommending ionizing radiation limits have the edge over those used in occupational health. They place a greater emphasis on preserving human health and well-being than do comparable systems for hazardous chemicals in the workplace".

(ii) Alternative Viewpoints

The practices and philosophy for regulating ionising radiation hazards may be more advanced than for chemical hazards. This does not mean that the ICRP's recommendations are universally accepted. In spite of its reputation it is surprising to find that its most recent recommendations, published in 1977, have been at the centre of a major controversy over the magnitude of risk from radiation exposure. Before this the ICRP has been involved, indirectly through some of its members, in earlier controversies over radiation effects[43].

The popular accounts that describe this controversy provide an alternative view of how radiological protection standards developed. These accounts suggest that scientific information was not the dominant factor. Instead, they have argued that the primary influence has been the political views of organisations like the U.S Atomic Energy

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[43]Green P.A (1984) The Controversy over Low Dose Exposure to Ionising Radiation, Msc Thesis, Birmingham: University of Aston

Commission[44]. This view, however, is frequently not backed up by analytical data or documentary evidence.

(iii) Insights from Analysis of Scientific Controversies

The radiation controversy is not the only example of a dispute between different scientific experts. In recent years a large literature has built up which has attempted to analyse and account for these controversies. This literature has not, with three exceptions, directly addressed the radiation controversy. Several papers have been about the controversy over nuclear power.

This source of literature seek to answer whether scientific controversies are about purely scientific factors, or about social considerations or a combination of the two? In an analysis of the origins of the debate over fall-out hazards, Kopp has argued that the source of the controversy lay in differing disciplinary, institutional and political interests. These interests acted together and a single determinant of scientists views on radiation hazards could not be isolated. Kopp has observed that scientists who expressed concern about fall-out hazards were more likely to be from a biological discipline, especially genetics and be from an academic background. They were also more likely to support a partial or total ban on atmospheric nuclear weapon testing. On the other hand, scientists who argued that fall-out hazards were small or insignificant tended to be from disciplines in the physical or medical sciences, to have institutional affiliations with the U.S Atomic Energy Commission (AEC) and to support continued testing[45].

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[44]See Footnote 28.

[45]Kopp C (1979) 'The Origins of the American Scientific Debate over Fall-out Hazards', Social Studies of Science 9 403-422

Nowotny and Hirsch have conducted an analysis of the controversy between Dr John Gofman and the AEC during the 1970s[46]. They have argued that this controversy arose partially as a result of conflicting scientific information. The main protagonists also argued over different basic concepts and held different political opinions, for or against nuclear power.

The influence of occupational or disciplinary affiliations in other scientific controversies have been analysed by a variety of authors. Robbins and Johnston have argued that many of these controversies have common underlying causes:

> "In particular, the conflict between various groups of scientist experts has been related to cognitive and occupational differentiation within the scientific community - that is, to differences in technical and cognitive standards and/or professional norms between different sub-groups of scientists"[47].

These differences, they argued, were important in the formation and maintenance of the "ideology of particular groupings of scientists". The ideological differentiation between different scientific groups providing the basis for conflict.

Other authors have argued that conflict is inevitable as the risk assessment process involves attempting to answer questions and making judgements outside the realms of science. Crouch, in an analysis of the controversy over the incidence of childhood cancer near the Sellafield Nuclear Reprocessing Plant in Cumbria, has argued that the scientific

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[46]Nowotny H and Hirsch H (1980) 'The Consequences of Dissent: Sociological Reflections on the Controversy of the Low Dose Effects', Research Policy 9 278-294

[47]Robbins D and Johnston R (1976) 'The Role of Cognitive and Occupational Differentiation in Scientific Controversies", Social Studies of Science 6 349-368

basis for confidence in radiological risk assessment is "seriously lacking". He suggests that many areas of scientific uncertainty were unresolvable in quantitative terms. Where scientific uncertainty existed official agencies, such as the U.K National Radiological Protection Board (NRPB), had to employ

> "a significant amount of subjective expert judgement"[48]

Crouch judged that quantitative risk assessment was an "essential part" of the standard setting process. However, he considered that controversy was inevitable without a "secure *social* basis" of confidence in the risk assessment.

An official historian from the U.S Nuclear Regulatory Commission also considers that controversy in the radiation field is inevitable. He gives two reasons for this judgement. First, the scientific evidence used in the formulation of protection standards is often "insufficient, inconclusive, or contradictory". This is a common feature of controversies in the occupational and environmental fields.

Second, and in his judgement, more importantly

> "issues that involve the use of radiation sources have not been strictly scientific matters; they necessarily require policy assessments and priority judgements"[49]

This meant that:

> "Just as divergent views emerged in the past regarding whether atmospheric testing provided benefits that compensated for the hazards of fall-out or whether the risks

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[48]Crouch D (1986) 'Science and Trans-science in Radiation Risk Assessment: Child Cancer around the Nuclear Fuel Reprocessing Plant at Sellafield, U.K', The Science of the Total Environment 53 201-216

[49]Walker S (1989) 'The Controversy Over Radiation Safety - A Historical Overview', Journal of the American Medical Association 262 (5) 664-668

> of nuclear power outweighed its advantages, different individuals and groups are likely to take different positions in the future regarding the seemingly timeless question of what constitutes an acceptable level of exposure to radiation".

These last two analyses do not explain the nature of the controversy., they merely accepts that controversies occur. Earlier research by the current author has attempted to provide an explanation for this controversy by examining the ICRP's structure, function and record. The affiliations of ICRP members were analysed. The results showed that they were primarily drawn from the international nuclear industry and its regulatory bodies. Another important group represented were scientists from sections of the medical profession involved in the use of ionising radiation, namely medical radiology.

The longest serving members of the Commission and its Committees had affiliations to the first two of these groups. In addition, the ICRP was judged scientifically unbalanced. More scientists from the physical and medical fields served on the Commission than biological scientists. The largest single type of scientific group represented were physicists. They were followed in number by medical doctors and radiologists. Scientists who investigate the effects of radiation on populations were poorly represented. Only three geneticists, one radiobiologist, one pathologist and one biophyscists have sat on the main Commission since 1950[50]. This research considered this imbalance surprising in view of the ICRP's function.

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[50]Green P.A (1984) The Controversy Over Low Dose Exposure to Ionising Radiation, Msc Thesis, Birmingham: University of Aston
Green P.A (1985) The International Commission on Radiological Protection London: Greenpeace U.K

This work sought to comment on the extent to which these affiliations had influenced the standard setting process. It was concluded that the disciplinary and professional affiliations of ICRP members appeared to be reflected in the recommendations adopted by the ICRP.

However, this analysis, and the other analyses of the radiation debate, do not adequately account for the origin of the controversy. They merely identify criteria which are relevant to the analysis of the controversy. The identification of apparent conflicts of interest in the decision making process of the ICRP should really be considered as starting point for further analysis and not an end point in itself.

It is not sufficient to simply argue that occupational or disciplinary affiliations have influenced the standard setting process. The ICRP is an international organisation whose members are drawn from a variety of occupational and disciplinary backgrounds that could have different institutional aims operating in differing national environments. Just as these background could influence the deliberations of the ICRP, they could also be a source of conflict within the ICRP itself. This conflict, if it exists, is not apparent in the ICRP's recommendations. This clearly implies that mechanisms exist for resolution of internal differences and forming consensus. The analysis of the role of the ICRP in the radiation debate has to demonstrate how these affiliations have influenced the form of its recommendations.

However, in spite of their limitations these academic studies have attempted to bridge the gap between the views of scientific determinism and social or political determinism. They provide the basis of a third

view that recognises the importance of scientific and social considerations in the formulation of ICRP recommendations.

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1.4: METHODS OF RESEARCHING THE DEVELOPMENT OF RADIATION PROTECTION PHILOSOPHY

There are a variety of approaches to presenting an historical analysis of the development of radiation protection standards and philosophy. Taylor, a founder member of the ICRP, has suggested that there are three main methods: (1) a systematic recounting of the development of new information and its influence on protection recommendations; (2) listing of the key reports by protection bodies, accompanied by synopses of their contents; and (3) a chronological reporting of the process by which protection recommendations have been developed[51].

He has observed that the first two approaches are largely available through the publications of the organisations concerned in the development of standards. For example, the records of public hearings such as the U.S Congress, reports from the United Nations, International Atomic Energy Agency, World Health Organisation and the normal scientific literature.

His writings include discussions on the philosophy behind the recommendations[52], a chronological summary of the recommendations of the

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[51] Taylor L.S (1979) Organisation for Radiation Protection The Operations of the ICRP and NCRP 1928-1974, U.S Department of Energy, DOE/TIC-10124

[52] Taylor L.S (1957) 'Editorial: The Philosophy Underlying Radiation Protection', The American Journal of Roentgenology 77 914-919

Taylor L.S (1958) 'Radiation Exposure as a Reasonable Calculated Risk', Health Physics 1 62-70

Taylor L.S (1965) 'Philosophical Influences on Radiation Protection Standards', Health Physics 11 859-864

ICRP and the NCRP[53] and an archive account of the development of the ICRP and NCRP[54].

On the other hand, another author, who has compared the different regulatory approaches for chemical and radiation hazards, has observed that the original reports of organisations like the ICRP do not contain details of the underlying philosophical or socioeconomic concepts[55]. The most recent ICRP recommendations (1977) did not list a single reference in support of its analysis of the biological effects of radiation or its recommendations[56]. Consequently, no information is available on the scientific or social basis of these recommendations.

Taylor has commented that the one area that has not been covered is the "inner process" of the development of recommendations and standards. The reason he cites for this is that

> "most records on this process are either buried in dead files or discarded for sheer lack of storage space"[57].

The nearest to this type of analysis has been conducted by Taylor in his six thousand page account of the work of the NCRP and ICRP between 1928 and 1974[41]. This work is, in many respects, a published archive of material on the development of ICRP recommendations. It contains

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[53]Taylor L.S (1971) Radiation Protection Standards, London: Butterworths

[54]Taylor L.S (1979) Organisation for Radiation Protection The Operations of the ICRP and NCRP 1928-1974, U.S Department of Energy, DOE/TIC-10124

[55]Halton D.M (1988) 'A Comparison of the Concepts Used to Develop and Apply Occupational Exposure Limits for Ionising Radiation and Hazardous Chemical Substances', Regulatory Toxicology and Pharmacology 8 343-355

[56]ICRP (1977) 'Recommendations of the International Commission on Radiological Protection', ICRP Publication 26 Oxford: Pergamon Press

[57]Taylor L.S (1979) Organisation for Radiation Protection The Operations of the ICRP and NCRP 1928-1974, U.S Department of Energy, DOE/TIC-10124.

verbatim quotes from letters between members, draft recommendations and other ICRP documents. Unfortunately, it is only a selection of the original material. For instance, Taylor often discusses and quotes from members comments on ICRP documents, but does not present the document under discussion.

This account is not a clear chronology of the development of ICRP and NCRP recommendations. It also contains a considerable amount of material on the operating rules of the ICRP, its funding and relations with other organisations. While this text provides an insight into the ICRP's thinking at several periods of their development, it is not an analytical account of the development of its philosophy. Such an account should discuss the main influences on the deliberations and recommendations of the ICRP. Taylor makes little or no attempt to discuss why certain recommendations were made - or to relate these to the basic scientific data. Nevertheless, this archive represents a valuable source of original material. It can be used along with other sources to enable an analysis to be made of the inner process of the development of radiation protection recommendations.

Taylor's own writings were based upon three main sources of information: (1) personal records of the time; (2) archive material from a variety of sources and (3) the published literature. His method is presented as an objective one:

> "I have sought diligently to avoid the injection of my own personal opinions into interpretations of events"[58].

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[58]Taylor L.S (1979) Organisation for Radiation Protection The Operations of the ICRP and NCRP 1928-1974, U.S Department of Energy, DOE/TIC-10124

He has not achieved this. It is clear from his account where his sympathies lie. For instance, Taylor's dislike of Gofman is clearly visible in his account of the controversy between Gofman and the AEC[58].

A major problem for any researcher is the reliability of source material. Taylor has questioned the reliability of literature reviews on the history of radiological protection as a source for the historian. Citing examples of errors of fact, or errors of interpretation that

> "comes about because, by not utilizing the basic documents to which they have referred, the writers have tended to interpolate their own interpretation or evaluation of the reasoning that lay behind the quoted statement"[59].

He also acknowledges that his writings have not been completely error free. Errors have arisen, he explains, because he used a review article as opposed to the source material. This admission would entitle one to question whether his archive account of the ICRP and NCRP recommendations was reliable. Its accuracy can be cross checked with the source material, such as minutes of meetings, where this is available. This process confirms the general accuracy of his account up to the mid 1960s. For the material that cannot be cross checked one has to assume that the same standards of accuracy have been maintained.

Access to archived records is essential for an analysis of the process of establishing the extent of different influences on radiological protection standards. This thesis draws upon several main sources of information. For basic scientific information on the biological effects of ionising radiation this thesis relies on the reviews that have been published by the U.K Medical Research Council, the United Nations and the

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[59]Taylor L.S (1981) 'Guest Editorial: Technical Accuracy in Historical Writing', Health Physics 40 595-599

U.S National Academy of Sciences. Where appropriate these have been augmented by particular scientific papers. If these have included new information that has a direct bearing on radiological protection recommendations. This material can be contrasted with scientific data contained in archived sources.

Information on how the basic scientific data is interpreted and used in the establishment of radiological protection standards is drawn from archived sources. These also enable an assessment to be made of the extent of social and political influences on the standard setting process.

Material, for the pre-war period, is largely derived from the open scientific literature, and from Taylor's published archive for the records of the early ICRP meetings.

A substantial part of this thesis is concerned with the reformation of the ICRP after the Second World War and the subsequent development of protection standards until the 1960s. For this period the official records of the U.K national committees are available as part of the official record at the Public Records Office. These records include minutes of meetings, supporting papers and letters between committee members. Several leading members of these committees also served on the ICRP. Also available are records of conferences and meetings held with other organisations such as the U.S AEC and with the ICRP.

These records, with the published literature, allow a clear assessment to be made of the relative importance of scientific evidence and social

considerations in the development of radiological protection standards during this period.

This is more difficult for the period after 1960. Because of the thirty year rule, that governs the public accessibility of official documents, official records are only available until 1959. However, the United Kingdom Atomic Energy Authority has granted privileged access to some records between 1959 and 1961, and to some records that are closed to public access from the 1950s[60].

The material that has been examined includes: the records of the ICRP and its committees during the 1950s and the records of the U.K Medical Research Council up to 1961. This material has been augmented by material from Taylor's archive of ICRP material and from the open scientific literature.

For the period following the 1960s I have relied on: published sources of information, such as original scientific papers; reports from the ICRP; reviews of the development of ICRP recommendations by individual members of the Commission such as Lauriston Taylor; and on the records of the U.K National Radiological Protection Board (NRPB). The NRPB granted permission for the minutes of their Board meetings to be studied.

An approach has also been made to the ICRP, both directly, and indirectly through the NRPB for access to their records. This request was initially refused on the grounds that its records were not catalogued. Instead, a

[60]Other Government agencies have not been so cooperative, notably the Health and Safety Executive which has refused access to a series of files covering the period 1945-1965 and the Department of Health which has not replied to a written request for access to files from the mid 1960s.

copy of Taylor's history was made available. No reply has been received to the indirect approaches. Consequently, without the ICRP's cooperation it has not been possible to present a definitive account of the development of their recommendations.

However, from the sources of information that have been available it has been possible to construct a detailed account that explains the key features of ICRP thinking and comment on the extent to which its recommendations are based upon scientific and social considerations.

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1.5: PROBLEMS ADDRESSED BY THESIS

Two common, and opposing views, exist over the formulation of protection recommendations by the ICRP. The first, and most widely accepted, is that its recommendations are *scientifically determined*. The second view, which is held by a number of the Commission's critics, is that its recommendations are *politically or socially determined*. Both views are simplistic and are not supported by a rigourous analysis of the formulation of ICRP recommendations.

The official view, of *scientific determinism*, does not accept that social considerations influence the ICRP's recommendations. These are presented as being primarily derived from scientific information alone. However, the ICRP is not the only organisation with a view of the risk from radiation exposure. Its recommendations have formed the basis of a major scientific and public controversy. This controversy is concern with both scientific and social issues, namely the magnitude and acceptability of radiation risk.

The Commission's critics also maintain that their position is scientifically determined. On the other hand, they argue that the Commission's recommendations have been set to allow the nuclear industry to develop unhindered. Science has no role in such *political or social determinism* of safety standards. This view ignores the eminent status held by many members of the Commission and implicitly, and often explicitly, assumes that the Commission is deliberately biased towards the nuclear industry.

Neither of these analyses, which represent the views of the two sides in the radiation controversy, adequately accounts for the complex process in which protection recommendations are formulated, or explains the origins of the radiation debate.

A third view is provided by academic studies of the origins of the radiation controversy and other similar disputes. This view suggests that both science and social factors are important in the assessment and limitation of risk. These studies have focused on the *origin* of controversy and have argued that this lays in a combination of differing disciplinary, professional and occupational factors.

This framework formed the basis of previous research by the current author. It aimed to explain the nature and origin of the radiation controversy, and suggested that the ICRP's recommendations have reflected a combination of scientific and social considerations. This work argued that the Commission's assessment of scientific data and its judgements on the acceptability of risk were influenced by the disciplinary, professional and occupational affiliation of its members.

This research, however, left many questions unanswered. This research analysed the disciplinary affiliations of members of the ICRP main Commission. It suggested that the largest single group represented were physicists. They were seconded in number by medical doctors and radiologists. Biological scientists on the main Commission were found to have been poorly represented. This research, however, did not identify which group or individual, if any, dominated the Commission's assessment of radiation risks. The Commission is also served by a number of committees, whose members could make an important contribution to the recommendations of the ICRP. The disciplinary affiliations and the role of these scientists in the formulation of ICRP recommendations was not analysed.

This research also examined the occupational or professional affiliations of members of the main Commission. It argued that members were primarily drawn from occupations within the nuclear industry and its regulatory bodies. Another important group were scientists from sections of the medical profession involved in the occupational use of radiation, namely medical radiology. However, other members, less in number, also had academic backgrounds. This research suggested that the practical needs of the nuclear industry had been consistently expressed in the Commission's recommendations. However, the institutional aims of the nuclear industry are unlikely to be same as the professional aims of radiologists. The research did not demonstrate how the interests of one group could dominate the ICRP's thinking.

The analysis of the ICRP's membership needs to account for the complex relationship between the different disciplinary, professional and

occupational affiliations of its members. The earlier research did not show *how* these different affiliations influenced the form of ICRP recommendations. Equally, this research did not assess and account for the interactions between members with different affiliation illustrating whether these led to conflict or consensus. If conflict arose was its source in the interpretation of scientific data on radiation hazards or over the methods by which radiation risks are limited?

Also this research did not illustrate the balance between science or social considerations in the ICRP's recommendations. Are they primarily scientifically or socially determined, or is there is complex relationship between science and social values in the assessment and limitation of radiation risk?

Considerations such as the affiliations of members are not the only factor that need to be accounted for in an analysis of the formulation of protection recommendations. The ICRP does not operate in a vacuum but in world with changing scientific information and social or political values. These changing pressures could also influence the Commission's deliberations.

These questions form the primary focus of this thesis. The aim of the analysis is not to simply examine the origin of controversy. An equally, if not more, important issue is the resolution of controversy and the maintenance of expert authority and influence. This issue forms the central focus of this thesis. The aim is to assess the process through which the ICRP formulates its radiological protection recommendations and comment on the extent that these are influenced by the affiliations of its members.

This aim can be expressed as three fundamental questions: (i) Do these affiliations lead to conflict and how is this resolved leading to a consensus view in the formulation of safety recommendations? (ii) How has the ICRP responded to changing scientific data and social pressures? (iii) Are the ICRP's recommendations based upon scientific information, or on social and political judgements.

The focus of the analysis is the ICRP and its relationship with other national authorities, particularly in the U.K and to a lesser extent the U.S. The aim is to identify the key scientists involved in the standard setting process, noting their scientific and occupational affiliations and their arguments used in putting forward any particular standard.

The analysis is presented as a chronological account of the "inner processes" in the development of the Commission's recommendations and covers the time from the turn of the century until 1990. It is divided into six time periods: 1895 - 1945; 1945 - 1950; 1950 - 1959; 1959 - 1977; and 1977 - 1990. Each one discusses the major developments in the ICRP's recommendations and philosophy.

For each period the primary focus is to analyse and account for the fundamental questions identified above in the formulation of ICRP recommendations. The aim is: (i) to identify and account for areas of *conflict* between Commission members and to identify the means by which a *consensus* is formed between them; (ii) to analyses and account for the Commission's response to new scientific information and social pressures. Do these led to pressures led to dramatic *changes* in recommendations or are there pressures ensuring a *continuity* in the Commission's recommendations? (iii) to demonstrate the extent to which the

Commission's recommendations reflect scientific information or social or political considerations.

Within the Commission's membership several different types of conflict could arise. First, conflict could arise along differing disciplinary lines, such as between physicists and biologists, or physicists and medical doctors, or any combination of these. Conflict could also arise on different occupational or professional grounds such as between practising radiologists and scientists working in industry.

Either one set of aims have dominated the Commission's recommendations or a consensus around a common purpose has been reached between the different members of the Commission. The establishment of such a consensus not only has to account for the views and aspirations of different occupational or professional groups, it must also account for the views of different disciplinary groups. This thesis aims to identify the mechanism by which consensus is reached.

The scientific and social pressures which could be exerted on the Commission include: (1) changes in basic scientific knowledge; (2) practical pressures from industry or the medical profession in connection with what was economic or achievable; (3) social pressure, from peer groups and from pressure groups outside the scientific community. The aim is identify the source of scientific and social pressure and detail how the ICRP have responded to such influences at different stages in its history. Is there a pattern to the way it responds to such pressure, or have changes occurred and why?

This thesis, therefore, is concerned with the formulation of protection recommendations by the International Commission on Radiological Protection (ICRP). An international organisation with a unique position in the field of occupational and environmental health. It is a non-governmental organisation and is widely regarded as the foremost authority in the field of radiological protection.

Despite its preeminent reputation the recommendations of the ICRP have formed the basis of a major public controversy over the magnitude and acceptability of radiation risks. Earlier research, focusing on the origin of the controversy, suggested that the Commission's recommendations were influenced by the affiliations of its members. The aim of this thesis is to assess the extent of such influences and comment on the extent that Commission's recommendations are based upon scientific information, or on social and political judgements. The central focus of this thesis is the process of conflict *and* its resolution as a means of maintaining authority and influence in the assessment and limitation of radiation risks.

CHAPTER 2: FROM PHYSICAL PROTECTION TO BIOLOGICAL TOLERANCE

Very soon after the discoveries of X-rays[1] and radioactivity[2], in 1895 and 1896 respectively, reports of injury begun to appear in the scientific press. The first was published in the English journal *Nature* on 5th March 1896[3]. This described possible eye damage following exposure to X-rays. This was reportedly followed, in July, by a paper that described a severe case of X-ray dermatitis[4]. Reports of skin burns also quickly followed in American journals[5]. By the end of 1896, 23 cases of severe X-ray injury had been reported[6,7].

The first report of a death due to over exposure to X-rays appeared in 1901. A coroner's jury in England is reported to have recorded that the accidental death of an X-ray worker was due to shock, exhaustion and through the effects of X-rays on a weakened system[8]. Kathren observes that this decision was noted in the American literature without comment[3].

William Rollins demonstrated experimentally, in 1901, that fatalities could be induced in guinea-pigs irradiated by X-rays. The injury to the

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[1]By Wilhelm Röntgen in November 1895.
[2]By Henri Becquerel in February 1896.
[3]Edison T.H (1896) 'Notes in Nature', Nature 53 No 1375 421
[4]Marcuse W (1896) 'Dermatitis und Alopecie nach Durchleuchtungsversuchen mit Röntgenstrahlen', Deutsche med Wchschr 22 481-483, Cited by Henshaw P.S (1941) 'Biological Effects of the Tolerance Dose in X-ray and Radium Protection', Journal of the National Cancer Institute 1 789-805
[5]Kathren R.L (1962) 'Early X-ray Protection in the United States', Health Physics 8 503-511
[6]Taylor L.S (1971) Radiation Protection Standards, London:Butterworths
[7]Scot N.S (1897) 'X-ray Injuries', American X-ray Journal 1 57-65
[8]News Item (1901) 'A Death Associated with the Use of Roentgen Rays', Boston Medical Surgeon Journal 144 26

animals was not just confined to skin damage but was also found within the body tissues[9].

The first X-ray induced carcinoma was reported by Frieben in 1902[10]. The number of cases increased dramatically during the next few years. By 1911, only fourteen years after the discoveries, Hesse reported identifying 94 carcinoma cases, of which 50 had occurred in radiologists[11].

Despite the very visible effects of over-exposure, progress in protection procedures was slow. This was largely because an agreed method of measurement did not exist. There was also little agreement over what was causing the injuries. Early theories ranged from: high frequency electrical phenomenon; ultraviolet radiation; ozone generation in the skin, electrical induction; the X-rays themselves; to idiosyncrasy or faulty technique[12]. Some contemporary authors have also suggested that there was also widespread resistance amongst the medical profession to the notion that X-rays were capable of causing harm[13].

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[9]Rollins W (1901) 'X-ray Light Kills', Boston Medical Surgeon Journal 144 173
Rollins W (1901) 'The Control Guinea Pigs', Boston Medical Surgeon Journal 144 317
Rollins W (1902) 'Vacuum Tube Burns', Boston Medical Surgeon Journal January 9th

[10]Frieben (1902) 'Demonstr. Arztl. Verein, Hamburg Oct 21 1902', Cited by Colwell H.A and Russ S (1934) X-Ray and Radium Injuries: Prevention and Treatment, New York and London:Oxford M Pubs

[11]Hesse O (1911) 'Das Röntgenkarzinom', Fortschr a. d Geb d. Röntgenstrahlen 17 82-92 Cited by Henshaw P.S (1941) 'Biological Effects of the Tolerance Dose in X-ray and Radium Protection', Journal of the National Cancer Institute 1 789-805

[12]Kassabian M.K (1907) Roentgen Rays and Electro-Therapeutics, Philadelphia:Lippincott

[13]Caufield C (1989) Multiple Exposures: Chronicles of the Radiation Age, London:Secker and Warburg

2.1: THE FIRST SAFETY RECOMMENDATIONS

A 1902 paper by Rollins has been cited by many authors as representing the first attempts to establish a safety standard. For instance, Taylor states that Rollins proposed that if seven minutes exposure to X-rays did not fog a photographic plate then the radiation was not of a harmful intensity[14]. Rollins had proposed this for testing the efficiency of shielding of the X-ray bulb and had not attached any biological meaning to his result[15].

The first protection recommendations were published in 1913 by the Deutsche Roentgen-Gesellschaft (German Radiological Society). These were followed in 1915 by recommendations from the British Röntgen Society. Both of these statements recognised that the effects of radiation may be cumulative.

The early German recommendations were general, warning of the hazard of X-rays:

> "Repeated radiation of any part of the human body with X-rays is dangerous and has on many occasions already led to severe injury and even death among radiologists"[16].

They also specified the minimum thickness of lead shielding that was required on x-ray apparatus[17,18].

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[14]Taylor L.S (1971) Radiation Protection Standards, London:Butterworths

[15]Rollins W (1902) 'Non-radiable Cases for X-light Tubes', Electrical Review 40 795

[16]German Radiological Society (1913) 'Translation of an Information Leaflet on X-Ray Protection', In Taylor L.S (1979) Organisation for Radiation Protection The Operations of the ICRP and NCRP 1928 - 1974 U.S Department of the Environment, U.S DOE/TIC-10124

[17]Although no information is available on how the specified thickness was derived.

[18]German Radiological Society (1913) 'Translation of an Information Leaflet on X-Ray Protection', In Taylor L.S (1979) Organisation for Radiation Protection The Operations of the ICRP and NCRP 1928 - 1974 U.S Department of the Energy, U.S DOE/TIC-10124

The British Röntgen Society discussed a paper, by Dr Sydney Russ[19], on the need for X-ray protection during their annual general meeting in June 1915. This led to the following resolution being adopted:

> "That in view of the recent large increase in the number of X-ray installations, this Society considers it a matter of greatest importance that the personal safety of the operators conducting the X-ray examinations should be secured by the universal adoption of stringent rules"[20].

As a result of this discussion the Röntgen Society published a single page statement in November 1915. This stated:

> "The harmful effects produced by X-rays are cumulative and do not generally appear until some weeks or months after the damage has been done.
>
> It is undesirable that any x-ray treatment should be carried out except under the direction of a qualified medical practitioner experienced in x-ray work.
>
> All x-ray tubes must be provided, when in use, with a protecting shield or cover which prevents the access of rays to the operators and which encloses the tube, leaving an adjustable opening only sufficiently large to allow the passage of a sheaf of rays of the size necessary for the work in hand. Even with this shielding the operator may not be completely protected in all cases (e.g, especially in screen work), and the use of movable screens, gloves and aprons are recommended.
>
> Operators should be warned that shields obtainable commercially are often ineffective and tests of their opacity should be made.
>
> Whenever possible the cubicle system should be used for x-ray treatment and the operator should be able to make all adjustments from a protected space.
>
> When screen examination is required it is essential that the screen should be covered with thick glass of proved opacity and that the screen should be independently supported and not

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[NB: Future references to Taylor's achieve account are listed as Taylor L.S (1979)]

[19] A physicist.

[20] Röntgen Society (1915) 'Annual General Meeting, June 1st, 1915 Discussion on Protective Devices for X-ray Operators', The Journal of the Röntgen Society, October 1915 110-113

held in the hands of the operator. If the hands are so used they should be properly protected.

The hand or any portion of the body of the operator should never be used to test the hardness or quality of the x-ray tube: any simple form of penetrometer can easily be arranged for this purpose"[21].

The subject of X-ray protection was discussed again by the Röntgen Society in February 1916. However, the need for any form of protection was rejected by many leading clinicians and radiologists.

The discussion was opened by Sidney Russ who identified two types of X-ray danger. He categorised these as (i) obvious (like skin damage) and (ii) hidden. He added that hidden dangers

"are only manifested in the course of time as the years go by. They are cumulative, and are, I think worthy of the very strictest attention"[22].

Russ was particularly concerned about physiological effects such as changes in the blood. However, other members of the Society felt that

"there is a tendency to attach too much importance to the dangers of X-rays".

This statement was made by Dr Reginald Morton[23], who added:

"Whatever the physicist may have to show with regard to them, from the physiological point of view secondary radiations have very little effect. There is another question raised by Dr Russ this evening, namely, the cumulative action of the rays. . . If the effects of X-rays are steadily and consistently cumulative, workers like Sir James Mackenzie Davidson and myself would have withered away long since. The fact is, we are capable of receiving a certain dose of X-rays and making a complete recovery therefrom without suffering

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[21]Röntgen Society (1915) 'Recommendations for the Protection of X-ray Operators', In Taylor L.S (1979)

[22]Röntgen Society (1916) 'The Injurious Effects Produced by X rays', Minutes of a General Meeting of the Röntgen Society, February 1st 1916, The Journal of the Röntgen Society April 1916 38-56

[23]A clinician.

any permanent disability. That gives use a margin of safety"[24,25]

Morton had been exposed, he said, to

"countless thousands of these X-ray doses"

without any apparent ill effects. He considered that this meant

"we must be in a position to throw off the effects of a certain amount of X-rays. What that dose is, approximately, I am not prepared to say".

There was no further activity on radiological protection until after the First World War. Henshaw, a research fellow with the U.S National Cancer Institute, has observed that as a result of the demands of war

"caution gave way to action and protection measures were soon forgotten"[23]

Taylor has also suggested that the "human characteristic of indifference" contributed towards this inaction[26].

The war also saw a marked increase in use of the X-rays. This increase and the disregard of basic protection techniques was to have a dramatic effect on the health of the early X-ray workers.

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2.2: PROTECTION FOLLOWING THE FIRST WORLD WAR

Following the War many of the early X-ray and radium workers died of aplastic anæmia and other diseases associated with over-exposure. One of these was Sir James Mackenzie Davidson, the clinician cited by Morton as proof that radiation effects were not cumulative. These deaths received

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[24]Sir James Mackenzie Davidson was Surgeon/Radiologist.

[25]Henshaw P.S (1941) 'Biological Effects of the Tolerance Dose in X-Ray and Radium Protection', Journal of the National Cancer Institute 1 789-805

[26]Taylor L.S (1971) Radiation Protection Standards, London:Butterworths

widespread publicity and had a dramatic effect on the medical professions reluctance to follow protective techniques.

I) X-Ray Protection in Britain

On December 1st 1920, *The Times* newspaper, printed an editorial under the heading "Martyrs to Science". This was reprinted by the British Röntgen Society in January 1921:

> "We honour those who venture their lives in battle, or save their fellows in fire or mine or the perils of sea. . . Science, too, has its heroes and martyrs who often have to endure a slow and prolonged torture from which their knowledge forbids any hope of escape. . . Few of the advances in science have been made without the conscious and prolonged martyrdom of brave men. . . It is now possible to use X-rays with safety to all tissues except those whose destruction is desired. These results have been attained only by the heroism of many men. A few months ago we recorded the death of Dr Cecil Lyster, in honour of whose sacrifice a Chair of Radiology was founded at Middlesex Hospital. Yesterday we had to report the death of Dr Charles Infroit, a French martyr, at the age of forty-six. He was chief of the radiographic laboratory of the Salpetrière Hospital in Paris. Ten years ago, in the early days of research on X-rays, he became affected with radiodermatitis and knew that he was a doomed man. He continued his investigations up to the end. He had to undergo more than twenty operations, which successively took from him all his fingers, then his hands, then his left arm, then his right arm. He died content with having devised an installation which would save his successors from his own fate. He is one of a succession of heroes: but, so long as the human race continues to produce such men, it will be worthy even their martyrdom in its service"[27].

In response to the deaths the President of the British Röntgen Society, Dr Robert Knox[28], wrote to *The Times* on 29 March 1921. He suggested the formation of a committee to address radiological safety. The April issue of the *Journal of the Röntgen Society* notes that this committee had been formed. It was chaired by Sir Humphry Rolleston, Past President of the

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[27]Editorial (1921) 'Martyrs to Science', The Times, reprinted in the Journal of the Röntgen Society January 1921 3

[28]A Radiologist.

Royal Society of Medicine[29]. Its members comprised radiologists, physicists and equipment manufacturers. It become known as the British X-ray and Radium Protection Committee (BXRPC)[30].

The *Journal* also commented on the publicity surrounding the deaths:

> "The general public have been greatly disturbed during the last few weeks by the attention the Press has given to X-ray matters. As usual, the Press have been very badly served by "our special correspondent", whose scientific competency is normally of less moment than his ability to write lurid journalese. A good deal of harm has been done, in the mind of the public, but we rather doubt whether much good would result from the adoption of similar press methods in any attempt at answering the propaganda. The average man is mainly guided by his doctor to the use of X-rays, and it is chiefly through the medical profession that we can best hope to reach the thinking public. An intelligent profession wants facts, not feuilletons; and we do not believe that aggrandizing articles in the press are calculated to further the progress of a subject whose scientific standing should be jealously guarded. If radiology is useful to mankind, and we know it is, nothing can check its strides, certainly not the truth"[31].

The first report of the BXRPC was published in July 1921. This listed the known effects of radiation as:

> "(1) Visible injuries to the superficial tissues which may result in permanent damage.
>
> (2) Derangements of internal organs and changes in the blood. These are especially important as their early manifestation is often unrecognised"[32].

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[29]A Physician.

[30]The membership of the Committee comprised: Sir Humphry Rolleston (chair); Sir Archibald Reid (Radiologist at St Thomas's Hospital); Dr Robert Knox (Radiologist, King's College Hospital); Dr G Harrison Orton (Radiologist, St Mary's Hospital); Dr S Gilbert Scott (London Hospital); Dr J.C Mottram (Pathologist, Radium Institute); Mr Cuthbert Andrews. Secretaries: Dr Stanley Melville (Physicist, St George's Hospital) Professor S Russ (Physicist, Middlesex Hospital).

[31]Editorial (1921) 'X-ray Protection', Journal of the Röntgen Society April 1921 50

[32]British X-Ray and Radium Protection Committee (1921) 'X-ray and Radium Protection', Journal of the Röntgen Society July 1921 100-103

The recommendations specified the basic working conditions of X-ray and radium workers: i.e, not more than seven working hours per day; Sunday and two half days off per week and one month, or two fortnights holiday per year[33]. They also specified the protective measures to be employed for different types of X-ray and radium work, such as the thickness of shielding required. The minimum thickness of lead shielding recommended was 2 mm, the same as in the 1913 German recommendations.

The British X-ray and Radium Protection Committee issued a second statement in December 1921. This recommended that X-ray and radium facilities in hospitals and other institutions should be inspected by the National Physical Laboratory[34]. In 1924, a revised set of recommendations were published by the Committee based on the experience of the National Physical Laboratory during its inspection work[35].

One member of the British Committee, G.W.C Kaye[36], later discussed the main issues that had guided the Committee in framing its recommendations. These included:

> "(a) Measuring under specified conditions the intensity of X-rays in terms of a specifiable and reproducible physical standard expressed, if possible, in absolute units.
>
> (b) Establishing a maximum tolerance dose in terms of a specifiable and reproducible biological standard, and if possible, expressing this biological standard in physical units.
>
> (c) Establishing figures for the transmission of X-rays of specified quality by lead and other absorbents.

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[33]This was amended in December 1921 to two, fortnights holiday per year.
[34]British X-ray and Radium Protection Committee (1921) Memorandum No 2, Following Preliminary Report, Memo, No 1 July, 1921, December 12, 1921, In Taylor L.S (1979)
[35]British X-ray and Radium Protection Committee (1924) 'X-ray and Radium Protection Committee Revised Report No 1 (December 1923)', The British Journal of Radiology (Röntgen Society Section) XX 27-34
[36]Of the National Physical Laboratory.

(d) Calculating the thickness of absorbent necessary to the intensity of a given beam of X-rays to that corresponding to the tolerance dose at some specified point"[37].

When the Committee was formed, general agreement did not exist between scientists over the relationship between physical measurements and biological effects. This meant that

> "the protective values recommended had necessarily to be framed, mainly from the point of view of physical measurements, and the accumulated experiences of older workers".

Consequently, it was

> "obvious that the protective values selected would have to be in the nature of compromise, as considerations of weight and cost would preclude any attempt at stopping the rays completely. Some small amount of radiation is bound to reach the operator, particularly during screening, but this should be made so small as to be innocuous".

Kaye reported that the Committee had considered using a "graded" system of protection where the requirements would vary according to the circumstances of each installation. However, it had been decided that such a system would be open to misinterpretation and misuse. The Committee had concluded that the recommendations

> "should seek to ensure adequate protection on an installation, no matter what the conditions"

and had recommended a single uniform system of protection that applied equally to all installations.

It is also interesting to contrast the view of Kaye, a physicist, with one expressed in 1927 by Humphry Rolleston, a physician. Rolleston was the chair of the British X-ray and Radium Protection Committee. He also

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[37]Kaye G.W.C (1928) 'Protection and Working Conditions in X-ray Departments', British Journal of Radiology 1 295-312

discussed the formulation of the Committee recommendations. His analysis concurred with Kaye when he stated:

> "the recommendations were worked out from the physical point of view so as to ensure virtually complete protection from irradiations, and not from the biological and clinical standpoint of limiting the amount of irradiation to what can be safely borne by the individual"[38].

He considered that this meant that the recommendations should

> "be based upon the principle of absolute safety and so err, if they do at all, on the side of excess".

Two interpretations can be made from the statements of Kaye and Rolleston's. First, Kaye's view could be interpreted as a more honest recognition of the practical problems of protection. He recognised that absolute protection was not possible. This can be contrasted with the view of Rolleston who did mention "absolute safety", while at the same time acknowledging that this only involved "virtually complete protection" from X-rays! An alternative interpretation would be that Rolleston accepted that absolute protection was not possible but believed that the balance should be towards safety.

(II) Protection Standards in other Countries

Several other countries also established protection committees during the early 1920s. The April 1921 issue of the *Journal of the Röntgen Society* noted that committees had been established in France and in the U.S.

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[38]Rolleston H (1927) 'Mackenzie Davidson Lecture - On the Effects of Radiations on Patients and Radiologists, and on Protection', British Journal of Radiology, (Röntgen Society Section) XXIII 266-291

The U.S Roentgen Ray Society had formed a "Safety Committee" in 1920. This had not issued any recommendations due to the death of its chair, Professor John S Shearer[39].

Taylor has suggested that this committee adopted a set of recommendations during their annual meeting in 1922[40]. More recently he has stated that this may be incorrect. He suggested that the U.S Roentgen Ray Society recommendations were simply a copy of the BXRPC's[41].

Other U.S scientists were also concerned with safety. One of these was Dr George E Pfahler. Taylor has described him as the "first consistent crusader" for better standards of protection[39]. Pfahler had published an editorial in 1916 that recorded many cases of severe radiation injury to physicians and warned against the misuse of X-rays[42]. It had been on his suggestion that the Roentgen Society established a safety committee in 1920.

In 1922 Pfahler was elected president of the U.S Radium Society. He suggested that it also form a safety committee, to be known as the Committee for Protection in Radiology. This would cooperate with the Roentgen Society Safety Committee and with the U.S National Bureau of Standards. He suggested that the latter organisation could be responsible for inspecting and calibrating equipment.

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[39]Pfahler G.E (1922) 'Protection Against Radiology', American Journal of Roentgenology and Radium Therapy 9 803-808
[40]Taylor L.S (1971) Radiation Protection Standards, London:Butterworths
[41]Taylor L.S (1979)
[42]Pfahler G.E (1916) 'Another Warning Against X-ray Burns', American Journal of Roentgenology and Radium Therapy 3 372

Pfahler also read out the July 1921 recommendations of the British X-ray and Radium Protection Committee. This seems the basis of Taylor's claim that the U.S issued recommendations on radiological safety in 1922[43].

Pfahler also argued that the patient

> "be protected against any stray or unintentional radiation"[44].

However, he also considered that radiologists should seek insurance to guard against "unjust claims" for injuries that patients believed were due to their treatment:

> "Frequently the patient sees nothing and hears nothing; and because of the mystery to the layman, and frequently because of the mystery to the general practitioner, any symptom or unusual development that occurs to a patient who is under treatment is apt to be ascribed to the treatment, or its effects"[42].

A protection committee was also appointed in Norway on 16 May 1922, during a meeting of the Norsk Forening for Medicinsk Radiologi. The committee was commissioned to prepare suggestions for regulations with

> "regard to arrangements for protection against the perils and deleterious influence on the health, to which patients, medical men and nurses may be liable owing to their work and stay at roentgen and radium institutes"[45].

This committee's recommendations were published in 1925. These listed the body tissues which were likely to be injured by X-ray as the

> "skin, genitals and blood producing-organs"[46].

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[43]Taylor L.S (1979) Organisation for Radiation Protection The Operations of the ICRP and NCRP 1928 - 1974, U.S Department of the Environment, U.S DOE/TIC-10124

[44]Pfahler G.E (1922) 'Protection Against Radiology', American Journal of Roentgenology and Radium Therapy 9 803-808

[45]In Taylor L.S (1979)

[46]Norsk Forening for Medicinsk Radiologi (1925) 'A Report by the Protection Committee', Translation In Taylor L.S (1979)

The diseases that were considered to arise from exposure were:

> "atrophy and other diseases of the skin (the roentgen and radium dermatitis and its sequelae), sterility, cancer and deadly diseases of the blood".

This committee was also concerned with protection of the patient and cautioned:

> "even patients who for curative purposes are exposed to these rays may be liable to injuries which, in their gravest form may cause death or permanent invalidity".

This advice particularly applied where the treatment was administered by poorly trained or "ignorant individuals". The committee was concerned that there was no formal training of radiologists, a situation it considered needed remedying. It proposed a central licensing board for all X-ray and radium facilities and for an official training programme for medical and dental students.

In 1928, the Swedish X-ray and Radium Protection Committee issued a set of proposals on protective procedures. These noted:

> "Slight pathological changes caused by daily small doses of radiation may, after a longer or shorter time, cause severe and extensive lesions, especially skin atrophies and slow-healing wounds from which malignant tumours may develop, occasionally followed by marked invalidity and death"[47].

The Committee warned that such

> "pathological changes may appear as a result of total irradiation already after a few years radiological work, if sufficient protection has not been adopted".

It further added that most

> "of the lesions caused by radiations are of an insidious and treacherous kind. On the very occasion of irradiation no visible or perceptible effect can generally be noticed, the damage instead appearing first after months or years. This is mainly the reason why, in radiological work, precise

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[47] Swedish X-ray and Radium Protection Committee (1928) 'Proposals to the Royal Medical Council', In Taylor L.S (1979)

protective regulations and repeated survey of rooms, apparatuses, etc must be carried out with greatest care".

The Swedish proposals also briefly listed the protection measures that had been adopted in other countries. These included Italy, where since 18 July 1925

> "precise protective regulations for patients and attendants as well as regulations for the protection of radiation in adjacent rooms are in law"[45].

The report also mentioned a 1925 update of the earlier German (1913) statement.

As with these other early recommendations, the detailed text of the Swedish recommendations was concerned with shielding and the general hours and conditions of staff. No reference is made to the actual levels of radiation that may be worked with.

The Norwegian and Swedish proposals were concerned with the regulation of X-ray and Radium work. Whereas the British and U.S were concerned with voluntary compliance with recommendations. Pfahler had argued:

> "No matter what the authority of the Committee, iron-clad rules cannot be laid down. The principles of protection must be given, and general guides or suggestions established, but the individual institution and the individual workers must make their application according to the circumstances, in each instance"[48].

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2.3: EARLY METHODS OF MEASURING RADIATION

A major problem facing these early committees was the absence of an agreed unit of measurement for X-ray intensity. These problems were compounded by incomplete data on the biological nature of radiation

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[48]Pfahler G.E (1922) 'Protection Against Radiology', American Journal of Roentgenology and Radium Therapy 9 803-808

damage. Consequently, the recommendations on the thickness of shielding were not based upon a quantitative relationship between the amount of radiation received and type of biological damage that resulted. The early U.K discussions were concerned with the percentage reduction in energy of X-rays transmitted[49] arising from different thickness of shielding[50].

Radiation exposures, until 1920, were measured by a variety of means. These included blackening of photographic films or plates; ionisation; photochemical reactions or photo-voltaic effects[51]. The most commonly used method of expressing the radiation quality, in physical terms, was the "effective wave length"[52].

Several attempts were made to standardise the method of measuring X-ray intensity, expressing as a specific unit. In 1918, Kroenig and Friedrich proposed the electrostatic unit, or "e" unit [53]. This was a unit of radiation intensity measured by an ionisation chamber.

Another standard was proposed by Solomon in 1922. This was based upon a monitoring instrument consisting of a gold leaf electroscope. It was

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[49]Measured by an Electroscope.
[50]Röntgen Society (1915) 'Annual General Meeting, June 1st, 1915, Discussion on Protective Devices for X-ray Operators', Journal of the Röntgen Society, October 1915 110-113
[51]Hirsch I.S and Holzknecht G (1925) The Principles and Practice of Roentgen Therapy New York:American X-ray Publication Company
[52]Taylor L.S (1971) Radiation Protection Standards, London:Butterworths
[53]Kroenig B and Friedrich W (1918) Physikalische und Biologische Grundlagen der Strahlentherapie, Berlin:Urban and Schwartzenberg In Taylor L.S (1979)

called the R unit[54]. There was no fixed relationship between these two units[55]

Taylor has commented that because of these physical uncertainties radiation effects were measured in simple biological units. The skin erythema dose (HED, haute-erythem-dosis, or USD, unit skin dose), was the amount of radiation required to produce reddening of the skin. However, the definition of an erythema dose varied widely amongst workers in the field. It ranged from slight reddening in the days after exposure to almost blistering of the skin[53].

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2.4: INDIVIDUAL PROPOSALS FOR A TOLERANCE DOSE

By the mid 1920s, attempts were being made to relate physical measurements with the amount of acute biological damage that resulted. This led to the development of the so-called Tolerance Dose. This was based upon the skin erythema dose.

Mutscheller made the first quantitative attempt to establish a tolerance dose. In 1924, he addressed a meeting of the American Roentgen Ray Society:

> "The results of inadequate protection against the harmful effects of over-dosage with roentgen rays that have been reported in the past are so appalling that a search for protection standards is one of the most important problems in roentgen-ray physics and roentgen-ray biology"[56].

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[54]Solomon I (1922) 'Sur la mesure de la dose profonde en radiotherapie thres penetrant', Bul de las Soc de Radiolo Med de France, January 1922 In Taylor L.S (1979)

[55]Taylor L.S (1971) Radiation Protection Standards, London:Butterworths

[56]Mutscheller A (1925) 'Physical Standards of Protection against Roentgen-ray Dangers', American Journal of Roentgenolgy and Radium Therapy 13 65-70

He considered that derivation of protection standards required "systematic cooperation" between physicists and biologists. However, Mutscheller clearly believed that absolute protection was not possible or practical:

> "At first thought it might appear simplest to design the protective shields and housing devices for roentgen-ray operators so heavy that their opacity would be sufficient to stop practically all rays from reaching the operator or bystanders. It is, however, obvious that the protective shields and apparatus would then become entirely too heavy and costly, so that we must deal with an equilibrium between the amount of protection obtained and the weight and cost of the protective shields".

This meant that

> "every operator therefore must be content to receive within a given time, a certain quantity dose of radiation and it is to be determined, evidently from biological observations just what that dose shall be to which the average operator can be exposed without danger to his health".

The purpose of his talk was to illustrate a technique for calculating the effectiveness of protective shields for X-ray apparatus. Mutscheller presented a formula to calculate the radiation dose at a given distance from a source of X-rays without a protective shield. He stated that:

> "in order to be able to calculate the thickness of the protective material for a protection shield, there must be known the dose which an operator can, for a prolonged period of time, tolerate, without ultimately suffering injury".

Based upon exposure levels observed in "several typical good installations" Mutscheller judged that:

> "it is entirely safe if an operator does not receive every thirty days a dose exceeding 1/100 of an erythema dose".

Adding

> "from the present status of our knowledge this seems to be the tolerance dose for all conditions of operating roentgen-ray tubes and roentgenography, roentgenoscopy and therapy".

Therefore, having

> "tentatively agreed upon a tolerance dose that may be safe and permissible without the necessity of constructing too heavy, clumsy and unwieldy protection screens and shields"

it was possible to calculate the correct thickness of a protective shield. His paper does not contain a further explanation for his tolerance dose of 1/100 of erythema dose every 30 working days. Taylor has suggested that he applied a safety factor of ten to his reasoning[57].

Taylor has commented, that at the time of his 1924 address, Mutscheller's proposal received little attention in the United States. As an explanation he observed that Mutscheller worked for a manufacturer of protective shields and was frequently accused of self promotion[58].

A Swedish physicist, Rolf Sievert, working independently also derived a value of the tolerance dose. Sievert's primary concern was also to assess the efficiency of shielding. He estimated that it would take between 1,000 and 10,000 years to receive a skin erythema dose from background radiation. On this basis, his judgement was that 1/10th of an erythema dose each year would be acceptable for radiation workers[59]. Reduced to a monthly value this would be essentially the same as Mutcheller's figure.

Three years later, Barclay and Cox, also physicists, published a study that attempted to derive a tolerance dose from observations of X-ray workers. This paper also discussed the effects of fractionation of exposure:

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[57]Taylor L.S (1981) 'The Development of Radiation Protection Standards (1925-1940)', Health Physics 41 227-232

[58]Taylor L.S (1979)

[59]Sievert R (1925) 'Einige Untersuchungen uber Vorricht ungen zum schutz gegen roentgen-strahlen', Acta Radiolo 4 61 In Taylor L.S (1979)

> "There is no question as to the cumulative effect of roentgen-ray doses of a certain magnitude, but it is evident that the time interval between the doses is a very potent factor. We might put it that the larger the dose, the longer the interval, while the smaller the dose, the more frequently can it be repeated without fear of cumulative effect and actual damage to the skin structure"[60].

They discussed the cases of two workers. The first received a daily dose of "at least" 1/140th (0.007) of a skin erythema dose over a period of six years. The second had been exposed to a daily dose of 1/440th (0.00023) of a skin erythema dose. The authors considered this an underestimate. They then asked if, using these observations

> "can we arrive at a figure as being safe, and one that can be tolerated day after day without risk?".

They suggested that a

> "protection scheme that reduces the possible incidence of rays on the operator to a daily dose that is in the region of 1/25 of that which has been known to be tolerated without any ill effects (0.007 USD) must be well within the limits of safety".

They therefore took as an "arbitrary standard" 0.00028 USD (unit skin dose) as their "safe limit for daily exposures". This was almost equivalent to the figure suggested by Mutscheller. This was equal to 0.00033 USD per day.

From their tolerance dose they calculated the amount of shielding required on X-ray apparatus. One millimetre of lead for roentgenography and two for roentgenoscopy.

Barclay and Cox also discussed the effect of radiation on the blood. They doubted whether some of the observed changes were deleterious:

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[60] Barclay A.E and Cox S (1928) 'Radiation Risks of the Roentgenologist', American Journal of Roentgenology and Radium Therapy 19 551-561.

> "The effect on the blood of massive doses of high voltage roentgen radiations and of radium even in small quantities is quite definite but we have considerable doubt as to whether the comparatively infinitesimal quantities of radiation to which the roentgen-ray worker is exposed in the course of his diagnostic work can have any influence in producing serious changes in the blood".

Their conclusions, they stated

> "do not differ widely from the recommendations of the English Radium and X-ray Protection Committee as regards roentgen diagnostic work. They seem to indicate, however, several points in which it is likely that these go beyond what is necessary".

Barclay and Cox considered that it was "a very striking fact" that their value for the tolerance dose agreed so closely with others. On the other hand, Taylor has commented that the only common factor was the judgement of the scientists concerned[61,62]. This is particularly true of Mutscheller and Sievert. Their tolerance doses both approximated to 1/10th of a erythema dose in a year. However, these papers also mentioned observations made on X-ray installations. It is possible that their figures, like those of Barclay and Cox, were also based upon the levels that were being achieved in installations of the time.

One problem with the studies mentioned was that no attempt was made to translate the biological unit into the physical units of exposure. This problem was compounded by the large number of units that existed, often with the same name[63]. Friedrich had attempted to relate the e unit to one definition of an erythema dose[64,65]. In 1926, Mutscheller stated

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[61] Taylor L.S (1979)

[62] He also emphasises that the tolerance dose estimates were not based on any observable effect on radiation workers. A statement that he continually makes in his writings.

[63] For instance, besides the Friedrich "e" unit, and the Solomon "R" unit already discussed, there was also the Duane's "E" unit and Behnken's "R" unit.

[64] As slight reddening of the skin on the day following treatment.

that one skin erythema dose equalled 1300 R units[66]. However, he did not say whose R Unit he was using.

In 1926, Meyer and Glasser reviewed eight separate studies where an attempt had been made to translate the erythema dose into R-units. The values ranged from 170 R to 2500 R, with a close grouping of six values between 1200 and 1800 R units. From this Meyer and Glasser judged that a 1300 R would best represent the erythema dose[67].

These figures included backscattering, i.e, radiation (X-rays) being reflected back from the surface of the person being irradiated. In 1927, Kustner attempted to derive a figure without backscattering. He sent a questionnaire to twelve German X-ray institutions asking how much radiation produced an erythema in their laboratories. From the responses received the average value was 550 R. He rounded this up to 600 R[68]. This became the accepted value.

On this basis the tolerance dose, 1/100th of an erythema dose per month, was equivalent to 6 R. Or assuming 200 working hours per month, 10^{-5} R per second.

These studies were discussed in a review by Kaye in 1928[69]. He also cited a Dutch Board of Health tolerance dose of 1/1000 erythema dose in

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[65]Where 170 e was deemed to be equivalent to 1 HED.
[66] Mutscheller A (1926) 'Further Studies of Physical Standards of Protection against Roentgen-ray Dangers', Radiology 6 314
[67]Meyer W.H and Glasser O (1926) 'Erythema Doses in Absolute Units', Radiology 6 320
[68]Kustner H (1927) 'Wiefiel R-Einheiten entspricht die HED', Strahlentherpie 26 120, In Taylor L.S (1979)
[69]He cited Mutscheller, Sievert, Solomon and Barclay and Cox.

15 days. From these studies Kaye quoted an average figure of 1/1000 erythema dose in five days, or 0.0002 USD per day[70].

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2.5: THE FIRST INTERNATIONAL STANDARDS

The absence of an agreed unit of X-ray intensity led, in 1925, to the formation of the International Congress of Radiology. This Congress discussed the question of units and protection procedures but did not make any recommendations. At the second Congress, held in Stockholm in 1928, progress was made in both areas[71]. The roentgen (r) was adopted as the unit of exposure. Safety recommendations were also adopted based upon proposals from the British X-Ray and Radium Protection Committee[72]. The BXRPC was chaired by G.W.C. Kaye of the National Physical Laboratory.

Taylor has observed that as part of

> "his ground work to assure useful results at the Stockholm Congress",

Kaye visited Giacchino Failla[73] and Lauriston S Taylor[74] in the United States to get their support for the British proposals. Kaye also asked Taylor to discuss the issue with Dr G Grossman as he was to be the German representative at the Congress[75].

In addition to adopting the British recommendations, the Congress Executive Committee proposed that an international committee be

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[70] Kaye G.W.C (1928) 'Protectiona and Working Conditions in X-ray Departments', British Journal of Radiology 1 295-312

[71] ICR (1925) 'The First International Congress', British Journal of Radiology (BIR Section) XXX 283-293

[72] Taylor notes that proposals from Sweden were also submitted. These were based upon their 1927 recommendations.

[73] Of the Radiological Society of North America.

[74] Of the U.S National Bureau of Standards.

[75] Taylor L.S (1979)

established to review them periodically. This was agreed and the International X-Ray and Radium Protection Committee (IXRPC) was formed[76,77,78,79]. It was also stated that the recommendations were not to be as regarded having any legal standing or formal significance. Such questions were judged best left to individual countries to deal with[75].

The recommendations were published in 1928 and were concerned with preventing the acute effects of radiation exposure. They list the known biological hazards as: (a) injuries to the superficial tissues and (b) derangements of internal organs and changes in the blood. No mention was made of the long term effects of exposure such as the induction of cancer. This can be contrasted the 1928 recommendations of the Swedish X-ray and Radium Protection Committee which did consider deleterious effects, such as malignant tumours, appearing many years after exposure[80].

Despite the general agreement over the value of the tolerance dose, the IXRPC recommendations did not recommend its adoption[81]. They were concerned with working conditions, shielding and positioning of X-ray equipment and the use of radium salts. The thickness of shielding was

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76 IXRPC (1928) 'International Recommendations for X-Ray and Radium Protection', British Journal of Radiology 1 358-363.

77 Sowby F.D (1981) 'Radiation Protection and the International Commission on Radiological Protection (ICRP)', Radiation Protection Dosimetry 1 237-240.

78 Taylor L.S (1958) 'History of the International Commission on Radiological Protection (ICRP)', Health Physics 1 97-104.

79 The membership of this committee comprised L.S Taylor (USA), G Grossman (Germany), I Solomon (France), R Sievert (Sweden), Dr Ceresole (Italy) with G.W.C Kaye and S Melville (England) as Honorary Secretaries.

80 Swedish X-Ray and Radium Protection Committee (1928) 'Proposals to the Royal Medical Council', In Taylor L.S (1979)

81 Taylor has stated that a tolerance dose was discussed but no agreement was reached. See Taylor L.S (1979)

expressed as a function of the voltage of the X-ray equipment, or the quantity of radium used.

Yet, the year previously Kaye had noted this general agreement around values of the tolerance dose. He was discussing the work of the British X-ray and Radium Protection Committee and concluded

> "Radiology is, in fact, no more dangerous, under proper conditions, than scores of other professions"[82].

This statement can be considered as a precursor of the modern protection philosophy of the ICRP.

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2.6: EMERGENCE OF AN OFFICIAL TOLERANCE DOSE

The radiation protection philosophy of the time was also discussed in a 1931 report for the League of Nations by Hermann Wintz[83] and Walther Rump. This suggested that in gauging radiation hazards comparisons could be made with toxicology. In toxicology

> "the most important thing to know is what quantities can certainly be tolerated by the body without ill-effects"[84].

This report argued that the term tolerance dose was incorrect. No dose could be regarded as completely harmless:

> "Experience has shown, however, that such a dose cannot be regarded as entirely harmless; for even though, after its administration, the tissue undoubtedly undergoes none of the morphological alterations which are known as Roentgen injuries, yet it is left with a reduced power of resistance to otherwise inoperative influences. . .

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[82] Kaye G.W.C (1928) 'Protection and Working Conditions in X-ray Departments', British Journal of Radiology 1 295-312

[83] Director of the University Gynaecological Clinic and Roentgen Institute, Erlangen.

[84] Wintz H and Rump W (1931) Protective Measures against Dangers Resulting from the use of Radium, Roentgen and Ultra-violet Radiations, CH 1054 Geneva:League of Nations Health Organisation

> . . . the tolerance dose is never a harmless one and that tolerance dose can in no case be readministered indefinitely to any particular piece of tissue after the visible effects had disappeared on each occasion. . .
>
> . . . The only dose, therefore, that could be harmless, would be one which would produce no effect whatever, on the particular piece of tissue concerned. . .
>
> . . . The conditions to be fulfilled by such a 'tolerance dose' are thus very stringent, and would seem to warrant the question of whether such a dose can exist at all".

They concluded that:

> "a really harmless dose of radiation can only be said to be given if it is incapable either of destroying or damaging the cells, or of exercising any stimulating action".

However, the authors argued that the "exact determination" of the magnitude of such a dose was impossible. This meant that one must

> "be content to speak of a harmless dose, whenever no alteration in the condition or activity of the body can be detected by available methods of clinical examination and observation".

They also discussed dose fractionation. They observed that if the erythema dose was spread over five days then, instead of being given in half an hour

> "the biological effect is about 35% less powerful than when the dose is administered at a single sitting".

This suggested to them that

> "the cell is able to deal rapidly with the energy of small amounts of X-rays, and that a particular effect cannot be secured by adding together the several doses separately given".

This observation was based upon acute radiation effects. The authors did not discuss the other known effects of radiation such as blood changes. Wintz and Rump also reviewed the individual studies on the magnitude of the tolerance dose and commented that their experience suggested that a

dose of 10 x 10^{-5} r/second could be regarded as safe. This was ten times higher than suggested by most other studies. However, since

> "the general standards of safety must on no account be set too low"

they recommended that the "admissible dose output" be set at one tenth of this level, i.e, 10^{-5} r/second assuming an eight hour day and 300 working days per year.

The IXRPC next met in 1931. The possibility of introducing tolerance levels was discussed but no recommendations were made. However, the recommended levels of shielding were calculated from a tolerance dose of 10^{-5} r/second[85] The 1931 recommendations also introduced the requirement that X-ray and radium workers should have regular medical and blood examinations to determine

> "the acceptance, refusal, limitation, or termination" of employment[86].

A tolerance dose was adopted by the IXRPC in 1934. The recommendations stated:

> "The evidence at present available appears to suggest that under satisfactory working conditions a person in normal health can tolerate exposure to X rays to an extent of about 0.2 international röntgens (r) per day. On the basis of continuous irradiation during a working day of seven hours, this figure corresponds to a dosage rate of 10^{-5} r per second. The protective values given in these recommendations are generally in harmony with this figure under average conditions. No similar tolerance is at present available in the case of radium gamma rays"[87].

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[85] Taylor L.S (1979)

[86] IXRPC (1932) 'International Recommendations for X-ray and Radium Protection revised by the International X-Ray and Radium Protection Commission and Adopted at the Third International Congress of Radiology, Paris, July 1931', British Journal of Radiology 5 82-85.

[87] IXRPC (1934) 'International Recommendations for X-Ray and Radium Protection Revised by the International X-Ray and Radium Protection

The U.S Advisory Committee on X-Ray and Radium Protection did not adopt this figure. Instead, its recommended an apparently lower limit of 0.1 roentgens per day[88].

> "The safe general radiation to the whole body is taken as 1/10 R/day for hard x-rays and may be used as a guide in radium protection. Five R/day has been taken as the tolerance for the fingers"[89].

> This limit had been first discussed by the U.S committee in 1931 for X-rays, and in 1932 it was agreed that it was applicable also to gamma rays from radium[90]. As with the IXRPC figure, this was also based upon a tolerance dose rate of 10^{-5} r/second. This would have been equivalent to a daily tolerance dose of 0.288 r (assuming 200 working hours a month). However, the U.S committee had decided to round this down to 0.1 r per day to avoid giving the impression of any precision in the recommendation[89].

Both the U.S and the IXRPC figure were based upon measurements made in free air without backscattering. There have been several statements, including some by Taylor, that suggest that the difference between the two figures was because one included backscattering and one did not. The evidence suggests that the difference between the two figures is because of the different degree of rounding down the daily dose.

In 1937, the IXRPC met for the final time before the Second World War. It agreed that the tolerance dose was also applicable to radium gamma

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Commission at the Fourth International Congress of Radiology, Zurich, July 1934', British Journal of Radiology 7 695-699

88This committee had been formed by Taylor following the 1928 Congress of Radiology. Its membership was comprised of: Giacchino Failla (Radiological Society of North America); Robert S Newell (Radiological Society of North America; Henry K Pancoast (American Roentgen Ray Society); J.L Weatherwax (American Roentgen Ray Society); William D Coolidge (X-ray Equipment Manufacturers); Wilbur S Werner (X-ray Equipment Manufacturers and Lauriston S Taylor (National Bureau of Standards).

89NCRP (1934) 'Radium Protection for Amounts up to 300 Milligrams' NCRP Report No 1 (NBS-HB18)

90Taylor L.S (1979)

rays[91]. The Committee did not meet again until 1950. Out of its founder members, only Taylor and Sievert were to survive the war.

The U.S Advisory Committee was to issue a further report before the United States became involved in the Second World War. This was concerned with radium protection and recommended the first tolerance level for ingested radioactivity. This was of 0.1 micrograms of radium[92]. This was recommended following investigations by Robley Evans into the bone cancer rates amongst radium dial painters[93].

The tolerance dose of 0.1 r per day and the radium standard formed the basis of the protection standards applied throughout the Manhattan Project.

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2.7: EARLY CONSIDERATIONS OF GENETICS

In 1927, a further effect of radiation was discovered when H.J Muller showed that X-rays could induce mutations in Drosophila[94]. He was awarded the Nobel Prize for this work in 1946. The U.S Advisory

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91 ICRP (1938) 'International Recommendations for X-ray and Radium Protection. Revised by the International X-ray and Radium Protection Commission and adopted at the 5th International Congress of Radiology, Chicago, September 1937, British Institute of Radiology (1938)', Radiology 30 511-515

92 NCRP (1941) Safe Handling of Radioactive Luminous Compunds, NCRP Report No 5 NBS-HB-27

93 For an introduction to the subject of the radium dial painters and the radium standard see:

Caufield C (1989) Multiple Exposures - Chronicles of the Radiation Age, London:Secker and Warburg

Evans R.D (1980) 'Origin of Standard for Internal Emitters', In Health Physics: A Backward Glance. Edited by Kathren R.L and Ziemer P.L, Oxford:Pergamon Press

Hacker B.C (1987) The Dragon's Tail - Radiation Safety in the Manhattan Project 1942-1946, Berkeley:University of California Press

94 Muller H.J (1927) 'Artificial Transmutation of the Gene', Science LXVI 84-87

Committee discussed the relevance of this work during 1933. However, it decided that as there was so little information available it could not be considered for protection recommendations[95]. It is not known if this was discussed by the IXRPC before the Second World War started.

In 1940 the U.S Advisory Committee again discussed the relevance of genetics. A Committee report from a meeting on 3 December 1940 notes that geneticists wanted the tolerance dose to be a factor of ten lower:

> "The generally accepted tolerance dosage rate is taken as 10^{-5} r/second for 7 hours a day (=3.6 x 10^{-2}r per hour). Geneticists point out that because of the cumulative effect of x rays the tolerance dose should not exceed 10^{-6} r/second. In many cases, the rigourous application of the international protective recommendations will reduce the dosage rate to the later value. In any case, an increase of about 30 percent in the thickness of a lead barrier will reduce the dosage rate from 10^{-5} to 10^{-6} r/second" [96].

The next day the Committee met again. R.R Newell[97] suggested that the tolerance dose should be reduced. He wanted it reduced by a factor of ten, coupled with an accumulated dose limit of 200 r in ten years. Taylor notes that it was tentatively agreed to make such a proposal.

Not all members of the Advisory Committee agreed to this change. Failla[98], who did not attend the 4th December meeting, argued against the proposal in a letter written in June 1941. He opposed the change for several reasons. First, he felt it was arbitrary:

> "I feel that this is a mistake for the following reasons: .1 roentgen per day is certainly a safe dose insofar as systemic changes are considered. If we bring in the genetic criteria then there is no limit at all and .02 roentgen per day is

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[95] Taylor L.S (1979)
[96] NCRP (1940) 'Report of Advisory Committee on X-ray and Radium Protection December 3, 1940', In Taylor L.S (1979)
[97] A radiologist who was the representative from the Radiological Society of North American.
[98] Representative from the Radiological Society of North America.

> just as arbitrary as .1 roentgen per day. To be sure, the smaller the dose the less the genetic damage but the possible damage is so slight that one can just as well stop at this point"[99].

By this stage the proposed reduction seems to have been changed to 0.02 r per day, a factor of five below the existing standard.

Paradoxically, Failla had previously argued for a 0.02 r per day tolerance dose for radium gamma rays. This figure, which he called the tolerance intensity, was for lifetime occupational exposure[100]. He considered that exposure at this level for long periods of time would be harmless. This proposal was not adopted by the U.S Advisory Committee.

Failla was now concerned with the practicality of a tolerance dose of this magnitude:

> "This question came up at the recent meeting on protection of workers in the luminous dial painting industry. The danger there of whole-body exposure to gamma rays is so slight in comparison with the danger of ingestion of radioactive material that the gamma ray protection is of little importance. On the other hand, if you set the limit low enough, complications in the handling of the material may arise which are entirely unwarranted.
>
> In the case of x rays it is a very simple matter to increase the protection, at least in new installations, so as to comply with the new requirement. In the case of radium, however, the new requirement would introduce serious complications in the handling of radon for therapeutic purposes. For these reasons, I am opposed to the change in tolerance dose and I hope that something can be done to modify the action of the Committee. Perhaps we can have a meeting in Cincinnati and discuss this matter from all angles. I should like to see what evidence members of the Committee have in support of the new tolerance dose. I do not know of anything in the literature which warrants the change".

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[99] Failla (1941) 'Letter to L.S Taylor June 18, 1941', In Taylor L.S (1979)

[100] Failla (1932) 'Radium Protection', Radiology 19 12-21

Finally, he was concerned that if the change was made then it would be difficult to amend later:

> "I do not think it wise to publish a statement at this time since it would probably be used by state authorities working on codes, and once the new tolerance dose gets into these codes it would be very difficult to get it out, What is the feeling of the people at the Cancer Institute in regard to this matter? I hope something can be done to bring about a review of the whole problem"[101]

The issue was discussed further by the Advisory Committee in September 1941. Several objections were raised against lowering the tolerance dose: (i) it was virtually impossible to keep within the present tolerance dose in fluoroscopy procedures or in the preparation of radium plaques; (ii) the standard would be ignored; (iii) medical-legal complications of introducing a standard that could not be met in diagnostic work.

Finally, it was agreed the Committee lacked sufficient evidence to warrant a reduction in the tolerance dose. Several possibilities were considered for further action: (i) the matter should be investigated further with the help of genetics experts; or (ii) Genetics should be ignored in the setting of a tolerance dose.

Failla maintained his position that the Committee should not worry about what happens to children in the third generation offspring of radiation workers. He believed it was impractical to go below 1/10 r per day and still carry out clinical work.

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[101] Failla (1941) 'Letter to L.S Taylor June 18, 1941', In Taylor L.S (1979)

This was the last meeting of the Advisory Committee before America entered the Second World War. The issue was not resolved and the tolerance dose remained at 1/10 r per day.

This was apparently the last time when this proposal was discussed. It appears that during the war the discussions were somehow lost and forgotten. Further references to the proposal do not seem to have been made until 1979 when Taylor discussed it in his history of the ICRP and NCRP[102]. He has never mentioned it in any of his earlier historical writings. He also mentions at a conference in 1980:

> "plans were made for releasing this report in collaboration with the National Institutes of Health. However, at just that point, the United States became engaged in the war and this report did not come to light again until sometime in the late 1960's when I was going through the early files"[103]

In 1981, he discussed it again, but only to refute a suggestion by another author that he had published a paper in 1941 proposing reduction of the tolerance dose[104].

This paper had not mentioned the Advisory Committee discussions. It cited a review by Kaye as supporting the finding that

> "a person may receive without injury"

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[102] Which is the source of this discussion.

[103] Taylor L.S (1980) 'Reminscenses about the Early Days of Organised Radiation Protection', In Health Physics: A Backward Glance, Edited by Kathren R.L and Ziemer Oxford:Pergamon Press

[104] Taylor L.S (1981) 'Technical Accuracy in Historical Writing', Health Physics 40 395-599

up to one fiftieth roentgen daily (0.02 r)[105]. Taylor did not endorse this suggestion, but did not dismiss it either[106]. He did not provide a reference for this review[107].

Taylor has observed that the possibility of a change in the tolerance dose soon became public knowledge[108]. His comments above undoubtedly contributed to this.

The authors of a 1941 survey of the degree of protection provided in American hospitals remarked that they had

> "learned with interest that the Advisory Committee on X-ray and Radium Protection has recently lowered its tolerance dose from 0.1 r to 0.02 r"[109].

In a footnote, Taylor was quoted as the source of this information.

This study was conducted by scientists from the National Cancer Institute of the U.S Public Health Service. It had found that many workers already kept their whole body exposures beneath this level proposed by the Advisory Committee recommendations.

This survey was discussed in another paper published in 1941. This was by Paul S Henshaw, a research fellow with the National Cancer Institute.

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[105] Taylor L.S (1941) 'X-Ray Protection', Journal of the American Medical Association 116 136-140

[106] This article seems to be the source of the incorrect assertion by Kathren that Taylor published an article in 1941 suggesting that the limit be lowered.

[107] Kaye's 1927 review had discussed five different studies on the tolerance dose in erythema's. It had suggested that an average figure would be 1/1000 of an erythema dose in 5 days, ie 0.0002 USD per day. If an erythema dose is taken as 600 r, this would be equivalent to 0.12 r per day.
Kaye also discussed protection in a book published in 1928: Kaye G.W.C (1928) Roentgenology: Its Early History, Some Basic Principles and Protective Measures, New York:Paul B Hoeber Inc

[108] Taylor L.S (1979)

[109] Cowie D.B and Scheele L.A (1941) 'A Survey of Radiation Protection in Hospitals', Journal of the National Cancer Institute 1 767-787

Henshaw also discussed a tolerance dose of 0.02 r per day, but in connection with Taylor's 1941 paper[110]. Henshaw suggested that this figure supported Failla's 1932 recommendation[111].

Henshaw's paper also observed that most of the published papers on radiation protection were written by physicists. He considered this

> "fortunate because protection for the most part is provided by cutting down on the amount of radiation reaching operators, a type of work on which physicists able to advise"[112].

Henshaw also emphasised that the problems of protection were not solely concerned with physics:

> "there is, nevertheless, a considerable body of biological information that can be brought to bear upon the general problem of protection".

By 1941, the tolerance dose of that time took two biological effects into account (i) injuries to superficial tissues and (ii) changes in the blood. For instance, Taylor had defined the tolerance dose as:

> "the amount of x-ray energy that a person may receive continuously without suffering any damage to the blood or reproductive organs"[113].

Henshaw considered this definition incomplete. Adding that it seemed

> "natural that physicists have avoided making comments on biologic matters, but it seems strange that radiologists have

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110 Henshaw P.S (1941) 'Biological Effects of the Tolerance Dose in X-ray and Radium Protection', Journal of the National Cancer Institute 1 789-805

111 Henshaw incorrect asserts that the U.S Advisory Committee recommended a tolerance dose of 0.2 r in 1931 and reduced this to 0.1 r in 1936. This claim is not supported by the documentary evidence.

112 Henshaw P.S (1941) 'Biological Effects of the Tolerance Dose in X-ray and Radium Protection', Journal of the National Cancer Institute 1 789-805

113 Taylor L.S (1941) 'X-Ray Protection', Journal of the American Medical Association 116 136-140

not shown greater concern for the types of injury to be guarded against"[114]

From published sources of information he listed the "known types of injury": (1) X-ray dermatitis; (2) Tumour induction; (3) Sterility; (4) Leukopenia; (5) Leukaemia; (6) Anaemia; (7) Bone necrosis; (8) Glandular disfunction and (9) Foetal injury.

To this list he added genetic effects. He did not consider the concept of tolerance dose was applicable to genetics. Commenting:

> "it would seem more appropriate to speak of tolerance injury".

This would imply that

> "we would set the amount of genetic injury we are willing to tolerate and regulate accordingly the amount of radiation that will reach the gonads before childbearing".

This statement acknowledges that genetics should be considered but implies that some level of genetic damage could be considered permissible.

He concluded:

> "Much more information is needed before the adequacy of the 0.1 r/day as a safety standard can be stated".

The U.S Advisory Committee had also discussed whether the term 'Tolerance Dose' was still appropriate in the light of the new information. The term "permissible dose" was suggested as an alternative[115]

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[114] Henshaw P.S (1941) 'Biological Effects of the Tolerance Dose in X-ray and Radium Protection', Journal of the National Cancer Institute 1 789-805

[115] NCRP (1941) 'Minutes of the Advisory Committee on X-Ray and Radium Protection, Cincinnati, September 25, 1941', In Taylor L.S (1979)

2.8: SUMMARY

This chapter has described the developments in radiological protection until the beginning of the Second World War. It shows the emergence of a protection philosophy largely promoted by physicists in response to what can be interpreted as carelessness by the medical profession.

The first attempts at formulating safety recommendations were made by professional societies in Germany, in 1913, and in Britain, in 1915. These came about largely as a result of the activities of particular individuals[116]. These standards were general in nature and warned of the hazards of over-exposure. They were published some fifteen years after the deleterious effects of exposure to X-rays were first reported.

As early as 1915 there was an appreciation, amongst some scientists, such as Sydney Russ (a physicist), that the effects of exposure to X-rays were cumulative. This meant that the deleterious effect may not become apparent until weeks or months after the exposure.

The reaction of the medical profession to calls for higher standards of safety highlights the difference in approach to safety between members of different scientific disciplines. The medical profession were the first radiation workers and were reluctant to take safety seriously.

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116 Taylor has referred to them as "a relatively small coterie of highly motivated scientific, technical and medical persons", who formed the early "radiation-protection community". This community was "originally conceived and put together by the radiological profession on both the national and international levels. Initially, it contained no radiobiologists for the simple reason that none existed as such. It was, however, an organization closely knit between physicists and radiologists, and, in 1928, its world size would have been something on the order of 30 individuals" Taylor L.S (1989) 'Will Radiation Control be by Reason or Regulation?', Health Physics 55 133-138.

The views of the clinicians and the early radiologists were typified by Dr Reginald Morton. He considered that the risks of exposure had been overstated. Arguing, that if the effects of radiation were cumulative, he and his colleagues like Mackenzie Davidson would have "long since" died. Morton considered that small doses of X-rays were harmless. Surprisingly, this argument is still made by some scientists today.

The sceptical attitudes of the medical profession changed dramatically following the deaths of a number of eminent physicians and clinicians. These deaths were highly significant and attracted a considerable amount of popular attention. This lead to the formation of new safety committees both in the U.K and abroad.

The first committee to be formed was in the U.K in 1921. Its membership comprised physicians, radiologists and physicists. At this stage, biologists were not involved in radiological protection.

The protection philosophy that emerged from these committees was one of "compromise" between the need to protect X-ray workers and the costs and weight of shielding. Absolute safety was recognised as impossible to achieve. Both physicist and physician alike considered that while some radiation would reach the operator it would be so small as to be "innocuous". This judgement was made without a detailed biological understanding of the nature of radiation damage.

In reality, decisions on the degree of physical protection provided by shielding relied heavily on the judgement of the scientists concerned. Without agreed methods of measurement, and with incomplete understanding

of biological effects, it would have been impossible to assess accurately the efficiency of any protective measure.

The judgements on the degree of safety were undoubtedly influenced by the nature of the type of radiation work under consideration. The risks were largely unknown and unquantified, whereas, the benefits from the medical uses of radiation were clearly defined. There was also a considerable amount of professional prestige associated with the developing fields of medical radiology. Quite clearly, the visible benefits, in patient care and professional prestige, were judged to outweigh the unseen and unquantified risks.

There were clear national differences over the extent to which the early recommendations should be enforced. The British and Americans were concerned with voluntary compliance with recommendations. On the other hand the Norwegian and Swedish protection committees proposed the *regulation* of X-ray work. This difference in approach was to have a crucial bearing on the development of international protection standards.

It was the lack of an agreed method of measurement, rather than the need for better safety standards, which led to the formation of the International Congress of Radiology. It was not until its second meeting that the International X-ray and Radium Protection Committee (IXRPC) was formed.

The first international recommendations were advisory in nature and were purely concerned with working conditions and shielding of X-ray apparatus. They were based upon British proposals. The aim was to prevent the acute, and visible, effects of radiation. The definition of

the biological effects of radiation was clearly influenced by the disciplinary and professional affiliations of the scientists involved. The International Congress of Radiology was composed of physicists and radiologists. The recogised effects of radiation were those that could be readiliy identified by the "available methods of clinical examination and observation". No mention was made of the less visible long term effects of radiation or of *tolerance doses*.

The concept of the tolerance dose had emerged during the mid 1920s as an attempt to define safety standards in biological units of damage. The transition to considering the biological effects of radiation was only possible by maintaining a narrow view of the types of biological damage produced. The unit adopted was the skin erythema dose. The dose required to produce acute reddening of the skin. This effect was clearly visible and could be measured. The pioneer of this approach was the American scientist, Mutscheller. He recognised the need for both a physical and a biological approach to protection.

Mutscheller also recognised that absolute protection was not possible. However, he was concerned to establish what amount of radiation the body could tolerate. Several other scientists also pursued similar lines of investigation during the late 1920s. All came, largely through judgement, to similar values. The IXRPC did not adopt a numerical tolerance dose until the 1934.

By this time the extent of biological knowledge of the effects of radiation has considerably advanced. Muller had shown in 1927 that X-rays were capable of damaging genetic material. Yet, when the last update of the IXRPC recommendations was published in 1937, safety

standards were still only concerned with the acute effects of radiation. No mention was made of the risks of cancer or of genetic damage. Some national authorities, such as in Sweden, had warned of the long term effects during the mid 1920s.

The first discussions of the relevance of genetics were held by the U.S protection committee in 1940. A proposal was made to reduce the tolerance dose by factor of ten. This was initially accepted, but later rejected. Some members of the committee maintained that the new figure would lead to severe restrictions in the medical uses of radiation. Practicality, therefore, became a major consideration in the derivation of tolerance limits.

Genetics were ignored in the derivation of the tolerance dose. However, the notion of biological tolerability was challenged by the new biological evidence. The Americans responded by proposing the renaming the tolerance dose as the *permissible dose*. This new term acknowledged that biological tolerance did not exist, but instead implied that some degree of genetic damage was permissible.

One scientist, a biologist who was not a member of the U.S Advisory Committee, questioned the committee's refusal to lower its tolerance dose. Henshaw made a plea that safety standards be devised to guard against a range of biological effects, in particular tumour induction, leukaemia, foetal injury and genetics.

This period also saw the first comparison between the relative safety of radiation work and that in other professions. In the mid 1920s Kaye commented:

"Radiology is, in fact, no more dangerous, under proper conditions, than scores of other professions".

This statement represents another important aspect of the developing protection philosophy. Radiation work, despite considerable scientific uncertainty, was *judged* to be safe even before the state of scientific knowledge allowed for the quantification of risk.

With the compromise nature of standards this judgement forms an important part of the protection philosophy of the 1990s.

CHAPTER 3: FROM TOLERANCE DOSE TO MAXIMUM PERMISSIBLE DOSE

The beginning of the Second World War saw the dawn of the atomic age and the rapid expansion of industrial and medical uses of radiation. During the war this activity was centred around the development of the atomic bomb.

Throughout the Manhattan Project safety standards were based upon the recommendations of the U.S Advisory Group on X-ray and Radium Protection. In addition, in many areas of work, particularly regarding inhalation and ingestion of radioactive substances, new standards and solutions had to be derived[1].

One other change was in terminology. Throughout the Manhattan Project the concept of *tolerance dose* was replaced by the *maximum permissible dose*, even though the maximum dose of radiation a worker could receive was not changed[2]. In the U.K the new term was not adopted until several years after the war.

In the U.K radiological protection was given a low priority. The recommendations of the X-ray and Radium Protection Committee were reprinted without change during the war. However, the risks from radiation exposure did not figure in the discussions over the development of the atomic bomb. In Gowing's account of the wartime atomic programme

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[1]The project's Health Division was directed by a radiologist, Robert S Stone, who had taught at the University of California Medical School since 1928.

[2]Stone R.S (1946) 'Health Protection Activities of the Plutonium Project', Proceedings of the American philosophical Society 90 (1) 11-19

Stone R.S (1952) 'The Concept of a Maximum Permissible Exposure', Radiology 58 (5) 639-660

Hacker B.C (1987) The Dragon's Tail - Radiation Safety in the Manhattan Project, 1942-1946, Berkeley: University of California Press

in the U.K no mention is made of tolerance doses. Gowing has commented that when the U.K Defence Services Panel of the Scientific Advisory Committee considered the MAUD report[3] in 1941, it discussed the possible effects from radioactivity from the bomb but did not mention genetic effects[4].

One of main results of the wartime developments was a dramatic increase in the number of people exposed to ionising radiation. This and the nature of the new hazards required a reappraisal of existing safety standards. Work started on this, on both sides of the Alantic, in the immediate post-war years. As was to be expected, this process was initially confined to those nations involved in the wartime development of atomic weapons: the USA, Britain and Canada. These countries were to have a major influence on the development of post-war radiological protection standards.

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3.1: REVISION OF PRE-WAR STANDARDS

In 1946, the newly created United States Atomic Energy Commission (AEC) assumed responsibility for the development of nuclear weapons and energy. This included taking over the activities of the Manhattan Project's Health Division[5].

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[3]The report that proposed that Britain should develop an atomic bomb.

[4]Gowing M (1964) Britain and Atomic Energy 1939-1945, London:Macmillan and Co Ltd
Gowing also noted that she only found one mention of genetic effects in the wartime records. This was about the concern that the German's use release radioactive fission products as a weapon.

[5]Mazuzan G.T and Walker J.S (1984) Controlling the Atom - The Beginnings of Nuclear Regulation 1946-1962, Berkeley:University of California Press

Soon after the AEC was formed Taylor reformed the pre-war Advisory Committee on X-ray and Radium Protection[6]. He invited the participation of scientists involved in the Manhattan Project in an attempt to ensure that the Committee continued to be recognised as a source of authoritative advice on radiological protection[7]. The Committee was renamed the National Committee on Radiation Protection and its membership and structure expanded to take account of the recent developments[8].

In Britain, in 1945, a new committee structure, responsible for radiological protection standards, was formed under the sponsorship of the Medical Research Council. The main committee was called the Research Committee on the Medical and Biological Applications of Nuclear Physics[9]. This held its first meeting on January 17th 1946. The purpose of this committee was defined as:

> "assisting the Council in the promotion of research in the medical and biological applications of nuclear physics and to report to the Advisory Committee on Atomic Energy"[10,11,12]

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[6]Taylor has suggested that three members, Failla, Curtis and Stone were all involved in the Manhattan Project. Stone was in charge of the Health Division but there is some confusion over whether he was ever a member of the USACXRP before the war. He is not listed as attending any of its meetings in Taylor's archive account of the work of the ICRP and NCRP.

[7]The Manhattan District the U.S Public Health Service were both invited to nominate a physicist and a radiologist to serve on the Committee.

[8]Taylor L.S (1979)

[9]Advisory Committee on Atomic Energy (1945) Suggestions for the Constitution of a Research Committee on the Medical and Biological Applications of Nuclear Physics - Copy of a letter (with enclosure) dated 24th October, 1945 to the Secretary from the Medical Research Council, 24th October 1945 A.C.A.E (45)33, In AB 16/149

[10]The Advisory Committee was also called the Anderson Committee.

[11]Committee on the Medical and Biological Applications of Nuclear Physics (1945) Minutes of First Meeting Tuesday January 17th 1946, Medical Research Council, In PRO:AB 12/122

[12]The members of the Committee were: Sir Edward Mellanby (physician); Sir Henry Dale (physician); Sir Joseph Barcroft (physician); Sir Ernest

This latter committee was responsible for advising the Government on the development of atomic energy for military and industrial purposes[13].

The MRC committee was therefore an integral part of the government advisory structures for the promotion and development of nuclear energy. Four of its members had been directly involved either in the decision during the war to develop the atomic bomb or at a high level in the subsequent development work[14].

Rock Carling (radiologist); Sir Charles Darwin (physicist); Professor Hopwood (physicist); Lord Horder (physician); Professor J.R Learmo; J.S Mitchell (physicists); J Ralston K. Paterson (radiologist); N.W Perrin (chemist), Professor Sydney Russ (physicist); Sir George Thomson (physicist), L.H Gray (radiobiologist).

[13]This in turn reported to the Official Committee on Atomic Energy, which reported to the Ministerial Committee on Atomic Energy, comprised of the Prime Minister and the few individual members of the Government that were party to the decision to proceed with development work in the atomic energy fields after the war.

[14]The chair of the MRC Committee was Sir Henry Dale, President of the Royal Society, who with Sir Edward Mellanby, MRC had been members of the Defence Services Panel of the Scientific Advisory Committee which had considered the MAUD report in 1941. This had initiated development of the atomic bomb. Dale was also a member of the Anderson Committee. Another member, Sir Charles Darwin was a member of the Technical Advisory Committee, answerable to Anderson. This committee was concerned with the engineering issues associated with the bomb project. N.W Perrin, had formerly worked with ICI, but had been associated with the MAUD project and once the decision had been made to proceed with development work during the war, had been deputy to the Director of Tube Alloys. Following the war, and during his membership of the MRC committee he was attached to the Directorate of Atomic Energy at the Ministry of Supply and was a member of the Official Committee on Atomic Energy. Another member, Professor J.S Mitchell, a physicist, who had been stationed in Canada during the War at the Chalk River site, was also a member of the Anderson Committee. Mitchell later became Professor of Radiotherapeutics at the University of Cambridge and later Regius Professor of Physics and continued as a consultant to the U.K atomic energy project until 1974 (when Gowing's books was published). Sir George Thomson, while an academic at Imperial college undertook contract work for Harwell after the war on the subject of thermo-nuclear fusion.

Several sub-committees were also formed under the main MRC committee. One of these, the Protection Sub-Committee was directly concerned with the establishment of radiological protection standards[15]. The chair of this sub-committee was Sir Ernest Rock Carling. A leading radiologist who was later to be the chair of the IXRPC when it reformed as the International Commission on Radiological Protection (ICRP)[16,17].

There is no documentary evidence that any member of the MRC committee, or its sub-committees, regarded the problem of radiation risk as raising fundamental questions over whether Britain should be pursuing work on atomic energy. If they did, this concern has not been minuted. Gowing, the official U.K historian on atomic energy developments notes:

> "Health and safety considerations were not a decisive factor in the prime decision to have an atomic energy project, though they loomed large in subsequent important decisions on sitting the piles and choice of systems, and in carrying out the programme. No one asked if the project was too dangerous to attempt, any more than if it was too costly: it was axiomatic that Britain must have it"[18,19,20]

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[15]The sub-committee was responsible for both basic tolerance levels and for derived levels i.e discharges limits from Harwell and the Windscale Piles.

[16]Rock Carling was originally a surgeon who, according to Gowing, became interested in radiological protection through membership of the Radium Commission and Trust.

[17]Its membership also initially included W. Binks (physicist); A.R Greatbatch who was on the staff of Dr W. Penny, the scientist responsible for the development and fabrication of a British atomic bomb; Dr W.P Grove from Thorium Ltd (radiochemist), the forerunner of Amersham which was responsible for Isotope production; Professor J.B.S Haldane (geneticist), Professor J.S Mitchell (physicist); Professor S Russ (physicist); Dr Janet Vaughan and Sir Lionel Whitby (physicist). This initial membership was later supplemented by several others including, Dr J.D Cockcroft (physicist) the Director of Harwell and Professor M.V Mayneord (physicist) who had been stationed at Chalk River during the War. Five of the members were also members of the Advisory Panel on Radiology set up by the Ministry of Labour and National Service.

[18]Gowing also notes that the first British attempt to put radiological safety in perspective was made in 1954 in an article by F.R Farmer, which examines the atomic energy safety record and compares the

The only question over whether atomic energy developments might pose unacceptable risks came from outside the official establishment. This was in two letters published in the medical journal *The Lancet* in 1946. The first letter started:

> "The official account of the development of atomic energy emphasises that 'the questions involved are not technical questions; they are political and social questions'. But the employment of nuclear fission on a large scale also involves biological problems which cannot be solved by any form of political or social control, even though atomic energy may be used for industrial purposes only"[21].

This author believed that:

> "before any country commits itself to further industrial projects concerned with nuclear fission, a frank discussion in public, and not only in committees of experts briefed by their governments, should be encouraged".

He also commented that

> "the Government should give permission to any person having knowledge of the biological effects of nuclear fission and related subjects, to disclose the nature of these effects; thus public opinion may be adequately informed and able to decide whether any group should be allowed to embark upon atomic ventures".

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figures and costs with those for road accidents and industrial accidents. However, a paper from 1949 by Edison also discussed the question of risk acceptability for the general population from radioactive effluent and made general comparisons with the chemical industry.

19 Gowing M (1964) Britain and Atomic Energy 1939-1945, London:Macmillan and Co Ltd

See also:

Gowing M (1974) Independence and deterrence, Britain and Atomic Energy, 1945-1952, Volume 1 Policy Making, London:Macmillan Press

20 Gowing also suggests that the question of the risks of atomic energy were treated as a technical, not a political or social, matter and were left "in the hands of the experts", with little interest from politicians except in the Radioactive Substances Bill of 1948. Amongst other things an advisory committee was established under this Bill. The majority of the Public Records Office files for this committee, dating from 1948 - 1965 are closed to the public. The Health and Safety Executive have refused a request to examine them.

21 Wiesner B.P (1946) 'Biological Dangers of Atomic Fission', The Lancet January 5th 33

The letter concluded:

> "It seems not impossible that frank disclosure of available knowledge will throw doubt upon the admissibility of the industrial employment of nuclear fission for whatever purpose. For it will hardly be maintained that any country has the right to scatter radioactivity, in war or peace, for any purpose whatever, and thus endanger the habitability of the plant or the nature of its inhabitants".

The second letter issued a similar warning:

> "The medical profession will have a heavy responsibility to bear if with full knowledge of the dangers ahead it waits until the industrialists have completed their plans before it starts to investigate their biological consequences"[22].

These letters were reported to the Directorate of Atomic Supply by J.S Mitchell, a member of the MRC Committee. Mitchell noted:

> "Both authors are reputable workers and their letters raise important issues"[23].

He suggested that a reply be sent stating all the questions asked, "and others", have been considered in establishing tolerance levels for industrial exposure to radiation. Mitchell commented that:

> "We have certainly taken no chances and I think it would be wise to say so. When the Cooperative Security Regulations permit, a large body of new experimental evidence will become available which should prove to all that the Project, as a whole, has considered with utmost seriousness its responsibilities with regard to biological dangers".

Mitchell also stated:

> "In almost every case the tolerance limits which we have recommended for the U.K and Canadian Projects are substantially lower than those employed in the U.S. For example, I have insisted on a tolerance dose rate of not more

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[22] Walker K (1946) 'Biological Dangers of Atomic Fission', The Lancet January 12th

[23] Mitchell J.S (1946) Letter to Sir Wallace Akers, Directorate of Atomic Energy, 14th January 1946, re: Letters in the Medical Press on Biological Dangers of Atomic Fission. In PRO:AB 6/114

than 0.05 r of gamma radiation per day, which is 1/2 the value used by the U.S Project"[24].

These letters were discussed by the Protection sub-committee, which had been instructed to draft a reply stating that the issues were being considered. This reply was to be signed by Sir Henry Dale, after consultation with Sir John Anderson[25], the cabinet minister responsible for Britain's atomic energy project. Dale replied to the letters in his capacity as a member of the Anderson committee and chair of the MRC CMBANP committee[26].

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3.2: BIOLOGICAL INFLUENCES ON TOLERANCE LIMITS FOR WORKERS

At the first meeting of the Protection Sub-Committee a memorandum written by Mitchell was discussed. This summarised the state of knowledge on radiation hazards and was based upon published data[27]. Mitchell believed that sufficient information was available to ensure adequate levels of protection against the acute effects of radiation. On the other hand, he considered that available information on the long term effects was "seriously deficient".

(I) Genetic Effects of Ionising Radiation

He considered that genetic damage was "one of the most important" biological effects of ionising radiation. An effect, which he commented, was considered linearly proportional to the tissue dose received. This

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[24]He also commented that his tolerance concentration for uranium in air bourne dust was 1/3 of the value used by the American's.

[25]Protection Sub-Committee of the MRC Research Committee on the Medical and Biological Applications of Nuclear Physics (1946) Minutes of the First Meeting on 8th February 1946, N.P/P/2, In PRO:AB 12/157

[26]The reply was printed in the Lancet on 16th March 1946.

[27]Mitchell J.S (1945) Memorandum on Some Aspects of the Biological Action of Radiations with especial reference to Tolerance Problems, 20th November 1945, Montreal PQ, MRC.46/204 H.I/17, In PRO:AB 2/207

implied there was no threshold dose below which genetic damage did not occur.

(II) Leukaemia Induction

Mitchell also drew readers attention to the induction of leukaemia by ionising radiation. He considered that a recent study of the leukaemia incidence in radiologists provided "conclusive" statistical evidence that radiation caused leukaemia[28]. This meant that leukaemia should be recognised as an occupational disease amongst radiation workers.

This paper, published in 1944, used data extracted from the obituary notices of the Journal of the American Medical Association and had shown that a significant excess of leukaemia had occurred between 1929-43, although the doses received were unknown. Mitchell suspected that they were of the order of 5 r per day for gamma rays.

Mitchell commented that this study implied that leukaemia induction was also proportional to the total dose of radiation received. This would mean that a threshold dose did not exist. He commented:

> "This matter is obviously of such importance that much further work is urgently required".

(III) Lung Cancer

Mitchell was also concerned over the possible induction of lung cancer by the inhalation of radioactive dusts and gases. He believed that this represented "one of the most serious hazards" likely to be faced by radiation workers.

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[28]Mitchell observed that the link with leukaemia had been first suggested in 1911 by a German scientist.
Jagié N, Schwartz G and Siebennock L (1911) Berlin Klin Wschr 48 1120

Again, Mitchell considered that a linear relationship between cancer incidence and dose should be assumed. He accepted that this assumption "may introduce a large safety factor" into the tolerance dose calculations.

(IV) Effects on the Foetus

The final deleterious effect to guard against was damage to the foetus. Mitchell suggested that the

> "great radio-sensitivity of the mammalian embryo renders it imperative that under industrial conditions there should be no opportunity for accidental irradiation of the developing human embryo or fetus"[29].

(V) Values of the Tolerance Dose

Mitchell did not accept that the existing tolerance dose was adequate for protection purposes. He considered that the calculation of a new tolerance dose rate was "probably the most important decision" that would be taken in the protection of radiation workers[30].

He gave two examples to support these beliefs. He observed that the basis of the figure recommended by Wintz and Rump in 1931[31] had been based upon the absence of observable effects at the tolerance dose. He did not consider that this approach could be regarded as a "sufficiently sensitive index of permanent radiation damage".

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[29] He cited a 1929 study that reported twenty five "grossly deformed children" out of seventy four full-time pregnancies, where the mother had been given therapeutic doses of radiation. Murphy D.P (1929) American Journal of Obstetrics and Gynaecology 18 179

[30] Mitchell J.S (1945) Memorandum on Some Aspects of the Biological Action of Radiations with especial reference to Tolerance Problems, 20th November 1945, Montreal PQ, MRC.46/204 H.I/17, In PRO:AB 2/207

[31] See Chapter 2.

He also commented that when the U.S tolerance dose had been recommended the genetic effects of radiation had been "deliberately ignored". Mitchell did not consider this approach to be an inadequate basis of p. otection.

He recommended that "every effort" be taken within the Canadian and U.K projects to ensure that a value of 0.05 r per day was never exceeded. This was half the U.S tolerance dose[32].

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3.3: THE DERIVATION OF OCCUPATIONAL TOLERANCE DOSES

Following the discussion of Mitchell's paper the Protection Sub-Committee established several research programmes to investigate the priority areas he outlined. These included the establishment of tolerance limits for total body gamma radiation, and studies of the long term genetic effects[33].

During their second meeting the Sub-committee agreed, that for the time being, investigations of the tolerance limits for whole body radiation could be left to the Harwell nuclear research establishment[34].

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[32] I have found no record stating that the U.S figure had ever been adopted by the British. The British Tolerance dose was based upon the ICRP recommendations.

[33] Other priority areas included (i) establishment of tolerance levels for fast and slow neutrons (ii) the study of effects of beta emitters in gases and dusts (iii) determination of secondary limits following intake of beta emitters such as Strontium-89 and tolerance limits for radioactive material in water and (iv) haematological investigations.

[34] Protection Sub-Committee of the MRC Research Committee on the Medical and Biological Applications of Nuclear Physics (1946) Minutes of Second Meeting, 10th May 1946 NP/P/6, In PRO:AB 12/157

(I) Organisational Requirements

This issue was next discussed during their fifth meeting in October 1946. During this meeting a panel was appointed to prepare recommendations on tolerance doses[35]. This was the Tolerance Doses Panel.

It was also noted at this meeting that the Americans were suggesting that the concept of 'tolerance dose' be changed to 'maximum permissible dose'. This was not discussed[36].

The first meeting of the Tolerance Dose Panel was held on the 29th November 1946[37]. Its primary objective was the establishment of the tolerance dose for X and gamma rays. All other tolerances would be based upon these figures.

The panel also discussed whether it should concern itself with the practicality and achievability of its recommendations[38]. The Panel considered that this fell within its terms of reference. It was agreed that the tolerance values should be communicated to other bodies, such as the British X-Ray and Radium Protection Committee (BXRPC), whose function

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[35]The initial membership of the panel included: W. Binks (physicist); Dr L.H Gray (radiobiologist); Professor M.V Mayneord (as chairman)(physicist); Dr E.R.A Merewether (physician - H.M Senior Medical Inspector of Factories) and Professor J.S Mitchell (physicist).
This was later expanded to include: Dr D.G Catcheside (geneticist); A.C Chamberlain (physicist); Dr J.D Cockcroft (physicist); Dr E.F Edson; Sir Ernest Kennaway; J.F Loutit (physician); Dr G.J Neary (physicist) and Dr F.W Spiers.

[36]Protection Sub-Committee of the MRC Research Committee on the Medical and Biological Applications of Nuclear Physics (1946) Minutes of the Fifth Meeting on 11th October 1946, NP/P/16, In PRO:AB 12/157

[37]At which the membership was extended to included Dr Cockcroft, director of the AERE Harwell, or his deputy Mr Marley. A geneticist, Dr D.G Catcheside was also invited to join the committee.

[38]Tolerance Doses Panel of the Protection Sub-committee (1946) Minutes of a meeting held on 29th November 1946 NP/P/TD/1, In PRO:AB 12/35

it was to recommend protective procedures. This did not occur as the BXRPC was inactive.

(II) Biological Basis of a Tolerance Dose: Blood Changes vs Genetics

The main issue that dominated these discussions were which biological effect should determine the level of the tolerance dose. Generally, the physicists disagreed with the biologists on the emphasis that should be attached to evidence supporting the need to reduce the tolerance dose. The minutes note that Binks, a physicist, held the opinion that too much attention had been paid to the U.S tolerance dose. He noted that workers exposed at the higher U.K level had not been seen to develop any ill effects. He also considered that the lack of any indication whether a higher dosage rate could be tolerated was a major difficiency.

Binks also rejected the concern over genetics. He did not accept that genetics were important at the current levels of exposure of U.K radiation workers. He considered that the likelihood of hereditable changes occurring was negligible.

Gray, a radiobiologist, considered that the value of the tolerance dose should be based upon available biological information. He raised the question of changes in the blood following low level exposure. In reply, Mitchell reported that Swedish authorities have recommended a lower tolerance dose than the U.S figure. In Sweden a tolerance dose of 0.01 r per day was regarded as a "safe working dose"[39].

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[39]This figure is repeated in a 1947 paper by the Swedish physicist, Rolf Sievert. This introduced the concept of two types of tolerance dose: (i) the "active tolerance dose" which he defined as the "minimum dose that causes a scarcely perceptible biological effect of a certain type" and (ii) the "safety tolerance dose" which was defined as the "the maximum dose that should be allowed for persons

Mayneord, the chair of the Panel, said that members had to decide whether such haematological changes were serious pathologically. This statement illustrates the element of judgement involved in deriving the tolerance dose.

At the Panel's second meeting Mitchell had asked whether the tolerance dose should be reduced to the Swedish level. Mayneord had commented that this would render radiation therapy impracticable. This illustrates, that contrary to the Panel's decision at their first meeting, the achievability and practicality of suggested tolerance values were important considerations. On the other hand, Mayneord considered there was sufficient evidence to show that the current international figure of 0.2 r per day should be reduced by a factor of four[40].

At the same meeting two memoranda on genetics were presented. The first by D. G Catcheside states:

> "All quantitative experiments show that even the smallest doses of radiation produce a genetic effect, there being no threshold dose below which no genetic effect is induced. Doses down to 0.1 r per day have been used on mice. The effects are cumulative, some of the effects being additive or linearly proportional to the total dose applied. Others of the effects, when produced by some kinds of radiations, increase in frequency in proportion to the power of the dose between 1 and 2, so long as the dose is not very small. When the dose rate is small, even these effects are apparently additive. . . It is very likely that the rates of mutation

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engaged in radiological work". Sievert considered that it was "advisable to calculate with a safety tolerance dose which was only 0.1- 0.2 of the active tolerance dose. He commented that "radiation quantities as low as 0.02-0.05 r per day can, after a comparatively short time, give rise to blood changes". This meant that it seemed "advisable at present to fix the safety tolerance dose for general irradiation at 0.01 r per day".
Sievert R.M (1947) 'Silvanus Thompson Memorial Lecture - The Tolerance Dose and the Prevention of Injuries Caused by Ionising Radiation', British Journal of Radiology XX (236) 306-318

[40] Tolerance Doses Panel of the Protection Sub-committee (1946) Minutes of the Second Meeting, on 1st May 1947, NP/P/TD/13, In PRO:AB 12/35

per roentgen found to be characteristic for lower plants and animals will hold also for induced mutation in man"[41].

The second was by Catcheside's deputy, Dr D.E. Lea, on the question of the tolerance dose. He starts this memorandum with the following statement:

> "In writing this memorandum I assume members of the panel to be familiar with and accept, the survey of Genetical Effects of Radiation prepared by D.G Catcheside"[42].

Of Catcheside's observations on deleterious effects caused by recessive gene mutations Lea states:

> "There will be no means of showing whether the abnormalities in the child were due to the occupational exposure of the parent, and so no question of liability to compensation can occur".

Lea concluded his discussion of gene mutations by stating:

> "It will not be possible to prove whether the effect in any particular instance was caused by radiation, so no question of liability for compensation can occur".

This meant that

> "if less than 1% of the population were exposed to radiation, the incidence of the abnormality in the population as a whole would probably be only slightly increased".

Lea's memorandum concluded:

> "If on grounds other than genetic, a tolerance dose of 1 r per week is put forward for radiation workers, then so long as less than 1% of the population is exposed to radiations there is not likely to be a noticeable increase in the incidence of hereditary abnormalities".

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[41] Catcheside D.G (1947) Genetic Effects of Irradiation with Reference to Man, Protection Sub-Committee of the MRC Committee on the Medical and Biological Applications of Nuclear Physics 6.2.47 MRC.47/77 NP/P/TD/3 In PRO: AB 12/35

[42] Lea D.E (1947) Memorandum on Tolerance Doses in relation to 'Genetic Effects of Radiation, Protection Sub-Committee of the MRC Committee on the Medical and Biological Applications of Nuclear Physics NP/P/TD/14 In PRO: AB 12/35

(III) Differences between U.K and U.S Tolerances

The third meeting of the Tolerance Dose Panel was held on 20th June 1947 to consider the question of basic tolerances. Attending this meeting were two American scientists representing the U.S Atomic Energy Commission. They were Professor R.D Evans and Dr J.G Hamilton[43].

The minutes note that at the start of the meeting Evans made "a plea" that the term 'tolerance dose' be replaced by 'maximum permissible dose'. The meeting discussed the differences between the U.S and U.K figures for tolerance doses[44]. Evans suggested that the two figures were not really different. The U.S one was measured in air, whereas the British figure, he believed, was measured on the surface of the body to approximate the tissue dose[45,46].

He considered it made sense to set the maximum permissible level at a value at which there was no evidence of any harm done to humans. This would be lowered "as soon" as evidence had accumulated proving that "harm" was being done[47].

The Americans were already contemplating a reduction to 0.3 r per week[48]. The minutes do not state if the American's discussed this with the Panel during the meeting. Several months earlier Dr J.E Rose, of the U.S

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[43]Hamilton was also a member of the NCRP Sub-committee's on Internal Dose and Radioactive isotopes. Evans, a physicist, had been a member of the pre-war sub-committee on Radioactive Luminous Compounds and had been responsible for the tolerance concentration of radium.

[44]0.2 r per day and 0.1 r per day respectively.

[45]This was incorrect. Both the original ICRP and NCRP figures had been based on dose in air.

[46]As seen in Chapter 2 the difference between these two figures was due to the extent of rounding down and not how they were measured.

[47]Tolerance Doses Panel of the Protection Sub-committee (1947) Minutes of the Third Meeting on 20th June 1947, NP/P/TD/44 NP/P/34, In PRO:AB 12/35

[48]Taylor L.S (1979)

Argonne National Laboratory[49], had written to Mitchell stating that the U.S limit was too high. Rose had commented that this decision took account of the

> "fact that a much larger segment of the population will be exposed in future"[50].

(IV) Criteria Used in the Derivation of the Tolerance Dose

The Panel did not discuss the tolerance dose again until the sixth meeting of the Panel, held on December 4th 1947. Mayneord opened the discussion by observing that four options existed. They were: keeping the present British figure (0.2 r per day); lowering the tolerance dose to the U.S level (0.1 r per day); a larger reduction to 0.05 r day, "favoured by some workers" or an even lower figure such as recommended by Professor Sievert[51].

Gray emphasised that, before a decision could be made, four different biological effects had to be considered: (a) general physiological, (b) genetic (c) sterility and (d) carcinogenesis.

General physiological effects and blood changes were considered first. Mitchell stated he would strongly recommend 0.05 r day on a six day a week basis, i.e, 0.3 r week. He supported this by stating that blood changes had definitely been detected at 0.25 r per day and that a safety factor of five was desirable.

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[49]Rose was also a member of the NCRP sub-committee's on Radioactive Isotopes and Monitoring Methods and Instruments.

[50]Rose J.E (1947) Extract of Letter to Dr J.S Mitchell from J.E Rose, Argonne National Laboratory, February 27th 1947, NP/P/TD/5, In PRO:AB 12/35

[51]Tolerance Dose Panel of the Protection Sub-committee (1947) Minutes of the Sixth Meeting on 4th December 1947, NP/P/TD/37, In PRO:AB 12/35

The discussion then turned to the practicality of this proposal. The minutes note that Mayneord stated that 0.05 r day

> "would be difficult to attain in practice but it should not be impossible".

Merewether, a physician and Senior Medical Inspector of Factories, stressed that practicality was not the issue. It was necessary to decide what was "safe".

This view point was disputed by Mayneord. He considered that practicality and safety were linked. This view emphasises the non-scientific considerations in the derivation of the tolerance dose. The minutes note that Mayneord "thought" that 0.05 r per day would be "extremely difficult" to achieve in a radium department.

The discussion then turned to Genetics. Catcheside considered that while there was no tolerance dose for genetic effects, a level of 0.1 r per day would be adequate providing that the exposed proportion of the population was not large.

Mayneord asked Catcheside what dose would produce a serious rise in the spontaneous mutation rate? He replied that as there was no information on genetic effects in humans, data had to be extrapolated from animals. A dose of 50 r per generation (25 years) would probably give an induced rate equal to the spontaneous rate. If the whole population was to receive 0.3 per week this would be equivalent to 400 r per generation. This would increase the incidence of abnormalities due to recessive genes by about 1000%. He judged that this would be intolerable.

The minutes note that Mayneord commented that "it was obvious" that the value of the tolerance dose depended on the size of the exposed

population. Catcheside stated that if the exposed population was limited to 10%, a 2% increase in abnormalities would be expected in the first generation, rising to 100% at equilibrium. Mayneord judged that this figure would be tolerable.

For carcinogenesis 0.05 r per day was considered tolerable for solid cancers and for leukaemia. A final decision on the tolerance dose was not reached at this meeting.

Following this discussion a series of memoranda were producing summarising the main arguments for setting tolerance levels for each of the effects. These were discussed during the Panel's eighth and ninth meetings. During the eight meeting, Binks expressed the opinion that the need to reduce the tolerance dose rested on the evidence of changes in the blood. He considered that this evidence was not sufficient to justify a reduction in the tolerance dose[52].

At the next meeting Mayneord asked the Panel to decide if the tolerance dose should be reduced from 0.1 r per day to 0.05 r per day.

Generally, the members with biological or medical background favoured this reduction, whereas the physicists did not[53]. There were two exceptions to this. Mitchell, a physicist, supported the reduction. Gray, a radiobiologist, did not. He believed that if all effects were

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[52]Tolerance Dose Panel of the Protection Sub-Committee (1948) Minutes of the Eighth Meeting, 26th February 1948, NP/P/TD/52, In PRO:AB 12/72

[53]At the ninth meeting the following tolerances doses were suggested: Merewether (physician), 0.05 r per day; Loutit (physician) 0.1 r per day if legislating for 5 years, 0.05 r per day if a longer period was contemplated; Mitchell (physicist), 0.05 r per day to cover the next 20 to 30 years; Gray 0.1 r per day (radiobiologist). Catcheside, 0.05 r per day (geneticist), Cockcroft (physicist), 0.1 r per day and Binks (physicist) 0.1 r per day.

judged to be harmful then the tolerance dose should be reduced to 0.01 r per day. However, he did not consider the evidence sufficient to justify a value lower than 0.1 r per day.

Cockcroft was opposed to a lower figure as this would introduce "administrative difficulties" at Harwell. He also commented that the current average dose at Harwell was lower than the "permissible level"[54]. He argued that if this were to be set at 0.1 r per day the average dose received by the workforce would around one third of this. He also suggested that the tolerance dose should be averaged over three months. The would allow higher doses in some weeks and provide greater flexibility. As a compromise Binks suggested a weekly value of 0.5 r (about 0.08 per day for a six day week). This was agreed by the Panel[55].

(V) Influence of U.S Action on the U.K Tolerance Dose

At the next Panel meeting, on May 6th 1948, Mitchell submitted new evidence which led to the Panel to reconsider its decision. Mitchell told the Panel that the U.S was planning to announce a figure of 0.3 r per week for workers in atomic energy establishments[56,57]. This recommendation was based upon experimental evidence regarding the

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[54]The minutes note that he used this term and not "tolerance dose".

[55]Tolerance Dose Panel of the Protection Sub-committee (1948) Minutes of the Ninth Meeting on 16th March 1948, NP/P/TD/54, In PRO:AB 12/72

[56]Tolerance Doses Panel of the Protection Sub-committee (1948) Minutes of the Tenth Meeting on 6th May 1948, NP/P/TD/57, In PRO:AB 12/72

[57]This level had been suggested by Dr Failla head of the Biophysics section of the U.S AEC and a member of the U.S NCRP executive Committee.

Failla had previously suggested, in 1932, that the tolerance dose for long term exposure to gamma rays from radium should be based on the level at which no changes in the blood were detected, 0.02 r per day. This is equivalent to 6 rems per year (the ICRP recommended a level of 5 rems in 1959). However, when the U.S proposed changing its 0.1 r per day limit to this level in 1941 based on genetic information Failla had vigorously opposed it.

reduction of life span and of spermatogenesis in several species of animals. The Panel had not previously considered reduction in life span as an important effect of radiation. Mitchell stated he was convinced by the evidence on life span reduction and quoted the example of a person of 30 years of age, with a life expectancy of 68 years. Irradiation at the rate of 0.5 r per week for 48 weeks per year from age 30 would reduce their life span about 3 years[58].

Mayneord acknowledged that the Panel had to choose between 0.3 and 0.5 r per week. The minutes note he asked the Panel if the new evidence justified the lower figure[59].

The comments of members indicate that this choice could not be made purely on scientific grounds. For instance, Merewether suggested that comparisons be made with other industrial hazards. Some of these reduced the life span to a greater extent than radiation (the average age of workers who suffered from silicosis was 55). Loutit agreed with this view, adding that it had to be admitted that radiation was a hazard. He suggested that the panel had to decide how much of a reduction in life span was acceptable. Catcheside stated that there appeared to be a reduction in life span at doses of 0.1 r per day, although he also agreed with the above statements. Rock-Carling added that account also had to be taken of the longer life expectancy of the present generation compared

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[58] At later meetings the Panel discussed the question of reduction in life span. They decided that in view of the large scale experiments necessary to give significant results and the greater urgency of other problems that no action should be undertaken.
Tolerance Dose Panel of the Protection Sub-committee (1949) Progress Report from the Tolerance Doses Panel for the Period October 1948 - January 1949, NP/P/45, In PRO:AB 12/34

[59] Tolerance Doses Panel of the Protection Sub-committee (1948) Minutes of the Tenth Meeting on 6th May 1948, NP/P/TD/57, In PRO:AB 12/72

to that of the last century. The discussion was closed with a suggestion from Cockcroft that the Panel consider the amount of radiation an individual was exposed in their lifetime.

This issue arose again at the next meeting, on the 27th May 1948. Mayneord suggested that there were three options open to the Panel: (1) reduce to tolerance dose to 0.3 r per week; (2) retain the tolerance dose at 0.5 r per week or (3) adopt a lifetime limit for radiation workers of 200 r[60].

Some members were concern over the practical problems of meeting a lower limit. The minutes note that Edson stated:

> "The lowering of the maximum permissible dose from 0.5 r to 0.3 r per week would make the position difficult for some employers, who would have to adopt rigourous measures in order to ensure that at no time was the value exceeded"[61].

Edson wanted more flexibility than the reduction would provide. This view was supported by Binks. Binks observed that National Physical Laboratory tests indicated that certain groups of workers, such as those who made up radium applicators, "at times" received doses in excess of 0.3 r per week. He did not see how such exposures could be avoided, as automatic methods did not seem feasible.

Mitchell advocated reducing the tolerance level. After further discussions, which were not recorded in the minutes, the Panel agreed it would be desirable to have a common standard with the U.S. However, the tolerance dose was not reduced to the American level. Instead, it was

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[60]This had been suggested by Cockcroft at the end of the previous meeting.

[61]Tolerance Doses Panel of the Protection Sub-committee (1948) Minutes of the Eleventh Meeting on 27th May 1948, NP/P/TD/58, In PRO:AB 12/72

fixed at 0.5 r per week for two years pending future negotiation with the Americans.

This was not the end of the matter. Failla attended the 14th meeting of the Panel, held on 17th September 1948, and suggested that the difference between the two values was more apparent than real. He explained that the U.S figure was measured in free air. Whereas, the British value was measured at the surface of the body. This measurement included a component of backscatter. Consequently, he argued, the energy absorbed in both case would be approximately the same. Following a discussion this was accepted by the Panel. It was also agreed that the blood forming organs should be regarded as the most sensitive tissue[62,63,64]

The tolerance dose of 0.5 r per week, measured on the body surface, was recommended to the Protection Sub-committee and was endorsed at its meeting on 8th October 1948. The following statement was adopted:

> "The Panel is of the opinion that, in circumstances in which the whole body may be exposed, over an indefinite period, to X or gamma radiation of quantum energy less than 3 MeV, the maximum permissible dose received by the surface of the body shall be 0.5 roentgen in any one week. This corresponds

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[62]The minutes note that this was the American view that was endorsed by the Panel.
Tolerances Doses Panel of the Protection Sub-committee (1948) Minutes of the Fourteenth Meeting on 17th September 1948, NP/P/TD/71, In PRO:AB 12/72

[63]Failla also contended that the ultimate aim was to base measurements on tissue dose and not air dose. In which case the limit would be 0.3 r per week to the bone marrow (this tissue being the "blood forming organs". The discussion centred around whether a measurement of dose in air, or on the surface of the body could be taken to correspond to tissue dose.

[64]The meeting also discussed restrictions on the lifetime dose. Failla, commented, that from a genetic point of view the AEC had considered that a lifetime dose 300 r. The minutes note that Binks considered that a lifetime dose would create difficulties for worker's, over their future career, who had received the recommended total. It was agreed not to put make any recommendations about lifetime dose then.

substantially to an exposure of the whole body of 0.3 r of X or gamma radiation in any one week, measured in air"[65].

(VI) U.S Discussions on the Reductions in the Maximum Permissible Dose

The agreement on the tolerance dose was also discussed at a meeting of the U.S Atomic Energy Commission held on 21 October 1948. This meeting was attended by Cockcroft. This meeting accepted the need to reduce the maximum permissible level but expressed concern over the practical implications of the new figure. The minutes note:

> "It is impossible to implement changes at once owing to the repercussions on plant operation; a proposal to change the tolerance level gradually was mentioned"[66].

Taylor has commented that when the NCRP was reformed in 1946, it was approached by the AEC for a statement on basic tolerance levels. Within a year the NCRP had agreed that the permissible dose would have to be reduced to 0.3 r per week. The change from daily to weekly limits had been made to provide more flexibility in the application of the new limit[67]. Taylor has also been quoted as stating that the NCRP just choose a level that the AEC could achieve[68].

The AEC also wrote to the NCRP to ask for guidance on the special benefits that should be allowed for radiation work. Taylor replied:

> "I personally believe that the only sound basis for dealing with radiation protection is to assume that any working condition can be made safe and that, hence, the condition is non hazardous"[69].

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[65] Protection Sub-Committee of the MRC Research Committee on the Medical and Biological Applications of Nuclear Physics (1948) Minutes of the Twelfth Meeting on 8th October 1948, NP/P/2, In PRO:AB 12/157

[66] U.S Atomic Energy Commission (1948) Extract from Minutes of Third Meeting of C.B.O Sub-group of Scientific Advisers on October 21, 1948, In PRO:AB 6/475

[67] Taylor L.S (1979)

[68] Caufield C (1989) Multiple Exposures - Chronicles of the Radiation Age London:Secker and Warburg

His reply also gives an important insight into his protection philosophy. Taylor judged that the benefit of doubt should be given to industry until a hazard could be shown to exist. He clearly recognised that the only way to demonstrate an unsafe working environment was through death or injury to the worker. The burden of proof, therefore, rested with the worker to demonstrate the existence of a hazard:

> "I see no alternative but to assume that the operation is safe until it is proven to be unsafe. It is recognised that in order to demonstrate an unsafe condition you may have to sacrifice someone. This does not seem fair on one hand, and yet I see no alternative. You certainly cannot penalize research and industry merely on the suspicion of someone who doesn't know by assuming that all installations are unsafe until proven safe. I think that the worker should expect to take his share of the risk involved in such a philosophy. The plant or laboratory goes to considerable pains and expense to insure safe working conditions within the limits of knowledge and in consideration of recommendations by disinterested bodies. In doing so he provides work for the worker and without this the worker might be out of job. If the worker demands an absolute guarantee of safety or benefits for imagined and unproven dangers he penalizes industry to the point where industry cannot operate.
>
> I am therefore inclined to believe that it is not possible to segregate occupations involving special hazards. If there are recognised hazards the work should not continue until these are eliminated to the point they are considered non hazardous. By the same token, I do not see how one can possibly evaluate a hazard as to degree without admitting that there is a hazard and that I would not admit"[69].

(VII) Influence of Genetic Risks on Tolerance Doses

The influence of genetic risks on the magnitude of the tolerance dose was raised again at the eight meeting of the Tolerance Doses Panel. A memorandum had been circulated for comment at the request of the secretary of the Ministry of Labour's Advisory Panel on Radiology[70].

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[69] Taylor L.S (1979)

[70] This statement had been published in the British Journal of Radiology one month before:
Ellis F (1948) 'The Genetic Effects of Non-sterilising Doses of Penetrating Radiation', The British Journal of Radiology XXI 1-4

This memorandum represented an agreed statement of geneticists "and others" from a meeting held at the London Hospital on 28th January 1947. Attending this meeting were several members of the MRC committee's including D.G Catcheside, his deputy Dr D.E Lea and Dr E.R.A Merewether, the Senior Medical Inspector of Factories[71]. It stated:

> "There is no doubt that:- (1) Irradiation changes the hereditary materials, no matter how small the dose may be. (2) The effects thereby produced are all cumulative with increasing dose, being simply additive for some types of change, but increasing geometrically for others. (3) These changes are almost entirely harmful and therefore undesirable. This information has been gained from the study of organisms other than man. It is therefore necessary to decide:- (A) How far these findings apply to man. (B) What dose is permissible to individuals and to the population as a whole"[72].

However, this meeting supported the Panels' argument that genetics were not the main factor in setting the tolerance dose, provided the exposed population was small. This grouping also considered that before a final decision could be made it was necessary to determine how much radiation the population was exposed to.

The memorandum was not discussed until over a year later, at the fourteenth meeting of the Protection Sub-committee[73,74]. The minutes

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[71] The affiliations of those attending the meeting were given as: Dr D.G Catcheside (Geneticist - University of Cambridge); Professor F.A.E Crew (Usher Institute); Dr Frank Ellis (London Hospital); Dr P.C Koller (The Chester Beatty Research Institute); the late Dr D.E Lea (Prophit Student, Royal College of Surgeons); Dr K Mather (the John Innes Horticultural Institution); Dr E.R.A Merewether (Ministry of Labour and National Service); Professor Penrose (University College, London) and Dr J Read (Mount Vernon Hospital).

[72] Ellis F (1947) 'Genetic Effects of Occupational Exposure to Radiation', Agreed Statement of Geneticists and Others at the London Hospital on 25th January 1947, NP/P/49 (RP/9/10) (NP/P/TD/50), In PRO:AB 6/86

[73] Protection Sub-Committee of the MRC Research Committee on the Medical and Biological Applications of Nuclear Physics (1949) Minutes of the Fourteenth Meeting on 28th April 1949, NP/P/54, In PRO:AB 12/158

note that Professor Mayneord reported that the Tolerance Doses Panel "felt" that the genetic effects of radiation were not the limiting factor. Adding

> "At present the population as a whole was unlikely to receive doses of radiation which were likely to be serious"[74].

The Committee then considered the possibility of establishing an inquiry, amongst medical radiologists and radiographers. It discussed whether such an inquiry would provide any information on the adverse effect of occupational exposure on fertility or the normality of offspring. Professor Haldane, a geneticist, agreed with Ellis that such a study would provide useful information. The minutes note that "even negative information would be valuable". On the other hand, "positive information would act as a pointer to a possible under-estimation of the risks".

It was suggested that the British Institute of Radiology be approached to see if they would cooperate in such a study. The discussion was concluded after it had been decided

> "on the suggestion of Professor Mayneord that the whole question should be referred back to the Tolerance Dose Panel for reassessment".

This study proposal was not followed up. At the twentieth meeting of the Tolerance Doses Panel, in May 1949, Mayneord, as chairman of the Panel, opened the discussion by asking if the Panel wished to consider the issue further[75]. No geneticists were present at this discussion. He

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[74]Dr Ellis attended this meeting by invitation.

[75]Neither Haldane or Ellis were members of this Panel, and unlike the Protection Sub-committee discussion did not attend. The minutes also note that Catcheside (geneticist), Cockcroft (physicist - he sent a deputy), Fuchs, Gray (radiobiologist), Kennaway and Mitchell (physicist) were also unable to attend. Consequently, no geneticists were at this discussion. This proposal was discussed by the following members Mayneord (physicist); Neary (physicist);

considered that very little could be added to the conclusions they had already reached. He also doubted whether any useful information would be gained by approaching bodies such as the Institute of Radiology. Rock Carling agreed. A survey would be expensive and impractical to make it retrospective. No formal action was taken[76].

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3.4: DERIVATION OF TOLERANCE LIMITS FOR POPULATION EXPOSURE

The question of maximum permissible doses was further discussed at a conference between the British, United States and Canadian authorities at Chalk River, Canada between 29th and 30th September 1949[77].

While the basic tolerance level for occupational exposure had already been agreed between the British and American authorities, the British and American delegates differed in their approach to limiting public exposure. In this case the main hazard would be from internal radiation

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Binks (physicist); Rock-Carling (radiologist); Edson; Loutit (physician); Mckay (Cockcroft's deputy); Merewether (physician); Spiers; Chamberlain (physicist) and Glucksmann.

[76]The Panel agreed that Loutit should informally discuss the genetic hazards of radiation with Professor Penrose.

Tolerance Doses Panel of the Protection Sub-Committee of the MRC Research Committee on the Medical and Biological Applications of Nuclear Physics (1949) Minutes of the Twentieth Meeting on 12th May 1949, NP/P/TD/110, In PRO:AB 12/86

[77]These talks were to concentrate on four main areas (i) the 'anatomical, physiological and chemical characteristics of the "Standard Man". This was used as the basis for calculations on the effects of internally deposited radionuclides. (ii) the relative biological effectiveness of different radiations. (iii) the maximum permissible exposure to external radiations. (iv) the maximum permissible exposure to internally deposited isotopes and the corresponding permissible concentrations in air and water. These are used to limit public exposure to radiation.

exposure. This could be limited by specifying tolerance concentrations of radionuclides in air and water[78,79].

For occupational exposure, the delegates agreed that the maximum permissible amount should be based on one tenth of the minimum value known, or estimated, to cause damage. Where there was little or no experimental data comparisons were made based on comparable toxicity with radium. For instance, plutonium was considered to be 15 times as toxic as radium.

Mitchell had suggested that different standards should be applied for exposure of workers and "large" populations. He commented that for large populations the maximum permissible dose should be a factor of 100 below that of plant personnel. This reduction factor had been used in determining the permissible discharge levels from Harwell into the Thames. While many of the U.S delegates were firmly against this proposal, it was accepted on a show of hands.

The delegates intended that the report from the conference should be produced in time for the Sixth International Congress of Radiology. This was due to be held in July 1950.

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[78]The conference was attended by the following: (i) U.S Delegates, Shields Warren*; Austin Brues; G Failla*; J,G Hamilton; L Hempelmann; de Hoffman; Wright Langham; K.Z Morgan*; H.M Parker*; L.S Taylor*; B.S Wolf; C.A Nelson. (2) Canadian Delegates, W.B Lewis; H Carmichael; A.J Cipriani; G.H Guest; G.C Laurence; G.E McMurtrie; E Renton; E.O Braaten (iii) British Delegates, J.S Mitchell; A.C Chamberlain; W.F Edson; G.J Neary. (*Members of the NCRP).

[79]Permissible Doses Conference (1949) Minutes of the Permissible Doses Conference held at Chalk River, Canada, September 29th-30th 1949, NP/P/TD/122,140,155, In PRO:AB 12/86

After the conference, this issue was discussed further by the Tolerance Dose Panel[80]. Questions were raised whether such a safety factor be applied to all isotopes, or just selected ones like those that concentrated in the bone. Binks suggested that it was necessary to assess the hazards on what would be statistically significant in certain population groups or based on the individual. There appeared to be an ethical distinction between the two. Cockcroft stated that the development of dual standards for workers and the public had been based on the principle that individuals of both classes should be treated with equal fairness. As an extension of this principle it seemed justifiable to use different safety factors when a large population was potentially exposed as opposed to a small one. Gray believed that the same question arose over genetic effects. He asked if the criteria of statistical significance was justifiable ethically? He stated that individuals exposed to the hazards of contaminated water in large or small communities might fairly expect the same degree of protection.

The Panel were informed by Mr Damon, Chief Alkali Inspector[81], that the principle of different limits applied to other hazards. In chemical plants, different safety factors were applied according to the population size. For large populations a factor of 100 was considered high.

Dr Key, the Chemical Inspector at the Ministry of Health, considered that a practical distinction should be drawn between contamination of air and water. Factory workers drink the same water as the general population. He did not accept there was a need for a safety factor for drinking

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[80]Tolerance Doses Panel of the Protection Sub-committee (1949) Minutes of the Twenty-fifth Meeting on 19th January 1950, NP/P/TD/134, In PRO:AB 12/86

[81]Who attended the meeting by invitation.

water. All noxious agents must be completely removed, even though small amounts might be tolerable. Mayneord replied by pointing out that all drinking water contains some natural radioactivity. The question, therefore, was to decide how much extra activity was permissible without endangering public health.

Edson had produced a paper that considered the general issues of effluent disposal and exposure of the public. He asked what was the purpose of limits for the general population? Were they to protect even the most sensitive member of the community? Or should they be regarded as levels that give adequate protection to the "average (or standard) man" in "normal" health? If the former criteria were adopted it would mean lower limits.

Edson suggested that the

> "intention of recommendations for maximal permissible exposures is possibly to avoid an unacceptable increase in mortality or morbidity from certain specific conditions capable of being induced even in healthy man by specific irradiation of his tissues"[82].

This entailed a careful definition of what is "acceptable". He commented that different criteria applied to workers and members of the public. In the former case the risks of an occupation were balanced by benefits such as pay and minimised by work procedures:

> "Normally, industrial and research employees work under circumstances which make a slight and occasional risk an accepted feature of the job, on behalf of the employer, and thus their employment. In Ministry of Supply establishments implications of the "risks" are minimised by payments for doing the job, previous knowledge of the health risks, supervision, training changes of work and exposure, hazard control, health supervision, absence of extremes of age or

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[82] Edson E.F (1950) Maximal Permissible Radiation Exposures In Radioactive Effluent Disposal, Department of Atomic Energy Production D.At.En(P)M/1842 NP/P/TD/131, In PRO:AB 12/86

subnormal health, and a capacity for self protection during known dangerous tasks"[83].

This was not so for the public at large where risks were imposed:

> "For the outside community, these factors are not present. Such a diverse community can merely accept the state of their atmosphere, food or drinking water, relying only upon legislation and enforcement to ensure that injurious agents have been removed or reduced. Possibly the desirable levels to an outside community are those which do not materially add to the possibilities of pain, injury disease or death currently accepted by the community".

He did not consider that the magnitude of one risk could be used to justify another:

> "It is obviously of little value to quote as accepted risks the existing death rates in industries of other types, or on the roads, or from certain diseases, when the community sponsors very many bodies attempting to reduce these death rates to as low as possible"[83].

Edson suggested that the Panel's recommended limits should be quantified by a statement of the probability of serious harm:

> "in framing its recommendations, the Panel could perhaps clarify them by qualification of the recommended values. For example, 'exposures giving a zero probability of loss of life on present data', or 'giving a zero probability of loss of life in persons of normal susceptibility', or 'giving a _% probability of increasing the death rate in the community from x per 10^6 per year by a further y".

Catcheside had also prepared a briefing paper. For genetic effects he did not favour a constant safety factor. Instead, he considered that the factor should vary proportionately with the size of the population at risk.

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[83] Edson E.F (1950) Maximal Permissible Radiation Exposures In Radioactive Effluent Disposal, Department of Atomic Energy Production D.At.En(P)M/1842 NP/P/TD/131, In PRO:AB 12/86

He noted that the maximum permissible exposure of 0.3 r per week amounted to 375 r in a generation (25 years). He calculated that to avoid an unacceptable increase in the incidence of genetic abnormalities only 0.25% of the population could be exposed to this level per generation[84].

During the following discussion Gray commented that the logical extension of Catcheside's arguments was that the permissible dose was of the order of natural background. Neary point out that there was a precedent for this. In the U.S Brookhaven National Laboratory it had been stipulated that the excess radiation levels outside the plant should be no more than the natural background. Edson commented that this recommendation was impractical.

Gray suggested that a decision had to be reached whether the population limit was to be based upon just detectable genetic effects in a population, or on a maximum permissible percentage increase in the effect, irrespective of the population size. If Catcheside's figures were accepted it implied the need for a great reduction in the environmental discharges of radioactive effluent in the U.K[85].

At the next meeting of the Panel, Gray stated that as it could no longer be assumed that exposure was confined to 1% of the population, it would not be possible to maintain that the permissible dose had negligible genetic effects. It was therefore necessary to determine what level of genetic damage was acceptable. Edson did not think the Panel was

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[84]Catcheside D.G (1950) Safety Factors for Genetic Effects of Exposure of Populations to Radiations, NP/P/TD/132, In PRO:AB 12/86
Catcheside D.G (1950) Estimate of Genetic Effect of Mild Chronic Irradiation of Populations, NP/P/TD/142, In PRO:AB 12/86

[85]Tolerance Doses Panel of the Protection Sub-committee (1949) Minutes of the Twenty-fifth Meeting on 19th January 1950, NP/P/TD/134, In PRO:AB 12/86

competent to decide what degree of harm to a community was acceptable., The population as a whole passively accepts a considerable variety of risks. The minutes note that Mayneord agreed but

> "felt that the Panel would be expected to give some indication of what degree of unwitting exposure it thought would be reasonably safe"[86].

Gray reminded the Panel that they had already admitted that there was a theoretical possibility of a 20 percent increase in the incidence of osteogenic sarcoma because of ingested radium and strontium. He argued that if a similar increase was assumed for genetic effects a safety factor of only 40 would be needed for population exposure. Edson commented that this would increase the annual death rate due to congenital malformations from about 5000 to 6000. The minutes note that Loutit was

> "emphatically of the opinion that a 20% increase of genetic damage was unacceptable".

He also corrected Gray's statement:

> "The Panel had not previously accepted a 20% in the incidence of osteogenic sarcoma, but a 20% increase in the natural radium of the body; it was recognised that this additional radium would probably have no effect on the incidence of osteogenic sarcoma"[87].

The minutes note that Binks remarked that the local variation in background radiation, for example within buildings, was comparable to the proposed increase. Loutit reported that he had discussed the genetics question with Professor Penrose. He had stated that the natural incidence

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86 Tolerance Doses Panel of the Protection Sub-committee (1950) Minutes of the Twenty-sixth Meeting on 4th May 1950, NP/P/TD/139, In PRO:AB 12/86

87 Tolerance Doses Panel of the Protection Sub-committee (1950) Minutes of the Twenty-sixth Meeting on 4th May 1950, NP/P/TD/139, In PRO:AB 12/86

of only a few of genetic abnormalities had been measured[88]. This raised the possibility that only a small fraction of the radiation induced mutations expected theoretically would be observed.

After further discussion Chamberlain asked whether the Panel would be prepared to accept a permissible dose of 1 r per generation to the whole population. For Harwell effluent this would approximate to around a 5% increase over background radiation doses. Mayneord replied by stating that the Panel must first consider "more carefully" the genetic consequences of population doses equivalent to natural background.

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3.5: THE INITIATIVE TO REFORM THE ICRP

While these discussions were taking place, plans were being made for the Sixth International Congress of Radiology. It was planned that the International X-ray and Radium Protection Committee (IXRPC) would be reformed at this meeting. The aim was to present an agreed text of the Chalk River conference as part of the discussions that were to take place over new international limits[89].

The IXRPC had not met since 1937, although during the war Taylor had been acting as "caretaker" of both the IXRPC, and of the ICRU. The decision to reform the two international commissions was made three years earlier as part of the plans to reorganise the International Congress of

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[88]It was decided at the 12th meeting that Loutit would have an informal discussion with Penrose, instead of the Panel organising a formal inquiry amongst radiographers in the incidence of genetic abnormalities in their children.

[89]The U.K delegates to the Congress were Rock Carling, Mayneord and Binks.

Radiology. The task of the reorganisation was given to Taylor and Mayneord[90].

Taylor and Mayneord meet in July 1948 to discuss the selection of new members of the IXRPC. This task was completed by 1949. It was decided that the membership should be organised along similar national lines to the committee that existed until 1938, i.e, based on expertise and not nationality. All the countries represented at the 1937 meeting should be invited to have a representative on the Committee. These included, Sweden, England, France, Germany, Italy and the USA.

Following discussions between Taylor and the Congress President, it was also decided to include a representative from Canada - because of the involvement of this country in the wartime atomic bomb project[91]. Consequentially, all three nations involved in the wartime atomic bomb project were represented on the committee. This was renamed as the International Commission on Radiological Protection (ICRP).

Once the membership of the ICRP had been decided, they began to plan for the 1950 recommendations. Initially this involved Taylor writing to each member asking for details of their existing national codes of practice and any new information that they wanted to be incorporated into the new recommendations. Taylor stated that the purpose of the exercise was not to provide a set of detailed recommendations. Instead the ICRP was to provide a set of enabling recommendations that could be then interpreted to suit individual countries needs.

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[90]Mayneord had been suggested by J Ralston K Paterson, a member of the MRC CMBANP and also president of the Congress.

[91]Taylor L.S (1979)

Before the Second World War, Britain had been represented at the Congress by the British X-ray and Radium Protection Committee (BXRPC). This committee was inactive during the war, although its 1937 recommendations were reprinted more than once. The future of this committee was discussed soon after the formation of the MRC Protection Sub-committee in 1946. Sir Henry Dale believed that as the BXRPC had an international reputation it should continue to function under the direction of the Royal Society. No decision was reached and the issue was not discussed again until 1950.

The role of the BXRPC was discussed at a meeting held on 25th May 1950 between representatives of the Protection Sub-Committee, several Government departments, and the BXRPC. The meeting discussed the difficulty of presenting a unanimous U.K viewpoint due to the large number of different bodies concerned. The BXRPC was no longer considered to have the necessary status in the new fields where radiation hazards were encountered[92].

(I) Protection Proposals from the British Members

It was agreed that the task of drafting a U.K discussion document would fall to the three representatives of the MRC Tolerance Dose Panel who were to act as U.K delegates. This would include the tolerance levels recommended by the Tolerance Doses Panel.

The draft document noted that:

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[92]Protection Sub-Committee of the MRC Research Committee on the Medical and Biological Applications of Nuclear Physics (1950) Note of a Discussion on the U.K Contribution on Protection from Radiation Hazards to the Sixth Congress of Radiology on 25th May 1950, In PRO:AB 12/34

> "whilst the values proposed for the maximum permissible exposures are such as to involve a risk which is small compared to the other hazards of life, nevertheless in view of the unsatisfactory nature of much of the evidence on which our judgements must be based, coupled with the knowledge that certain radiation effects are irreversible and cumulative in the whole population, it is strongly recommended that every effort be made to reduce exposures to all types of ionising radiation to the lowest possible level".

For exposure of the general population the proposal stated:

> "the maximum permissible exposure of a large population should be regulated so that a statistically significant increase of genetic abnormalities will not arise".

This could only be achieved if the exposed group were less than 0.2% of a whole population of 50 millions[93].

These proposals were discussed by the Protection Sub-committee and by the Tolerance Doses Panel in July 1950, just prior to the International Congress. They were accepted, subject to a minor change of emphasis.

Professor Haldane had expressed concern over genetic damage resulting from exposure of large populations. The minutes note that his objection could be met by changing the word "significant" to "undetectable" in the statement on population exposure[94]. Haldane maintained that while an increase in abnormalities may be undetectable it might still be undesirable[95].

The question was passed to the Tolerance Doses Panel who agreed that any statement concerning large populations should be guarded in its wording. However, it was felt that the issue should be discussed again later. The

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93This statement represents a five fold reduction in what was considered acceptable only three years previously, when it was considered permissible to expose 1% of the population to the tolerance level.

94The minutes do not record who made this suggestion.

95Protection Sub-Committee of the MRC Research Committee on the Medical and Biological Applications of Nuclear Physics (1950) Minutes of the Seventeenth Meeting on 6th July 1950, NP/P/67, In PRO:AB 12/34

next meeting of the Panel was arranged for August 6th 1950 at Buckland House to coincide with the second tripartite conference. This was due to be held just after the Sixth Congress of Radiology[96].

Not all members of the Tolerances Doses Panel were convinced of the desirability of having a separate standard for population exposure. In early July 1950, Chamberlain, who worked at AERE Harwell, sent a brief memo to Cockcroft, Marley, Edson, Loutit and Neary. This noted that if the proposal was adopted

> "we may be in difficulty on two grounds. (a) Members of the 'general population' enter atomic energy establishments - e.g, postmen, milkmen contractors' men and visitors. (b) The belief held by insurance companies and others that radiation work is a dangerous occupation will be encouraged"[97].

(II) The 1950 meeting of the ICRP

Prior to the Congress the proposals from the various countries represented at been circulated for discussion. In January 1950 Taylor had written to Binks stating:

> "I am inclined to believe that as far as the International Recommendations are concerned, we should stick to essential generalities and not attempt to go into great detail. I think we can arrive at permissible levels and that we can use the figures discussed in the Chalk River meetings"[98].

Much of the basic information upon which the Chalk River figures had been based were not available to scientists outside the tripartite bomb project. This applied to the other members of the ICRP. For instance,

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[96] Tolerance Doses Panel of the Protection Sub-committee (1950) Minutes of the Twenty-ninth Meeting on 13th July 1950, NP/P/TD/152, In PRO:AB 12/86

[97] Chamberlain A.C (1950) Memo on Draft British Proposals to VIIth International Congress of Radiology, to be discussed at Protection Sub-committee on 6.7.50 and Tolerance Doses Panel on 13.7.50, Health Physics Division, AERE Harwell, In PRO:AB 12/34

[98] Taylor L.S (1979)

the German ICRP representative, Dr Jaeger, wrote to Taylor in January 1950 questioning the proposal for a weekly value of 0.3 r. He asked:

> "What sort of considerations may have led to the acceptance of the number '0.3 r per week' and if, in addition, a dose of 0.025 r/day or approximately 0.15 r per week should not be maintained for the reproductive organs. In Germany one considers the value of 0.3 r per week too high for the prevention of genetic damage"[99].

Several years earlier, in 1946 the Protection Sub-committee had received a request from the French Atomic Energy Project for "non-secret" information on protection matters. This request was vetoed by Canada[100].

The 1950 meeting of the ICRP took place over one day at the Sixth International Congress of Radiology as planned. The ICRP's 1950 recommendations are not very different to the list of proposals from the British delegation. In effect they represent a formal acceptance of the principles that had been developed by the tripartite nations since 1945. It was, however, the first time that these recommendations had been made available to a wider audience.

(III) 1950 Recommendations of the ICRP

The 1950 recommendations list the major biological effects of concern as: (a) Superficial injuries (b) General effects on the body, particularly the blood and blood-forming organs, e.g, production of anaemia and leukaemia. (c) The induction of malignant tumours. (d) Other deleterious effects including cataract, obesity, impaired fertility, and the reduction of life span. (e) Genetic effects.

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99 Taylor L.S (1979)

100 Protection Sub-Committee of the MRC Research Committee on the Medical and Biological Applications of Nuclear Physics (1950) Minutes of the Fifth Meeting on 11th October 1946, NP/P/16, In PRO:AB 12/157

The tolerance dose for radiation workers was reduced from its 1934 value of 0.2 r per day (equivalent to 1 r per week), to 0.5 r per week (measured at the surface of the body). This was considered equivalent to 0.3 r per week, measured in free air, as previously agreed by the tripartite nations. The ICRP explained that:

> "The figure of 1 r per week previously adopted by the International X-Ray and Radium Protection Commission seems very close to the probable threshold for adverse affects, particularly for radiations of high energy which are more frequently encountered than formerly"[101]

In addition, the concept of "tolerance dose" was replaced by the "maximum permissible dose. The Commission did not clarify how this differed from the previous concept.

The Commission judged that exposure at its maximum permissible dose represented

> "a risk which is small compared to the other hazards of life".

This statement was not based upon any quantifiable biological data on the effects of radiation. The Commission commented on the

> "unsatisfactory nature of much of the evidence on which our judgements must be based".

They therefore suggested that

> "it is strongly recommended that every effort be made to reduce exposures to all types of ionising radiation to the lowest possible level".

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[101] ICRP (1951) 'International Recommendations on Radiological Protection', British Journal of Radiology 23 46-49

There was one major departure from the recommendations previously agreed by the tripartite authorities. This concerned population exposure. The 1950 recommendations of the ICRP only dealt with occupational exposure[102]

(IV) Immediate Response to the ICRP Recommendations

A further meeting of the tripartite states was held along with the Tolerance Dose Panel just after the Congress of Radiology at Buckland House in Oxfordshire[103]. The purpose of the meeting was to review the secondary limits for various radionuclides, so that they could be recommended to the ICRP for publication. In addition, the questions of genetics and reduced limits for the general population were also discussed. Mayneord opened the discussion by stating that in view of the discussions held during the Congress of Radiology it was doubtful if a comprehensive decision on genetics would be possible at the conference. He observed that during the ICRP meeting there had been

> "objections in some quarters to the adoption of two different standards of exposure for occupational groups and large populations because of anticipated unfavourable public reaction"[104]

Furthermore, the decision by the ICRP to ignore this issue

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[102]The recommendations also note that the members of the ICRP preparing the report were: Rock-Carling, Taylor; Binks; Mayneord; E.L Chérigié (a french radiologist); Cipriani; R.R Newell, the American radiologist who had proposed that the U.S Advisory Committee on X-ray and Radium Protection reduce its tolerance dose to 0.02 r per day (equivalent to 0.1 r per week) in 1941; R.G Jaeger (a German physicist) and Sievert.

[103]Four members of the ICRP attended this meeting. Taylor (U.S); Cipriani (Canada); Binks and Mayneord (U.K).

[104]Neary G.J (1950) Report on Permissible Doses Conference, Buckland House, AERE Harwell, August 4th, 5th and 6th 1950, AERE Harwell:MRC Radiobiological Research Unit NP/P/TD/156, In PRO:AB 12/86

"was felt to be regrettable by some individuals both inside and outside the Commission"[105]

The objection to reduced limits for the public largely came from the U.S delegates. Shields Warren emphasised the "political difficulties" of having two standards and the need to consider "war time emergencies" when higher exposures may result[106]

It was finally decided that permissible concentrations for occupational groups only should be presented to the ICRP

"without explicit reference to medical supervision or to the genetic risks of exposure of considerable proportions of the population".

The permissible concentrations were published as a supplementary document to the ICRP recommendation[107]

(V) Policy of Pursuing Links between National Committees and ICRP

At its 1950 meeting the ICRP decided to establish six committees and recommended that a parallel structure of organisation be adopted at the national level[108]

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105 Dr Mayneord also considered that the lack of a genetics' committee at the international level was a serious omission. The MRC CMBANP had apparently recommended to the ICRP that one be established:- Committee on Protection Against Ionising Radiation, (1951) Minutes of 1st Meeting on 29th March 1951, PIRC/4, In PRO:AB 12/122. He subsequently changed his mind, and argued that there were advantages in discussing the genetic hazard with other hazards in the existing sub-committees as this would more likely lead to a balanced judgement. Instead he suggested that two geneticists be appointed to the U.K Internal and External Dose Sub-committees:- Medical Research Council Committee on Protection Against Ionising Radiation (1952) Minutes of 3rd Meeting on 12th June 1952, PIRC/17.

106 Neary G.J (1950) Report on Permissible Doses Conference, Buckland House, AERE Harwell, August 4th, 5th and 6th 1950, AERE Harwell:MRC Radiobiological Research Unit NP/P/TD/156, In PRO:AB 12/86

107 ICRP (1951) 'Supplement on Maximum Permissible Amounts of Radioactive Isotopes', British Journal of Radiology 23 50-53

108 The committees were: (i) Permissible dose for external radiation; (ii) Permissible dose for internal radiation (including handling of

It was proposed that while the main Commission would only meet irregularly, these committees would provide the focus of close contact with the existing national organisations. These links were strengthened by allowing the chairs of the ICRP committees to be appointed from outside the Main Commission. It was also considered desirable that the ICRP chairs were

> "so far as possible . . . selected from the corresponding sub-committees of the various national committees"[109]

Members of sub-committees do not appear to have been equally selected from all the countries represented on the Commission. Most of the ICRP's committee members, during this period, were also members of the national protection committees of the U.S, U.K and Canada. The chairs of ICRP Committee I and II also chaired the parallel U.S NCRP committees. Consequently, the tripartite nations held the majority influence on the ICRP during this period. An illustration of the close relationship between the U.S and British scientists is illustrated by the following quotes. In 1953, Dr Morgan, chair of the ICRP and NCRP sub-committees on Internal Radiation, wrote to Binks inviting him to serve on the ICRP committee:

> "It is evident to me at the Harriman Conference that you in your position at Harwell and I here at Oak Ridge share many problems in common, and as a consequence are perhaps more inclined to agree on a given philosophy or set of permissible values for exposure to ionising radiation than with colleagues from our own countries who are perhaps not as closely associated with many of the practical problems of

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radioisotopes); (iii) Protection against X-rays generated at potentials up to 2 million volts; (iv) Protection against gamma-rays, beta-rays and X-rays above 2 million volts; (v) Protection against heavy particles including neutrons and protons and (vi) Disposal of radioactive wastes.

109 Mitchell J.S (1950) 'Conference on re-organisation of the Committee on the Medical and Biological Applications of Nuclear Physics', Letter to Professor Himsworth, MRC, 13th October 1950, In PRO:AB 6/114

> Health Physics. This is an additional reason why I welcome the opportunity to extend you this invitation and hope to receive a favourable reply"[110]

Binks accepted the invitation and stated:

> "I shou'd very much welcome collaborating with you on this Sub-committee as I entirely agree that our operational problems are very similar and that permissible values for exposure should be fixed with the practical problems of Health Physics in view"[111]

The use of the identical term, "the practical problems of Health Physics", is illuminating. It illustrates that scientists with different occupational affiliations shared a common view about the balance between the new findings in biology and the practical considerations of industry. Morgan worked for the U.S AEC, and Binks worked for the National Physical Laboratory.

(VII) Reorganisation of U.K Protection Structure

Following the Sixth International Congress of Radiology the MRC committees in the U.K were also reorganised along similar lines following a suggestion by Rock-Carling. The membership of the existing committee structure had overlapped considerably. For instance, of the 12 committees and sub-committees concerned with radiation protection Rock-Carling was chair of five and a member of five more. Rock-Carling noted himself that

> "the same persons were on most of the . . . committees and it is now proposed to spread the burden more widely"[112]

The MRC Protection Sub-Committee and Tolerance Dose Panel were reformed as the Committee on Protection Against Ionising Radiation. This

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110 Morgan K.Z (1953) Letter to W Binks, May 15th 1953, In PRO:AB 12/288
111 Binks W (1953) Letter to K.Z Morgan 10th June 1953, In PRO:AB 12/288
112 Rock Carling E (1950) Letter to Himsworth re Nuclear Physics Committee 9th October 1950, MRC.50/570, In PRO:AB 12/155

Committee was concerned with the establishment of the basic permissible levels. It had several sub-committees including the External Dose Sub-committee and the Internal Dose Sub-committee.

Even after this reorganisation the overlaps in membership remained. Rock Carling and Binks remained members of the new MRC PIRC and most of the other U.K committees. This was seen as important by the nuclear industry, with whom Rock Carling and Binks had a close relationship. This is illustrated by a letter from Dr A.S Mclean to a colleague at Windscale. Mclean was a member of the PIRC and worked for the Medical Department, Ministry of Supply Factory, Capenhurst:

> "Recently I have been seeing a lot of some of the main handicappers in the field of radiological protection, with the general idea of blowing the Industrial Group trumpet a little in places where it would do most good. As a result Sir Ernest Rock Carling (chairman of the International Commission on Radiological Protection and member and adviser to almost every British committee) and Walter Binks (secretary of the International Commission on Radiological Protection and secretary of almost every British committee) have shown a desire to visit Windscale and talk . . . In the meantime, however, I thought that you would like to be well warned in advance because the occasion will provide you with an excellent opportunity to put something across about the Windscale experience to people who really know and who really matter"[113]

Two months later Rock Carling wrote to Cockcroft the Director of the AERE, Harwell:

> "It has reached my ears that the people at Aldermaston are worried lest the Code of Practice to be promulgated by the Statutory Committee under the Radioactive Substances Act should embarrass them.
>
> I have had a long conversation at Windscale with the General Manager and others there and I don't think we are likely to

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113 Mclean A.S (1954)' Letter to Mr D.R.R Fair, Health Physics Department, Department of Atomic Energy, Windscale', Medical Department, Ministry of Supply Factory, Capenhurst 4th January 1954, In PRO:AB 12/435

> say anything that would put them on the spot. We have Marley on the Sub-committee of the Main Committee and I have got Mclean, the Medical Officer at Windscale to be appointed to the MRC Committee, but it just occurs to me that it might be an advantage to have somebody - Greatbatch for example on the Sub-committee. Darwin, as you know, is away and we have been carrying on for a few months without him and so I am writing as Vice-Chairman"[114]

The use of the term "we" also implies the selection of committee members who shared similar views over the practical needs of industry.

Rock Carling's letter concluded with a statement illustrating the compromise between scientific evidence and the practical needs of industry when establishing radiological protection standards:

> "It is going to be difficult to steer a course between the 'scientific' appreciation of safety and what I might call the 'judicial'".

(VIII) The Effect of an Incorrect Assumption about the Permissible Dose

The 1950 recommendations of the ICRP were published in several journals world-wide during 1951. Just prior to publication, experimental work conducted by Binks questioned the validity of the assumption that the U.K permissible dose was equivalent to the U.S figure. This work, on the magnitude of backscatter from gamma rays, had been prompted by Taylor. He had discovered an error in a table giving the thickness of lead required to produce the permissible dose from radium sources. The figures given were based upon the old permissible dose, rather than the new. As secretary of the Commission, Binks consulted with Mayneord and recommended that no action be taken until the next Congress. This was scheduled for 1953[115]

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[114] Rock Carling E (1954) Letter to Sir John Cockcroft, AERE Harwell 5th March 1954, In PRO:AB 12/435

[115] Taylor L.S (1979)

This error meant that many workers were potentially exposed to over the permissible weekly dose. However, the issue was not resolved until several years later. In 1955 Mclean wrote to Binks:

> "At recent meetings of the Authority Health Panel this matter has been discussed in some detail and we are of the opinion that the assumption inherent in this convention is valid in only a very small number of cases, and that in practice we run the risk of exposing many of our employees to doses in excess of the maximum permissible level. There is a certain amount of experimental evidence from our establishments which indicates that the backscatter effect is usually only a very small proportion of the 60% which we have assumed"[116]

The practical significance of this error is shown in a further statement by Mclean:

> "Having come to this conclusion, we feel that the convention does not fulfil the spirit of the recommendations of the ICRP nor do we feel confident that we could maintain a strong position if we were challenged in a court of law, for example. Of course, if we abandon the convention altogether there would be some slight restriction on our activities at Windscale and Harwell in particular".

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3.6: SUMMARY

The key question for the official safety committees of the late 1940s was what to extent safety standards should reflect current biological knowledge? The committees knew that radiation could cause cancer in exposed individuals and possibly genetic damage in future generations. However, the pre-war safety standards only aimed to prevent acute effects of exposure such as skin damage. This approach was no longer adequate. The resolution of this question was dominated by the British and Americans: the two main partners in the wartime atomic bomb project.

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[116] Mclean A.S (1955) Letter to Walter Binks, 15 February 1955. In PRO:AB 12/435

The standards that were developed in these countries were not based upon scientific information alone. Social judgements made by the scientists on the safety committees were equally important. Biological theory suggested that there was no such thing as a safe dose of radiation. Any level of exposure, no matter how small, could be expected to produce some damage.

The evidence supporting this theory had to be weighed against the practical needs of the new nuclear industry. Some damage to health was considered inevitable. The key question was how much could be considered *permissible*? The physicists and biologists were divided on this issue. Generally, the physicists favoured higher levels of risk than the biologists. This division was a feature of most of the key post-war discussions.

The divisions along disciplinary lines did not prohibit the formulation of a consensus view. The evidence suggests that the scientists were united by a common "belief" that the practical considerations of the new industry were of paramount importance in the derivation of the tolerance dose. This "belief" was shared by scientists with differing occupational affiliations. Scientists with similar views were actively selected to serve on the national and international committees.

The American and British safety committees did not discuss whether the potential benefits of nuclear technology justified the risks to workers or to society. Instead, the only recorded questions of official policy were raised outside these formal structures. The function of the safety committees, and the scientists on them, were to set the "permissible" levels of exposure.

These committees initially discussed whether safety standards should be based on what was "safe", or on what was practical for industry. This question was soon resolved. Practical considerations were very important in the adoption of a safety standard. If a standard was not practical it was not adopted. The new standard was also expressed as a weekly limit. This provided industry with greater flexibility than the daily limit it replaced.

The members of the official committees were not united in their approach to reconsidering the biological basis of the tolerance dose. Biological scientists were particularly concerned over the risks of genetic damage to future generations. In general, the physicists rejected this concern. The views of the physicists were usually adopted.

Genetic risks were ignored in the establishment of the maximum permissible dose for radiation workers. At first this decision was justified by the argument that if less than one percent of the total population was exposed to radiation there would not be a *detectable* increase in the incidence of hereditary abnormalities.

When it became known that this assumption was incorrect the need to decide on an acceptable level of risk was explicitly discussed. Comparisons with safety standards in other industries were proposed. Further reductions in the permissible dose were not. The issue of whether the relative hazards in other industries could be used to justify radiation hazards was raised in a written memorandum but did not feature in the discussions.

The value of the maximum permissible dose was based upon evidence of changes in the blood. Here again, the ultimate decision was heavily shaped by practical considerations. The Swedish approach, of setting the permissible dose at a level at which blood changes had not been observed, was rejected by the British and the Americans. Sweden, however, was not planning the development of a nuclear industry in the late 1940s. Considerable scientific doubt existed over whether such blood changes were deleterious. The benefit of doubt was given to industry. This approach mirrors the philosophy outlined by Taylor when he argued that scientific uncertainty could not be allowed to impede the development of industry. Taylor's approach explicitly recognised that evidence of harm would be provided by the "sacrifice" of radiation workers.

The Americans and the British also collaborated in planning the recommendations of the ICRP before its reformation. Scientists from other countries were excluded from this process. Consequently, the Commission's recommendations were shaped by a common view that the practical needs of industry had to be balanced against the evidence of biological harm. Where scientific uncertainty existed the burden of proof lay with the positive identification of harm. The benefit of scientific uncertainty was given to those producing the risk and not those facing it.

The Americans and the British did not always agree. Disagreements arose over the extent to which concern for genetics required separate standards for workers and the public. The Americans were firmly against dual standards. The extent of their influence is revealed by the ICRP's 1950 recommendations. No mention was made of population exposure. This view

was shared by several British scientists working within the nuclear industry. They argued that dual standards would encourage the view that radiation was dangerous work.

The ICRP also adopted the American idea of the *maximum permissible dose* to replace the *tolerance dose*. The new term had two linked meanings. First, it acknowledged that biological tolerability did not exist, there was not a safe level of exposure. Instead, some exposure could be considered *permissible*. This was a social and not a scientific judgement. Second, the term implied a ceiling or a maximum upper limit to this "permissible" exposure. This was in direct contrast to the less strict notion of tolerability under the term it replaced. The value of the maximum permissible dose was reduced, but only to a level that was practical for industry.

CHAPTER 4: FROM MAXIMUM PERMISSIBLE DOSE TO PERMISSIBLE DOSE

The publication of the ICRP's 1950 recommendations did not end the debate over the maximum permissible dose. The recommendations had reflected a compromise between "the scientific appreciation of safety" and the 'practical needs of industry'. A decision was taken not to use the scientific evidence on the genetic effects of radiation in the derivation of the maximum permissible dose.

Nevertheless, the Commission had judged that the risks at the maximum permissible dose were small compared with "other hazards of life". The issue of whether the existence of these "other" risks could justify the risk from radiation exposure was not addressed by the ICRP. There was also insufficient biological data to allow such a quantification of risk.

This began to change during the 1950s as more was learned about the biological effects of radiation. Leukaemia began to be recognised as a disease caused by exposure to radiation. Like genetic damage, it was considered probable that a threshold dose did not exist. This meant that the risk existed even at small levels of exposure.

During this period public and scientific concern began to grow over the genetic consequences of atmospheric nuclear weapon testing. In response, the United Nations, the United States and the United Kingdom conducted extensive reviews of the effects and sources of radiation exposure.

The developments were to have a major influence on the development of the ICRP's protection philosophy. How the ICRP responded is discussed in this chapter.

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4.1: EARLY CONCERNS OVER HAZARDS OF FALL-OUT

The tripartite discussions had not resolved the population exposure question. Atmospheric nuclear weapon tests had started in the early 1950s and some scientists were becoming increasingly concerned. This concern was heightened by the reports of contamination in the United States from the Nevada desert tests[1].

Scientists from different disciplines approached this issue in different ways. This is illustrated by the following letter. In late 1951 Professor Haddow[2] wrote to Sir John Cockcroft[3]:

> "One or two of the biologists here - myself included - are again a little anxious following reports of radioactive contamination at the Kodak plant in Rochester apparently related to the recent Nevada explosions. You already know of my anxieties on the subject in general, and I confess I am somewhat hesitant to mention them again since one usually gathers from the physicists that they have very little foundation. I did however have a word with Mayneord the other day, and I don't think I am misinterpreting him when I say he is not entirely free from misgivings"[4].

Haddow was concerned over the future risks of atmospheric weapon testing:

> "In the present case of course one realises that risk to the population may be minimal, but one has in mind not the state of affairs today but what it may be in fifty years' time. In any event one is entitled to ask questions, e.g if slight contamination occurs 2,500 miles away, what is the situation say a hundred miles around the explosion site? Secondly. if we are booked - as we seem to be - for an almost indefinite series of test explosion, of which I imagine we had already had something of the order of twenty, how long can this be

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[1] For a popular account of the Nevada tests see: Caufield C (1989) Multiple Exposures - Chronicles of the Radiation Age, London: Secker and Warburg

[2] A biologist who was later to be a member of the MRC Committee on the Medical Aspects of Nuclear Radiation.

[3] A physicist who was Director of the Atomic Energy Research Establishment, Harwell and member of the MRC Committee on Protection Against Ionising Radiation. This was the successor to the Protection Sub-committee of the Research Committee on the Medical and Biological Applications of Nuclear Physics.

[4] Haddow A (1951) Letter to Sir John Cockcroft, 12th November 1951, In PRO:AB 6/1448

protracted without some long-lasting effect (even slight) on a terrestrial scale? The biologists can only indicate, (and have already done so), the nature of the possible hazards, but I believe the time has now come when the physicists must give some opinion (reassuring or not) as to the future: otherwise it will become increasingly difficult to counter those who already believe (perhaps wrongly) that there is some sort of conspiracy of silence. To my own mind there appear to be all possibilities, ranging from (a) virtual absence of any perceptible risk in foreseeable time, to (b) the possibility that purely military considerations will over-ride any other advice.

I am prepared to have you believe all these anxieties to be utterly groundless, and if you can prove them to be so no one will be better pleased than myself. One does not however require to excuse oneself too much, and I certainly gathered on a trip to the States in September that certain cases of leukaemia in Japan are now being fairly confidently related to the Hiroshima and Nagasaki explosions. One thing does frankly terrify me, namely the appearance of morale committees and stooges whose only job seems to be to provide the "right" answers and avoid anything in the nature of unpleasantness. All we require are the facts"[5].

In his reply, Cockcroft stated that he did not see any cause for alarm:

"We are naturally keeping a check on the radioactive contamination of the atmosphere and ground and up to the present I do not see any cause for alarm. We shall however keep this continually under review. We, of course, are not at all concerned with conditions within a hundred miles of the explosions and it should be the job of the U.S scientists to worry about this and not ourselves.

I am not quite sure what you mean by the morale committees and stooges, are you suggesting that these exist in this country?"[6].

The increased incidence of leukaemia among the atomic bomb survivors was first publicly recorded in a scientific paper published a year later.
Folley J.H, Borges W and Yamawaki T (1952) 'Incidence of Leukaemia in Survivors of the Atomic Bombs in Hiroshima and Nagasaki', American Journal of Medicine 13 311-321

[6]Cockcroft J (1951) Letter to Professor Haddow, 15th November 1951, In PRO:AB 6/448

Six months later, the MRC Committee on Protection Against Ionising Radiation (PIRC) discussed Haddow's letter[7]. The Committee also judged that no risk existed. The minutes note that this decision was based upon "restricted" and "confidential" information supplied by Cockcroft. The Committee agreed to keep the situation under review[8].

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4.2: MAGNITUDE OF THE MAXIMUM PERMISSIBLE DOSE

In 1952, the first of several important epidemiological studies was published. This was an analysis of the leukaemia incidence in the atomic bomb survivors of Hiroshima and Nagasaki. This study related the leukaemia excess to the distance from the hypocentre of the explosions[9]. However, the data in this paper were not sufficient to allow the detailed quantification of risk.

From the evidence available, it does not appear that the ICRP discussed it[10]. Its discussions were centred on the relative importance of blood changes and genetics in determining the value of the permissible dose.

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[7]The members of the Committee were Mayneord (physicist); Binks (physicist); Rock Carling (radiologist); Cockcroft (physicist); Edson; Gray (radiobiologist); Loutit (physician); Merewether (physician); Dr W.G Marley (physicist); Dr G.J Neary (physicist); Dr E.E Pochin (physician); Dr K Williams; Dr E Rohan Williams (radiologist); Dr F Gordon Spear; Professor F.W Spiers; Mitchell (physicist); Sir Lionel Whitby (physicist) and Professor B.W Windeyer (radiologist).

[8]Committee on Protection Against Ionising Radiation (1952) Minutes of the 3rd meeting, 12th June 1952, Medical Research Council, In PRO:AB 12/122

[9]Folley J.H, Borges W and Yamawaki T (1952) 'Incidence of Leukaemia in Survivors of the Atomic Bombs in Hiroshima and Nagasaki', American Journal of Medicine 13 311-321

[10]Also, the study was not mentioned in the 1956 report from the Medical Research Council or the 1958 report from United Nations on sources and effects of radiation.

(I) ICRP Discussions on the Relevance of Blood Changes and Genetic Effects

In 1952 a conference was held, in Stockholm, to discuss the biological basis of the maximum permissible dose. This was attended by scientists from the ICRP, its sister organisation, the International Commission on Radiation Units and Measurements (ICRU) and the Joint Commission on Radiobiology from UNESCO[11,12,13]

Prior to the conference, delegates had been invited to consider the following questions for discussion:

> "(a) What doses per year and per capita of the population are, according to our present knowledge, permissible from a genetic point of view?
>
> (b) What radiation doses, under different conditions, cause significant blood changes?"[11].

(a) The Permissible Genetic Dose

The British delegation suggested that the population dose should be limited to 0.1 r per year per individual. They judged that this

> "might lead to an increase of 10 percent in the spontaneous mutation rate"[11].

They considered this target was achievable without

> "any serious practical or economic difficulties".

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[11] Binks W (1952) Report on the Conference on Radiobiology and Radiation Protection, held in Stockholm, 15th - 20th September, 1952, PIRC/18, In PRO:AB 12/122

[12] The following British scientists attended the meeting; L.H Gray (Joint Commission on Radiobiology); M.V Mayneord (JCR, ICRP, ICRU); E Rock Carling (ICRP) W. Binks (ICRP, ICRU); F. Ellis (ICRU).

[13] The ICRP members present also held a separate meeting.

This figure amounted to a dose of 3 r by age 30. It was based upon a MRC survey of the gonad doses received from various sources of radiation[14].

Binks stated that this survey had found that the background radiation dose was 0.1 r per year. An average of 0.011 r was received from artificial sources of exposure[15].

In response to this, Muller, an American geneticist, expressed satisfaction that the dose levels from artificial sources were low[16]. Muller had previously advocated a limit of 0.02 r for the average per capita dose received before reproduction. He was particularly concerned whether this limit could be achieved[17].

One the other hand, Sievert thought that the level proposed by the British would lead to "considerable embarrassment" in Sweden where the background radiation dose amounted to between 0.05 r and 1 r per year[18]. Over 30 years, the accumulated dose would be between 1.5 r and 30 r. A further 5 r could also be received, depending on whether a person lived in a wood or concrete house.

Sievert considered that the genetic hazards of doses of less than 5 r per capita could be regarded as lacking "practical significance".

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[14] These included (1) natural background radiation, (2) occupational exposure, (3) X-ray diagnostic procedures and (4) other causes including X-rays from television sets.

[15] This figure is an average for the figures quoted by Binks for men and women: 0.0075mr (men) and 0.015 mr (women). A further 0.03 r was received from Potassium-40 in the body.

[16] The American scientist who first showed that radiation could produce genetic damage. Muller was a member of the ICRP during the early 1950s.

[17] Binks W (1952) Report on the Conference on Radiobiology and Radiation Protection, held in Stockholm, 15th - 20th September, 1952, PIRC/18, In PRO:AB 12/122

[18] A total figure for the dose from terrestrial gamma rays, building materials and cosmic radiation.

A further view was expressed in a written statement read to the meeting. Dr Murinelli of the U.S NCRP stated the

> "present permissible dose of 15 r per year can be considered adequate from the genetic point of view, if one considers the lack of knowledge on what causes mutations besides ionising radiation"[19].

Murinelli considered that the attention on the genetic hazards of radiation was misdirected:

> "If one grants the desirability of reducing the mutation rate in man and the willingness to spend a given amount of effort on it, it seems rational to ask the question whether the greatest benefit is to be derived by reducing the impact of some other mutagen in preference to a reduction in the radiation level".

When the meeting attempted to agree on a population permissible dose this was opposed by Taylor[19]. It was finally agreed:

> "(i) That an assessment of the exposure to radiations of all kinds received by the population in Great Britain indicates that the average dose per head of the population, at the present time, is due to an overwhelming extent to natural radiation.
>
> (ii) That, despite the small amount of available data concerning the genetic effects of radiation, it is reasonably certain that exposure to radiation other than natural radiation does not constitute a significant genetic hazard at the present time and that accordingly a figure for the dose per head of population per generation need not be stated.
>
> (iii) That such genetic evidence as is at present available indicates that, in circumstances in which exposure of large populations occurs, it is necessary to apply a considerable factor of safety to reduce the permissible level below that of 0.3 r per week in tissue allowed to persons occupational exposed"[19].

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[19]Binks W (1952) Report on the Conference on Radiobiology and Radiation Protection, held in Stockholm, 15th - 20th September, 1952. PIRC/18. In PRO:AB 12/122

The US representatives did not support this last statement[20].

(b) Significance of Blood Changes

The discussion then turned to the effects of radiation on the blood-forming organs. There was considerable disagreement over what level of exposure was required to produce a detrimental effect.

Of the different views expressed, Murinelli, in a written statement, proposed the highest level:

> "1 r per day seems to be the limit below which no changes in blood picture are detected in well-controlled animal experiments"[21].

This statement can be contrasted with that of Jaeger, a German member of the ICRP, who suggested, in another written statement, that the lower limit for induction of blood changes was 0.1 r per day.

Sievert commented that statistically significant blood changes had been observed after a few years irradiation at 10 to 20 r per year. However, he considered that such changes should be regarded as an "unreliable" danger signal rather than proof of injury.

A Dutch scientist, Dr Oosterkamp, referred to a recent recommendation of the International Electrotechnical Commission. It had recommended that workers who handle X-ray emitting equipment a level of 0.6 ur (micro-röngtens) per second should be regarded as "intrinsically safe"[22]. This amounted to around 0.1 r per week for a 48 hour week.

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[20] This is noted without explanation in: Marley W.G (1952) Notes on Radiobiology Conference, Stockholm September 1952, Harwell: Atomic Energy Research Establishment, In PRO:AB 15/2328

[21] The old tolerance dose of 1 r per day had been reduced because of the evidence of blood changes at lower doses. See Chapter 3.

[22] At its 1953 meeting the ICRP stated that it did not consider any level to be "intrinsically safe".

The British delegates commented that the maximum permissible dose, of 0.5 r per week,[23] had been set in spite of evidence that detectable blood changes occurred at lower levels. Their explanation indicates that the benefit of scientific uncertainty was given to industry. Until the observed blood changes could be shown to be deleterious they were assumed to be safe. The need for a further reduction in the maximum permissible dose was rejected as it would create practical and economic difficulties for industry:

> "It was felt that until it could be shown that the changes were statistically significant, were due to radiation and not to other causes, and were deleterious, a further lowering of the permissible level was not justified since it would, in many cases, create practical and economic difficulties"[24].

The British delegates concluded:

> "The new evidence since 1948, is in the view of the Protection Committee, insufficient to warrant a change of attitude at this time regarding the maximum permissible level".

The conference finally agreed that the ICRP's maximum permissible dose should remain unchanged[25].

(II) Tripartite Discussions on the Value of the Maximum Permissible Dose

Just prior to the Stockholm meeting, the MRC PIRC had discussed preparations for the 1953 ICRP Copenhagen meeting. It was suggested that a report be prepared that would form the British recommendations to the Commission. It also was decided that it would be advantageous if these

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[23] Measured at the surface of the body.

[24] Committee on Protection Against Ionising Radiation (1952) Joint Statement from the British Members of the Radiological Conference in Stockholm, 1952, Medical Research Council, In PRO:AB 12/122

[25] It was also agreed that blood counts were (i) unnecessary for workers exposed to less than 0.1 r per week, (ii) advisable for workers exposed to between 0.1 r and 0.3 r per week and (iii) necessary for workers exposed above the permissible dose.

recommendations were agreed with the U.S and Canadian authorities[26,27]. A meeting was arranged in New York[28].

The New York discussions centred around draft reports of the U.S NCRP Sub-committees 1 and 2[29,30]. These reports were on the Permissible Dose for External and Internal Radiation.

(a) Relaxing the Occupational Permissible Dose

The conference considered three proposals for relaxing the maximum permissible dose. First, it endorsed the Sub-committee 1 suggestion that the word "maximum" be omitted from the definition of the "permissible dose". The discussion preceding this agreement was not reported. The only explanation given is that the word maximum would be introduced into detailed protection rules for permissible levels of radionuclides in individual tissues. The agreed definition of permissible dose was:

> "A permissible weekly dose is a dose of ionising radiation accumulated in one week, of such a magnitude that, in the light of present knowledge, exposures at this weekly rate for

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[26] Committee on Protection Against Ionising Radiation (1952) Minutes of 3rd Meeting, 12th June 1952, Medical Research Council, In PRO:AB 12/122

[27] One of the issues to be discussed concerned the permissible doses recommended by the Internal Radiation Sub-committee, as the values it had proposed were considerably smaller than the corresponding US values.
Committee on Protection Against Ionising Radiation (1953) Programme for UK Delegation to the Tripartite Conference on Permissible Levels of Radiation to be held in Washington, D.C, USA on the 30th and 31st March and 1st April 1953, Medical Research Council, PIRC/24, In PRO:AB 12/122

[28] Committee on Protection Against Ionising Radiation (1952) Minutes of 4th meeting of the MRC 30th October 1952, Medical Research Council PIRC/22, In PRO:AB 12/122

[29] It had been agreed during the separate informal ICRP discussion in Stockholm that these would form the basis of the ICRP report: see Taylor L.S (1979)

[30] Committee on Protection Against Ionising Radiation (1953) Tripartite Conference on Permissible Doses, Arden House, Harriman, N.Y USA, March 30th - April 1st 1953, Medical Research Council, PIRC/26, In PRO:AB 12/122

> an indefinite period of time is not expected to cause appreciable bodily injury to the average person at any time during his lifetime"[30].

Second, Failla[31] suggested that the permissible dose could be modified by age, so that workers over forty five years could receive twice the permissible level. He justified this by arguing that genetic considerations were less important in older workers.

This suggestion was opposed by Morgan[32], the British delegates and some of the Canadians. A compromise was proposed by Dr Shields Warren and Dr Austin M Brues[33] :

> "In older individuals in whom genetic factors are unimportant, it may be justifiable to raise the maximum permissible dose level by a factor of 2"[34].

This was agreed by the meeting[35].

Third, the NCRP Sub-committee 1 had also proposed that the permissible dose could be exceeded in some circumstances. It had recommended that in

> "exceptional circumstances in which it is necessary for a person to receive in one week more than the basic permissible weekly dose, the unit of time may be extended to 13 weeks, provided that the dose accumulated during a period of any 7 consecutive days does not exceed the appropriate basic permissible dose by more than a factor of 3 and provided further that the total dose accumulated during a period of any 13 consecutive weeks does not exceed 10 times the basic permissible weekly dose"[34].

In effect this allowed 3 r to be received per quarter. An alternative proposal, of 4 r in six months, was suggested by Mitchell. Dr Bugher,

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[31]Chair of the ICRP Committee I, and the NCRP Sub-committee 1.
[32]Chair of ICRP Committee II, and NCRP Sub-committee 2.
[33]Of the US-AEC. Both scientists were also members of the NCRP.
[34]Committee on Protection Against Ionising Radiation (1953) Tripartite Conference on Permissible Doses, Arden House, Harriman, N.Y USA, March 30th - April 1st 1953, Medical Research Council, PIRC/26, In PRO:AB 12/122
[35]This was passed by 17 votes to 4 (There were 22 people at the meeting, 14 US, 4 Canadians and 4 UK).

of the U.S AEC argued that if the permissible dose could never be exceeded

> "many operations would be rendered difficult"[36]

He suggested that the figure should be 3.9 r in 13 weeks, irrespective of whether the dose was received in one episode or several. Failla proposed that Bugher write to the NCRP asking approval to adopt this. At this point another U.S delegate, Shields Warren stated that this was not a matter for the conference.

(b) Permissible Dose for Genetics

The question of genetics was also discussed. Failla proposed that genetic risks be ignored in the draft NCRP Sub-committee 1 report. Instead, he suggested, genetics should be considered in a separate report. This would take six months to prepare. It was recognised that this would not be ready in time for the Copenhagen meeting of the ICRP.

(c) The Permissible Dose for Population Exposure

The discussions on population exposure centred around the issue of whether a safety factor should be applied to the permissible concentrations of radionuclides in air and water. The British and Americans disagree over the magnitude of this factor. The MRC PIRC had adopted a factor of a hundred, compared to factor of ten in the United States. After a discussion, which was not recorded, the U.S value was adopted. The conference agreed the following resolution:

> "Following accepted practice in the industrial and public health fields, it is recommended, in the case of prolonged

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[36]Committee on Protection Against Ionising Radiation (1953) Tripartite Conference on Permissible Doses, Arden House, Harriman, N.Y USA, March 30th - April 1st 1953, Medical Research Council, PIRC/26, In PRO:AB 12/122

exposure of a large population, to reduce by a factor of 10, the permissible level for radioactive isotopes accepted for occupational exposures. It is understood that such level are additional to the natural background"[36].

(III) British Reactions to the Conference Decisions

The MRC PIRC discussed the agreements reached at the conference during its sixth and seventh meetings. Although, it had endorsed them it was decided that a separate statement be submitted to the ICRP putting forward its views on protection matters[37]. The Committee also contradicted the decision of the British delegates and decided that it was

"preferable, for the sake of clarity"

to retain the word maximum in the definition of the permissible dose.

The minutes of the seventh meeting note that the draft proposals to the ICRP should be amended to incorporate this change[38]. However, this decision appears to have been reversed without discussion by the Committee. The copy of the proposals in Taylor's archive account do not refer to maximum permissible doses and only discuss permissible doses[39]. No other reference to this document is made in the minutes of the Committee meetings.

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[37]Committee on Protection Against Ionising Radiation (1953) Minutes of the Sixth Meeting, 21st May 1953, Medical Research Council PIRC/28, In PRO:AB 12/122

[38]Committee on Protection Against Ionising Radiation (1953) Minutes of Seventh Meeting, 2nd July 1953, Medical Research Council, PIRC/31, In PRO:AB 12/122

[39]Committee on Protection Against Ionising Radiation (1953) Proposals to the ICRP, Medical Research Council, In Taylor L.S (1979)

(IV) ICRP Adoption of the "Permissible Dose"

The ICRP met in Copenhagan in July 1953 where the change from maximum permissible dose to permissible dose was adopted and its definition refined to:

> "A permissible dose is a dose of radiation that, in the light of present knowledge is not expected to cause appreciable bodily injury to a person during his lifetime"[40].

Appreciable bodily injury was defined as:

> "any bodily injury or effect that the average person would regard as objectionable and/or competent medical authority would regard as being deleterious to the health and well-being of the individual".

The report of this meeting was published, with the reports of the various ICRP committees, in 1955. Publication of this report was sponsored by the 'British Electrical Industry'[41]. No change in the permissible dose was recommended; although the value of the permissible dose for the skin was increased from 0.5 r to 0.6 r[42].

Even though the available biological information was insufficient to allow the detailed quantification of risk, the ICRP judged that the risks of exposure at the permissible dose were small:

> "the values proposed for maximum permissible doses are such as to involve a risk which is small compared to the other hazards of life, nevertheless, in view of the incomplete evidence on which the values are based, coupled with the knowledge that certain radiation effects are irreversible and cumulative, it is strongly recommended that every effort be

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[40] Committee on Protection Against Ionising Radiation (1953) Report on Decisions reached by the International Commission on Radiological Protection, Copenhagen, July 1953, Medical Research Council, PIRC/33, In PRO:AB 12/47

[41] Taylor L.S (1958) 'History of the International Commission on Radiological Protection', Health Physics 1 97-104

[42] ICRP (1955) 'Recommendations of the International Commission on Radiological Protection', British Journal of Radiology Supplement No 6 1955

made to reduce exposures to all types if ionising radiations to the lowest possible level"[42].

The biological basis of the permissible dose was discussed further in the report of Committee I, on the Permissible Dose for External Irradiation. This repeated earlier statements that genetics were not the limiting factor in the derivation of the permissible dose:

> "in formulating the recommendations emphasis has been placed on the deleterious effects of ionising radiation manifestible in the lifetime of the individual. Genetic changes possibly injurious to the race as a whole in future generations have been considered, but under present conditions they do not constitute the limiting factor in setting up permissible levels of exposure".

This differs from the draft Committee I report considered at the 1953 meeting. This stated:

> "At present the number of persons occupationally exposed to radiation is very small in comparison to the total population of the country and therefore the dose per individual of the whole population is correspondingly small. Thus genetic damage to the population as a whole in future generations from occupational exposure is now a limiting factor. It may become necessary later to impose further restrictions on the exposure of persons in the reproductive age, in terms of accumulated dose rather than a weekly dose"[43].

The final report of Committee I further explored the philosophical basis of the permissible dose. As no level of exposure was risk-free, it was based upon considerations of practicality, and on judgements about levels of risk that could be considered "negligible":

> "It is obvious that any significant departure from the environmental conditions in which man has evolved may entail a risk of possible deleterious effects. Strictly speaking, therefore it must be assumed that long continued exposure to ionising radiation as a dose rate higher than that due to the natural radioactivity of the earth and cosmic rays, involves some risk. Since no radiation level higher than the natural background can be regarded as absolutely "safe", the problem

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[43] ICRP Sub-Committee I (1953) Preliminary Draft of Report for Discussion at Copenhagen Meeting. In Taylor L.S (1979)

is to choose a practical level, that in the light of present knowledge, involves a negligible risk"[44].

The practical considerations were emphasised in its advice on exposure within the permissible limit. Committee I offered different advice from the main Commission. It stated that doses should be kept to the lowest *practicable* level, as opposed to the lowest *possible* level.

Committee I also discussed whether exposures above the permissible dose were allowable:

> "Since it is generally impossible to predict how long a person may be occupationally exposed to radiation, it is prudent to assume that it may continue throughout his life. Therefore, 'temporary' exposure at levels higher than the permissible weekly dose should not be permitted. If this does occur it must be assumed in general that it alters unfavourably the radiation tolerance status of the individual and measures tending to restore it to normal shall be initiated as soon as practicable"[45].

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4.3: PRACTICAL IMPLEMENTATION OF ICRP RECOMMENDATIONS

The ICRP's 1953 recommendations presented several practical problems to industry. On the one hand, the change to a permissible dose, as opposed to a maximum permissible dose, implied greater flexibility. On the other, Committee 1 had stated that exposures in excess of the permissible dose should not be permitted.

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[44] ICRP (1955) 'Recommendations of the International Commission on Radiological Protection', British Journal of Radiology Supplement No 6 1955

[45] Members of the Committee involved in the preparation of the report were Failla (physicist); Bugnard L (physician); Catcheside (geneticist); Loutit (physician); Muller (geneticist); Sievert (physicist); Stone (radiologist); Shields Warren (physician).

(I) Can the Permissible Dose be Exceeded?

(a) Comments from the Nuclear Industry

Soon after the ICRP meeting Dr A.S Mclean, from the Medical Department at Capenhurst, wrote to Mayneord asking for the definition of the permissible dose to be clarified[46].

> "I am writing to ask for your advice about a fundamental part of our radiation protection philosophy. My problem can be put in the form of a deceptively simple question - Is a Maximum Permissible Level a maximum permissible level?"[47].

He quoted a definition which suggested that the maximum permissible dose must not be exceeded:

> "for example (I quote from an editorial in a recent issue of the British Journal of Radiology), 'A maximum 'permissible' amount of radiation. . . should never be exceeded and seldom, if ever, reached,' is just sufficiently equivocal to be of immense value to the man responsible for radiation protection, be it in the hospital, factory or laboratory".

He was concerned that this type of definition could result in higher costs to the nuclear industry and adversely affect its economic viability:

> "I would like to take as an example the question of biological shielding. There is no doubt that the enormous shields of metal and concrete account for a very substantial part of the costs of the construction of a reactor, and I may not be very far wrong if I suggest that the very economic feasibility of the concept of nuclear fission as a source of power will depend as much upon our ability to reduce these heavy capital investments to a minimum as it will upon any other single factor".

This meant the "any-radiation-is-bad" philosophy required reexamination. He suggested that the basis for this would be to assume

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[46]Mclean was a member of the MRC PIRC. He also became a member of the ICRP, and was the first director of the National Radiological Protection Board (NRPB).

[47]Mclean A.S (1953) Letter to Professor W.V Mayneord, 23rd November 1953, PIRC/39, In PRO:AB 12/122

> "that the design engineer is so skilled that he can arrange shielding dimensions and associated operations in such a way that the operating personnel will receive any pre-selected amount of radiation exposure"

The question, therefore, was to decide what level of exposure should the engineer aim for. He suggested:

> "that the only logical answer to this question is that the designer should be guided by the principle that a maximum permissible amount of radiation is an amount which should seldom be exceeded from week to week and which should never be exceeded in the average over a reasonable period".

He recognised that the argument against this view "must inevitably" have its basis in genetics. On this point, he considered it relevant to quoted from the MRC report on the recent ICRP meeting:

> "It is stated that 'A permissible dose is a dose of ionising radiation that, in the light of present knowledge, is not expected to cause appreciable bodily injury to a person at any stage during his lifetime'. The list of critical organs and effects from this point of view includes gonads with respect to impairing fertility; there is no mention of genes.
>
> Finally, I feel sure that we should consider the radiation hazard in terms of a calculated risk very much as we do when we talk of such things as road accidents, the hazards of coal mining and, perhaps, even Smog!"[48]

(b) Comments of the PIRC

Mclean's views were discussed at the 10th meeting of the PIRC. Mitchell disagreed with Mclean. He considered the permissible dose must be based in genetics and a lower level should be applied to the general population.

He commented, if the limit was set at 0.3 r per week for a large population, then the total dose per generation would be 400 r. Whereas,

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[48]Mclean A.S (1953) Letter to Professor W.V Mayneord, 23rd November 1953, PIRC/39, In PRO:AB 12/122

the dose required to double the spontaneous mutation rate had previously been estimated at 50 to 100 r.

Mayneord asked Mitchell if he would insist on a reduction factor of ten for small groups, or could the design engineer work to a level two to three times higher? Marley did not consider this sufficient. He commented that as construction and design costs were enormous it might be necessary to work to ten times the permissible level.

On the other hand, Mclean replied that it was not the intention in atomic energy establishments to go over 0.3 r per week. Marley pointed out that this referred to average doses.

Finally, it was agreed that when designing for small groups of workers, one could legally work to 0.3 r per week. The Committee cautioned, however, that the designer would be advised to apply a safety factor of two to three as the administrative difficulties arising from over-exposure were considerable. The Committee also agreed that as genetics was important for large populations, the permissible dose should be reduced by a factor of ten, or "perhaps" one hundred[49].

(II) Averaging the Permissible Dose

The question of averaging the permissible dose, and over what period, was also considered by the MRC in early 1954. Two proposals were under discussion. These were from the U.S NCRP and the Protection Sub-committee under the Radioactive Substances Act. The proposal from the latter committee suggested:

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[49]Committee On Protection Against Ionising Radiation (1954) Minutes of the 10th Meeting, 24th June 1954, Medical Research Council, PIRC/56, In PRO:AB 12/122

> "In the case of accidental or emergency exposure of radiological worker in any one week to a dose in excess of the maximum permissible amount, an average weekly dose shall be assessed for the irradiation of the worker during the 13 weeks prior to, and including, the week in which the over-exposure occurs".

Where the average dose exceeded the permissible dose

> "the worker shall be removed to duties involving considerably less exposure, for a compensatory period adequate to reduce the rate of exposure to a value below the permissible weekly level. If the average weekly value of 13 weeks in question is less than the maximum permissible weekly value, the worker can continue with his duties"[50].

During the discussion, Marley mentioned the current practice at Harwell; where a person's previous radiation history was used to decide if they should be removed from radiation work for a compensatory period or not.

Merewether was concerned over the legal aspects of the recommendation. He considered that the permissible dose should not be averaged. If over-exposure occurred, that person should be removed from radiation work.

Pochin proposed that the recommendation of the Statutory Committee be prefaced by the phrase:

> "Accepting the ICRP level of permissible exposure as 0.3 r in a week, then. . .".

This was agreed, as was the suggestion that the phrase

> "during the 13 weeks prior to and including",

be replaced by

> "13 consecutive weeks including"[50].

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[50] Committee on Protection Against Ionising Radiation (1954) Minutes of the Ninth Meeting, 14th January 1954, Medical Research Council, PIRC/47, In PRO:AB 12/122

At the next meeting Marley stated that Atomic Energy Research Establishment (AERE) had considered the operational implications of this decision. It would result in a considerable complication of records, as continuous records would have to be kept for all the staff involved. In contrast the proposal from the Statutory Committee would have led to simpler operating procedures: it would only be necessary to keep continuous records following an over-exposure when the total dose for the 13 weeks up to and including the week of the over-exposure exceeded 6.5 r (surface dose).

He also commented that difficulties would also be encountered by Atomic Weapons Research Establishment (AWRE) in conducting atomic weapon trials[51].

Mayneord, the committee chair, responded by stating that specific difficulties must not be allowed to determine the rules for all radiation workers. He offered to meet representatives of the Department of Atomic Energy to discuss their specific problems and to draft an additional clause to the present recommendation appropriate to their needs[52].

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[51] Arnold notes that the MRC approved the limits used at the U.K Atomic Weapon Trials in Australia The limits approved prior to the Hurricane test were: (1) Normal Working Dose rate 0.1 r a day (gamma) (2) Lower Integrated Dose (LID) 3 r (gamma) (3) Higher Integrated Dose (HID) 10 r (gamma)
Arnold suggests that these limits corresponded to the limits set by the ICRP. This is incorrect. The permissible limit adopted by the MRC in the late 1940s was 0.05 r per day.
Arnold L (1987) A Very Special Relationship British Atomic Weapon Trials in Australia London: HMSO

[52] Committee On Protection Against Ionising Radiation (1954) Minutes of the 10th Meeting, 24th June 1954, Medical Research Council, PIRC/56, In PRO:AB 12/122

While it may appear that the nuclear industry did not get the total flexibility it needed from Committee's deliberations, this is not so. Marley subsequently wrote to Mclean:

> "You will remember that we discussed at the Protection Committee Meeting the subject of whether people should be stood-off following an over exposure to radiation in one week. Certainly I agree with Binks on the wording of the resolution which he thought had been agreed at the meeting. I thought it worthwhile writing to tell you that at first glance the wording appears to suggest that we lost the day, but you will find if you do a series of simple calculations to find out what happens in various circumstances that the wording adopted really does give us all that is required. In fact, it is a masterly wording, due to Binks, which probably will satisfy even Merewether. The important point for us is that it will give us the extra facilities that we need and is virtually equivalent to averaging over 13 weeks in the case of any slight over exposure and longer, if necessary, so as to bring the average dose per week down to the tolerance level"[53].

(III) Economic Impact of the Permissible Dose

In 1954 the ICRP sought funding to secure its continued existence. As part of this process several briefing papers were written. These provide an insight into the way the ICRP's philosophy was developing; illustrating it's belief that the development of nuclear energy was important, although not entirely devoid of risk.

A paper by Binks commented that while protection procedures were important, they must be reduced to a minimum if nuclear energy was to be economic:

> "The development of atomic energy for the generation of power, and the use of radioactive isotopes for the treatment of disease and for manifold purposes in research and industry, involves exposure to so-called ionising radiations which are potentially dangerous. Protective measures are costly and must, therefore, be reduced to the minimum if

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[53]Marley W.G (1954) Letter to A.S Mclean, Ministry of Supply Factory, Capenhurst, 24th April 1954, In PRO:AB 6/979

progress in the practical applications of atomic energy is not to be impeded by economic difficulties"[54].

This meant that the permissible dose

> "must be set as high as is consistent with a hazard that is not greater than in other occupational hazards".

However, it was not possible to quantify the magnitude of the radiation hazard faced by workers in the new industry. Binks noted:

> "This is partly because, as regards human beings, experience is limited on one hand to maximum dangers from atomic bombs and on the other, to the much smaller dangers from radiation applied for treatment in hospitals, or arising from the use of radioactive material in luminising and similar industrial processes. Another reason for the paucity of knowledge is that the effects, on man, may not be recognisable until after an interval which may be as great as twenty years. Collection of evidence from all countries using greater or smaller quantities of nuclear energy sources, is continually bringing to light fresh evidence of serious damage to human beings, and of deaths from cancer and other causes due to radiation".

Binks commented that the increase in knowledge about biological effects was not keeping "pace" with the expansion of the nuclear industry:

> "The rate at which knowledge is accumulating increases year after year but still hardly keeps pace with the expansions of radiation in industry, or with the construction of machines which now run, not at tens, but at hundreds of million volts. To be of use for nuclear power, nuclear reactors ('piles') must become increasingly efficient, and with increasing efficiency there may well be corresponding increase in danger from them".

Binks cautioned that the rapid pace of development of atomic energy would be associated with new hazards:

> "Radiation exposure will no longer be confined to radiological workers themselves or to patients undergoing treatment, for the general population will become increasingly involved due to the release of a certain amount

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[54]Binks W (1954) Memorandum to all ICRP Members from Walter Binks on Future Organisation and Financing, 12 January 1954, In Taylor L.S (1979)

> of radioactivity into the atmosphere and into drinking water supplies. Furthermore, notwithstanding the safeguards already laid down in the light of present knowledge, by accident very large numbers of people may nevertheless be seriously affected by radiation, with a very appreciable mortality. In addition, damage by contamination of buildings, rivers, crops, cattle, fisheries etc may involve great expense. Already in the USA millions of dollars have been spent to repair or replace buildings so damaged. In this country too there have been similar accidents, though on a much smaller scale. It should be mentioned that actions for compensation are already being brought against employing authorities and individuals, and claims are presented under Pension Regulations and Industrial Acts for damage to health or life sustained by reason of undue exposure to radiation"[55].

The evidence suggests that these risks were not considered sufficient to argue against the expansion of atomic energy.

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4.4: POLICY IMPLICATIONS OF IGNORING GENETICS

The subject of genetics had been discussed on many occasions without any action being taken. By mid 1954 it was clear the subject could not be ignored for much longer. Rather than aiding the development of nuclear energy, the continued avoidance of the genetic question was beginning to hamper it. There was an urgent need to determine the permissible level for genetic effects. This is illustrated by the following correspondence.

In early 1954, the Radiochemical Inspector, A.W Kenny, wrote to Binks at the Radiological Protection Service[56].

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[55] Binks W (1954) Memorandum to all ICRP Members from Walter Binks on Future Organisation and Financing, 12 January 1954, In Taylor L.S (1979)

[56] This was formed in 1953 to coordinate radiological protection work in the UK.
Smith E.E (1975) Radiation Science at the National Physical Laboratory 1912-1955 London: HMSO

> "I have spoken to you previously and written to Professor Mayneord about the formulation of a policy to define the genetic effects which should be permitted. There have been discussions within this Ministry and it would seem that the increasing likelihood of water supplies being contaminated by radioactivity makes it desirable that a clear policy should be formulated. I have been instructed, therefore, to seek advice of the Medical Research Council"[57].

Kenny wanted answers to a number of questions. These included what the genetic detriment would be if the permissible levels for radioactivity in water (for Londoners) were ten times, and one hundred times those used then.

He also wrote to Marley:

> "I am sending you herewith for information a copy of a letter to Mr Binks which is the first move in an attempt to get a firm policy on the permitted genetic effects of radiation. I have been coming round to the opinion that a lack of a clear policy may seriously hamper the development of atomic energy"[58].

The matter was raised at the PIRC. Mayneord and Binks drafted a letter that pointed out the levels and safety factors advocated for large populations were based primarily upon judgements, after

> "considering the various aspects of the problem"[59].

Not all members of the PIRC agreed that safety factors should be used for determining permissible discharge levels from nuclear installations; particularly where only small populations were involved. In June 1954 Mclean wrote to Binks:

Radiological Protection Service (1950-1957) Policy and Programme of Work (PRO: MH 58/736)

[57]Kenny A.W (1954) Letter to W. Binks, Radiological Protection Service, 3rd February 1954, In PRO:AB 6/979

[58]Kenny A.W (1954) Letter to Dr Marley, AERE, Harwell, 3rd February 1954, In PRO:AB 6/979

[59]Committee On Protection Against Ionising Radiation (1954) Minutes of the 10th Meeting, 24th June 1954, Medical Research Council, PIRC/56, In PRO:AB 12/122

"In practice we apply reduced maximum permissible levels in all cases involving outside populations, particularly in the assessment of effluent problems. On the one hand, this is said to be desirable because the populations concerned do not enjoy the same quality of medical supervision as those exposed in the course of their work. On the other hand, it is claimed that this approach is made necessary by the genetic factors involved in the exposure of large populations. I am not at all clear about the relative importance of these factors and it would help me to have your opinion.

The following problem exemplifies the type of difficulty which arises. In calculating the permissible discharge of liquid effluents into the sea from Windscale Works we have to think of a number of groups of people. One of these is a group - probably only a dozen or two in number who may consume quite large quantities of fish taken from the area. Another is a very small section of the population of South Wales who are in the habit of eating the edible seaweed porphyra umbilicalis which is harvested on the shores of West Cumberland. By what factor and why are we to reduce the occupational M.P.L's for these people. The genetic approach is hardly appropriate in these cases and, if this is so, is the permissible dose really, 'a dose of ionising radiation of such magnitude that, in the light of present knowledge, exposure at this weekly rate for an indefinite period of time is not expected to cause appreciable body injury to the average person at any time during his lifetime?'"[60]

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4.5: SCIENTIFIC RESPONSE TO PUBLIC CONCERN OVER FALL-OUT

By the mid 1950s a major public and scientific controversy had developed in response to the level of atmospheric nuclear weapon testing[61]. This concern led the U.K government to direct the MRC to establish a new committee to prepare a report on the hazards of radiation to 'man'. Similar bodies were established by the United Nations and the U.S National Academy of Sciences. The reports of these committees were to have an important influence on the ICRP's recommendations.

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[60] Mclean A.S (1954) Letter to W Binks, Radiological Protection Service, 23rd June 1954. In PRO:AB 12/35

[61] Green P.A (1984) The Controversy over Low Dose Exposure to Ionising Radiation Msc Thesis Birmingham: University of Aston

(I) MRC INVESTIGATE RADIATION HAZARDS

The MRC Committee was established during mid 1955. It was chaired by Sir Harold Himsworth, Secretary to the MRC. Of those invited to join most had been connected with the MRC protection committees of the late 1940s and early 1950s[62].

While this committee was presented to the public as independent, some evidence suggests that its deliberations were more carefully controlled. Correspondence between Cockcroft and Himsworth show that the scientists were supposed to have a free hand to

> "ventilate any questions or ask anything that they had in mind"[63].

This should be contrasted with the Government decision that the Committee should maintain close contact with its opposite number in the US. This would be informal and not discussed in public.

Further evidence is contained in the following letter. In July 1955, the Prime Minister's Office wrote to Lord Salisbury to state that Himsworth:

> "is anxious to avoid at almost all costs the danger of a minority report. . . Once the ground has been covered and this synthesis made, there will be still be the no less important and even more delicate task of drafting the report, so as to ensure it says what ought to be said on this question; and; as was stressed above, of avoiding the submission of a minority report"[64].

Kopp C (1979) 'The Origins of the American Scientific Debate over Fallout Hazards', Social Studies of Science 9 403-422

[62]The other members were Sir Ernest Rock Carling*; Sir John Cockcroft*; Professor A Haddow*; Professor A Bradford Hill; J.F Loutit*; Professor K Mather; Professor M.V Mayneord*; Professor P.B Medawar; Professor J.S Mitchell*; Professor L.S Penrose; Sir Edward Salisbury; F.G Spear*; Professor J.R Squire; Professor C.H Waddington; Professor Sir Lionel Whitby*; Professor B.W Windeyer*. Members marked * served on the MRC protection committees.

[63]Himsworth H (1955) Letter to J.D Cockcroft, 19th April 1955, In PRO:AB 6/1603

[64]Akers (1955) Letter to Lord Salisbury, 8th July 1955, In PRO:AB 6/1603

Both the U.S and U.K committees published their reports in 1956, although their conclusions were known to the ICRP, and each other well in advance.

(a) Leukaemia Induction

One of the first issues to be considered by the Committee was a paper by Richard Doll on the leukaemogenic effect of thermo-nuclear explosions. This suggested that the dose-response relationship for leukaemia was a linear no-threshold one. On reading this Cockcroft wrote to Himsworth,

> "I was rather surprised by his conclusions and as a result went back to his premises.
>
> I would be very interested to know whether the animal experiments really do support the conclusion that the incidence of leukaemia is proportional to dose down to small values.
>
> I personally feel extremely sceptical about the conclusions from his arithmetic and would want to join the critics if this comes up for discussion on the main committee"[65,66].

Doll had been planning to publish the paper but was persuaded against this by Himsworth; who replied to Cockcroft stating:

> "Originally Doll sent this paper to me asking if I had any objection to its publication. In reply I raised with him the same point you did, namely the evidence for his premise that the incidence of leukaemia is proportional to the dose down to small values. In consequence I suggested that, as the Individual Effects Panel was going to discuss leukaemia in some detail, it might be a good idea if his paper was circulated to them along with others on the same subject. I also made the point that in my opinion it would be most undesirable for a series of publications on particular aspects of nuclear energy to be published whilst our committee was sitting. I have since heard from him saying that he agreed to the paper being circulated and that he appreciated the point about publication"[67].

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[65] Cockcroft J.D (1955) Letter to H. Himsworth, 10th June 1955, In PRO:AB 6/1603

[66] Mitchell has made this suggestion in 1945. See Chapter 3.

[67] Himsworth H (1955) Letter to J.D Cockcroft, 14th June 1955, In PRO:AB 6/1603

Cockcroft also passed to Himsworth comments on Doll's paper from the Harwell Health Physics Division. These were circulated to all the Committee members except for Doll:

> "I have sent these to the individual authors with the exception of Dr Doll. A large part of the first meeting and practically the whole of the last meeting of this Panel was occupied in discussing the leukaemia problem. I am hoping that at the next meeting we may be getting within sight of some conclusion. I think that then, in courtesy to Dr Doll, we ought to let him know of the criticisms that have been raised on his paper"[68]

Other members of the MRC PIRC also objected to Doll's paper. Mclean wrote:

> "it is a subtle and pseudo-logical piece of work, suspiciously plausible and ingeniously modest. . . alarming conclusions have been drawn, through an extravagant extrapolation, from assumptions which can only be regarded as speculative. The more unreasonable theories have a high publicity value provided that they are spiced with sensationalism, and herein lies the real danger of Doll's paper"[69]

Doll had suggested that the nuclear test programme may cause one hundred additional cases of leukaemia in the U.K. Nevertheless, the nuclear establishment were keen to build contacts with him:

> "I have given a good deal of thought to your proposition that we should build up contact with Doll and I am entirely in favour of it. I am sure that the only grounds on which we shall be able to defend ourselves in leukaemia cases and in cases of the other types of malignant diseases which may be associated with radiation will be on the one hand statistical and on the other of running records of individual exposure rates. As you pointed out to me, we can expect that in due course a dozen or two such cases may arise in people who have worked for the Atomic Energy Authority and, so, it is clearly a very important issue.

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[68] Himsworth H (1955) Letter to J.D Cockcroft, 5th July 1955, In PRO:AB 6/1603

[69] Mclean A.S (1955) Letter to J.D Cockcroft, 1st July 1955, In PRO:AB 6/1603

> If you would care to consolidate your contact with Doll I should certainly be grateful to join in with you when the time is opportune"[70].

The final published report discussed the links between radiation and leukaemia and confirmed the suggestion, first made by Mitchell in 1945, that leukaemia was a disease caused by radiation exposure[71].

Several pieces of evidence were cited in support of this observation. An excess of leukaemia had been observed amongst the survivors of the atomic bombings in Hiroshima and Nagasaki. However, there was insufficient data to establish the form of the dose-response relationship.

On the other hand, evidence was found for a relationship between dose and incidence in studies of patients given X-rays for ankylosing spondylitis. This study found no evidence of a threshold for leukaemia induction. The dose-response relation was, depending on the method used to calculate the doses of radiation received, either linear, or curvilinear. Either way, this suggested that

> "even small amounts of radiation will have an appreciable effect if given to a large enough population"[72].

The Committee concluded that the evidence it had discussed left

> "no doubt that ionising radiation can induce leukaemia in man, and that the average latent period between exposure and the development of the disease is only a few years"[73].

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[70] Author unknown (1955) Letter to Chamberlain, Health Physics Department, AERE, UKAEA, 20th June 1955, In PRO:AB 6/1783

[71] MRC (1956) The Hazards to Man of Nuclear and Allied Radiation, London: HMSO

[72] Court Brown W.M and Doll R (1956) 'Leukaemia and Aplastic Anaemia in Patients Treated with X-rays for Ankylosing Spondylitis', In MRC (1956) The Hazards to Man of Nuclear and Allied Radiation, London: HMSO

[73] The report also discussed a number of other cancers that could be related to radiation exposure. Evidence was present for (i) cancer of the lung. This was associated with exposure to radon and its

(b) Other Somatic Effects

The report only briefly mentioned changes in the blood following radiation exposure, commenting that blood changes could occur at doses as low as 1 r per week.

The effects of radiation on pregnancy were also discussed. There was "considerable" evidence from records of patients treated with radiotherapy and from the Atomic Bomb Casualty Commission (ABCC) that "heavy" irradiation of pregnant women could lead to children with some form of abnormality, such as mental retardation or microcephaly. Evidence from the ABCC was also cited as showing that large doses of radiation may also cause miscarriage or stillbirth[74].

(c) Genetic Effects

The report also discussed the genetic effects of radiation. It attempted to derive an estimate of the genetic doubling dose. This is the dose of radiation required to double the spontaneous mutation rate. It was considered that a representative value lay between 30 and 80 r; although the possibility could not be ruled out that for some effects the doubling

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decay products in mines; (ii) Cancer of the bone from the ingestion of radium; (iii) Cancer of the skin from excessive exposure to X-rays and (iv) Cancer of the thyroid also from exposure to X-rays.

[74]These effects were first described in 1946 in confidential reports of the British Mission to Japan on the 'Effects of Atomic Bombs at Hiroshima and Nagasaki':

"Pregnant women who survived within 1,000 meters of the centre of damage in Hiroshima, at all stages of pregnancy, have had miscarriages. Pregnant women who survived up to 1 1/4 miles from the centre of damage have had miscarriages or premature infants who died very soon. Even beyond this range, up to nearly two miles, only about one third of women have given birth to what appear to be normal children. Two months after the explosion miscarriages, abortions and premature births throughout Hiroshima were nearly five times as frequent as in normal times, and formed more than one quarter of all deliveries. Some effects on the reproductive organs have also been found, in the case of men up to perhaps 3/4 mile from the centre of damage".

dose was less than 30 r, and for others more than 80 r. The minimum the Committee could "reasonably" consider was 15 r.

(d) The Risks from Sources of Radiation

The report also attempted to quantify the risks arising from exposure to different sources of radiation. Several value judgements were made by the Committee. It was suggested that in the future

> "nuclear energy will constitute a major, if not the most important, physical factor upon which our civilisation will depend"[71].

The Committee judged that this meant it was necessary

> "to maintain a sense of perspective and to weigh, as society has done in the case of steam power, electricity and the internal combustion engine, the risks entailed against the advantages to be gained from the employment of this newer source of power"[71].

The Committee judged the risks from nuclear energy to be small:

> "in view of the small numbers likely to be employed in atomic power production and of experience already gained in the effectiveness of protective methods, it seems probable that a given amount of power might be made available to the community at a smaller cost in accidents, illness and disability than involved in present methods of mining and power production"[71].

The Committee considered that the ICRP's permissible dose provided a satisfactory working level, provided it was not maintained for "years on end". The average dose within the United Kingdom Atomic Energy Authority (UKAEA) was 0.4 r per year. In "all recent years" no one had received an *average* dose in excess of the permissible dose. Ninety percent of the workforce averaged less than 1/10th of the weekly permissible dose.

Public exposure to radioactive effluents was regarded well controlled. However, the Committee did indicate some areas where improvements could

be made. These included, diagnostic radiology and various miscellaneous uses of radioactivity such as the routine X-raying of children's feet when fitting shoes. It was "hoped" that this practice would be abandoned.

(e) Recommendations

To avoid the somatic effect of radiation, of which leukaemia was probably the most easily induced, a lifetime dose of 200 r was recommended:

> "an individual could, without feeling undue concern about developing any of the delayed effects, accept a dose of 200 r in his lifetime, additional to that received from natural background, provided that this dose is distributed over tens of years and that the weekly exposure, averaged over any period of 13 consecutive weeks, does not exceed 0.3 r. We recommend, however, that the aim should always be to keep the level as low as possible".

To prevent the genetic effects of exposure the Committee recommended that:

> "an individual. . . can accept a total gonad dose of not more than 50 r from conception to age thirty, additional to that received from natural background, without undue concern for himself or his offspring".

The Committee further recommended that the population exposed, at this level, should not exceed one fiftieth of the total population. No explanation was given for how this number was derived.

The Committee judged that, based upon the UKAEA records, these limits were "attainable".

A recommendation was not made on the permissible level of exposure for the whole population; although the Committee considered that it was highly desirable that a figure should be named soon as possible. Meanwhile, the Committee stated that it was

"unlikely that any authoritative recommendation will name a figure for permissible radiation dose to the whole population, additional to that received from natural background, which is more than twice that of the general value for natural background radiation. The recommended value, may, indeed, be appreciably lower than this".

The Committee concluded that atmospheric weapon testing did not present a hazard:

"The present and foreseeable hazard from external irradiation due to fall-out from the test explosions of nuclear weapons, fired at the present rate and in the present proportion of the different kinds are negligible".

However, it cautioned:

"Account must be taken, however, of the internal radiation from the radioactive strontium which is beginning to accumulate in bone. At its present level, no detectable increase in the incidence of ill-effects is to be expected. Nevertheless, recognising all the inadequacy of our present knowledge, we cannot ignore the possibility that, if the rate of firing increases and particularly if greater numbers of thermonuclear weapons are used, we could within the life-time of some now living, be approaching levels at which ill-effects might be produced in a small number of the population".

In the U.K the report was accepted by the UKAEA, who noted that observance of the new cumulative limits would cause some inconvenience but could and should be achieved[75].

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4.6: ICRP INTERIM RECOMMENDATIONS ON GENETICS

By early 1956 it was evident that the conclusions of the investigations by the MRC and U.S National Academy of Sciences would require a reconsideration of the magnitude of the permissible dose[76].

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[75] UKAEA (1956) Extract from the Minutes of the Atomic Energy Authority, 6th September 1956

[76] Himsworth H (1956) Letter to J.D Cockcroft, 16th April 1956, In PRO:AB 6/1603

(I) Proposal for Reductions in the Permissible Dose

The ICRP was aware of this before publication and decided that it should take action first[77]. During 1956, it held several meetings, in Geneva (April), Mexico (August) and New York (October/November) to discuss whether the permissible dose should change and if so by how much[78].

(a) The Occupational Permissible Dose

During the joint meeting of Committees I and II in Geneva, Failla stated he would rather not reduce the weekly permissible dose. On the other hand, he recognised that it might be necessary to limit the dose accumulated in the reproductive life span and in the total life span. To meet this requirement he suggested additional limits of 5 r per annum and "about" 150 r in thirty years[79]. This proposal amounted to a one third reduction in the annual dose a worker could receive.

The alternative was to leave things as they were. This raised the possibility that other bodies might make more restrictive recommendations first. Taylor instanced the U.N Scientific Committee, which was "heavily weighted" with geneticists[79].

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[77]The MRC and NAS reports were published in June 1956, before anything from the ICRP.

[78]The Mexico meeting coincided with the Eighth International Congress of Radiology. The November meetings were held jointly between the ICRP and International Commission on Radiological Units (ICRU). They were held following a request from the newly formed United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) that they compile a report on population exposure from radiation, especially from medical procedures.

[79]ICRP (1956) Joint Meeting of Committees I and II, Friday 6th April 1956, In Taylor L.S (1979)

Marley stated that he would prefer not to reduce the annual dose by a third. He suggested instead 50 r up to age thirty and 200 r up to age sixty[80].

The effect of a reduced permissible dose on the nuclear industry also had to be considered. However, Failla pointed out that,

> "from what he had heard, cutting the tolerance by three in this way would not seriously interfere with any atomic energy project"[81].

Morgan[82] was more concerned with the effect of the current permissible dose on his workers. If they reduced the permissible dose he did not think

> "they would be yielding to unscientific pressure. The present basic rate was 15 r per year. He would not like to have (say) 400 of his workers getting 628 r in their working life, in order that nuclear power might sell competitively with coal and oil"[83]

Other members like Stone[84] did not feel that the available evidence justified a change. On the other hand, Failla judged that

> "it would be wrong to wait 50 years until strict proof had become available. It was legitimate to note tendencies and to keep on the safe side. There were some indications that leukaemia was increased and that life span was decreasing. The point at issue was what degree of exposure had produced this".

The minutes of the meeting note that he qualified this statement by adding:

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[80] This was essentially the recommendation of the MRC Committee.
[81] ICRP (1956) Joint Meeting of Committees I and II, Friday 6th April 1956, In Taylor L.S (1979)
[82] Chair of Committee II.
[83] ICRP (1956) Minutes of Joint Meeting of ICRP Sub-Committees I and II 6th April 1956, In PRO:AB 12/287
[84] A Radiologist.

> "If what was now proposed interfered seriously with the peaceful development of atomic energy, he would not support it, but they were told that it would not interfere appreciably".

The meeting agreed:

> "In order that the maximum permissible weekly doses be not exceeded and that the spirit of the general recommendation 'that exposure to radiation be kept to the lowest practicable level in all cases' be adhered to, general experience indicates that the average yearly dose received by those occupationally exposed will not normally exceed 1/3 of the maximum permissible limit. It is felt that it would be prudent to limit accumulated doses to 50 rems by age 30, and beyond that age to average doses of 50 rems per decade"[85].

It was also agreed that the permissible dose could be averaged over a thirteen week period:

> "In exceptional cases in which it is necessary for a person to receive, in one week, more than the basic permissible organ doses, the unit of time may be extended to 13 weeks (1/4 year), provided that the total dose in any organ accumulated during a period of any 13 consecutive weeks does not exceed 10 times the respective basic permissible weekly dose"[86].

A further series of proposals were put forward by Taylor during the November meetings in New York[87], these were based upon different ways of limiting the accumulated dose. It was subsequently decided that the permissible dose should be based around an accumulated dose of 50 rems by age thirty and 200 rems in a lifetime.

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[85] ICRP (1956) 'Minutes of the Plenary Session of the Commission and Committees, held on Monday, April 9, 1956', In Taylor L.S (1979) and ICRP Main Commission: Minutes, Papers and Agenda 1953-1960, (PRO:AB 12/286)

[86] ICRP (1956) Minutes of the Plenary Session of the Commission and Committees, held on Monday, April 9, 1956, In Taylor L.S (1979) and ICRP Main Commission: Minutes, Papers and Agenda 1953-1960, (PRO:AB 12/286)

[87] ICRP/ICRU (1956) Minutes of Joint ICRP/ICRU Meeting on 31 October 1956, New York, In PRO:AB 12/287

However, there was considerable discussion over the practical application of these limits. Morgan emphasised that retention of the basic weekly permissible dose, of 0.3 rem, was important for atomic energy purposes. Following a further discussion it was agreed that this figure would be retained and would be supplemented by limits on cumulative dose:

Accumulated Dose	50 rem up to 30th Birthday.
	50 rem per decade above age thirty.
Operational:	5 rem per year average but
	a) not more than 10 rem per year maximum,
	b) not more than 3 rem per quarter.

It was emphasised that these figures excluded the dose received by diagnostic and therapeutic radiation[88].

Taylor was opposed to limiting occupational exposure to a maximum of 10 rems per year. He subsequently wrote to Sievert:

> "With regard to the November 1956 amendments, I would take strong exception to only one part and this is the statement that when averaging the dose to 50 rems up to age 30 or per decade thereafter, not more than 10 rems should be permitted in any one year. My objection is only to the 10 rem limitation. I feel very strongly that at very least for the time being the ICRP should keep its recommendations in sufficiently general form, so as to allow interpretation in different countries according to their particular needs. I do think we should retain the 50 rem per decade figure, but I believe that we should allow more freedom in the interpretation in the way it is averaged".

He commented that the U.S NCRP allowed 15 rems in a year:

> "For example, in this country the NCRP has agreed to its averaging by the age-proration principle which I am sure you are familiar. . . Here we would allow up to 15 rems in one year provided that the dose did not exceed the age-prorated maximum. Even this does not allow all of the latitude that one would like and which would be reasonable within the 10 year averaging principle"[89].

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[88] ICRP/ICRU (1956) Minutes of Joint Meeting of ICRP/ICRU held on November 1st 1956, In PRO:AB 12/287

[89] Taylor L.S (1957) Letter to Sievert, November 4th 1957, In Taylor L.S (1979)

(b) Choosing a Permissible Dose for Population Exposure

During the joint committee meeting in April, Failla had observed that geneticists wanted the accumulated dose for the population to be less than 10 r. However, Taylor considered that the Commission should not be "stampeded" by geneticists[90].

Other members of the Commission believed that, because of the world-wide interest, some statement should be made regarding the genetics question. However, all were agreed that a value for the population permissible dose could not be recommended then because of lack of information[91].

It was also pointed out that confusion had arisen following publication of the 1954 report. The difference between "large populations" and the "whole population" had not been made sufficiently clear. The recommended reduction factor was not intended for calculating permissible exposures for the total population. It had been intended for smaller numbers of people who were not normally exposed to radiation during their work.

Consequently, many geneticists had claimed that the ICRP was not protecting the interests of the whole population. Its intention had been to recommend a 1/100th reduction factor. It was agreed that the Committee I report should prepare a statement that the matter was still under consideration.

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[90] ICRP (1956) Joint Meeting of Committees I and II, Friday 6th April 1956, In Taylor L.S (1979)
ICRP (1956) Minutes of Joint Meeting of ICRP Sub-Committees I and II 6th April 1956, In PRO:AB 12/287

[91] ICRP (1956) Minutes of the Plenary Session of the Commission and Committees, held on Monday, April 9, 1956, In Taylor L.S (1979) ICRP Main Commission: Minutes, Papers and Agenda 1953-1960, (PRO:AB 12/286)

Following the Geneva meeting Morgan wrote to all the members of his Committee[92]. Another NCRP member, H.M Parker[93], had written to him to ask:

> "What would be the effect on the nuclear industry of setting the average permissible integrated exposure to the population (to age of 30) equal to 5 to 7 rads to the gonads as a result of nuclear reactor operations".

Morgan qualified this question with the following comment:

> "This question had been raised with reference to recommendations by geneticists who were thinking of the possibility of setting an average gonad dose of 5 rads in addition to background. . . I think it should be emphasized that this question refers to <u>average</u> and not <u>individual</u> exposures since we are concerned here with genetic effects. Therefore, small segments of the population might accumulate 50 to 55 rads provided the average dose to very large "socially related" groups does not exceed, to the age of 30, a total of twice background from artificial sources"

He observed that the dose to the gonads from background radiation to age was frequently quoted a 5 rads. However, he calculated this dose to be 3 rads. This was the value used by the British[94].

The difference was extremely important. A background dose of 5 rads in thirty years would allow an additional dose from artificial source of 10 rads. This could be comprised of: 3 rad from medical exposures; 1/3 of a rad to 3 rads from fall-out and 5 to 7 rads from all other exposures such as disposal of radioactive waste.

If however, the background dose was 3 rads in thirty years this would only allow an additional 6 rads from exposure to artificial sources.

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[92]Morgan K.Z (1956) <u>Letter to all Committee II Members, May 21st 1956</u>, In PRO:AB 12/286

[93]Former Manhattan Project, NCRP member and Director of the Radiological Sciences Department of General Electric Company.

[94]Who also queried the U.S 5 rad figure.

This would only allow from 0 to 3 rads from non-medical sources of exposure and fall-out.

He concluded that it was important to make accurate measurements of the background dose to the gonads otherwise:

> "there may be no genetic exposure permitted from reactor operations"[95].

During the November meetings the Commission discussed a number of different proposals for the population permissible dose up to age thirty[96]. In all, the gonad dose from background was stated as 4 rems:

Table 1: Average Dose (Rems) to the Whole Population up to Age 30

MRC	(UK)	BG + 2x BG (all sources) (4+8) = 12
NAS	(UK)	BG + 10 rems (all sources) (4+10) = 14
NCRP	(US)	BG + 6 rem + Medical (4+6+3) = 13
ICRP		BG + BG (4+4) = 8 + 3 medical (?) = 11
C Stern[97]		BG + 5 rem including all sources (4-5) = 9

The meeting considered that despite the vagueness of this information a figure was required for the general population to order to permit planning to proceed. A permissible dose of 10 rems was adopted:

> "Until better knowledge is available, it is prudent to limit, so far as possible, all ionising radiation received by the gametes. At the present time, it would appear that an average per capita gonadal dose up to age 30 of 10 rem in addition to natural background would not produce any unacceptable damage to the human race, and it is therefore recommended that this dose should not be exceeded. For purposes of calculation, it is assumed that the average dose to the gonads from background radiation is 4 rems for 30 years. This average per capita dose does not apply to any single individual but must be defined by averaging the exposures of all individuals in a large population. Many individuals will be exposed to doses considerably above this average by virtue of occupational and/or medical exposure,

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95 Morgan K.Z (1956) Letter to all Committee II Members, May 21st 1956. In PRO:AB 12/286

96 ICRP/ICRU (1956) Minutes of Joint Meeting of ICRP/ICRU held on November 1st 1956. In PRO:AB 12/287

97 A U.S geneticist.

but this is counter balanced by the fact that the great majority of the population will be exposed to much lower values.

The average per capita dose includes that received from natural radiation, medical exposures and exposures from all other sources of radiation. After allowing for the natural background and for the estimated average medical exposure, the amount remaining would be the value for the permissible exposure from all other sources of radiation".

The Commission did not agree on how the 10 rems should be allocated. Instead, it was decided that this should be up to each country to decide

"in order to permit the planning of atomic energy and other installations to proceed"[98].

This was not the end of the matter. Some members of the Commission were not convinced that the permissible dose should be changed. Sievert did not accept that development of the nuclear industry should be hindered solely because of concern over genetics. In late 1957 he wrote to Taylor to comment that the risks of atomic energy were worth accepting:

"I am quite sure that the viewpoints of the geneticists must be partly revised because it is a nonsense to place radiation safety in a special position only because of the possibilities of a dangerous effect in a distant future. We must consider that in the atomic age there must be a reasonable ratio between the risks and the aim of the work, and if mankind can gain very much of development in atomic energy we certainly must be ready to pay for it, even in the form of some injurious effects"[99].

(II) The Nuclear Industries Response to the Reduction in the Permissible Dose

The response of the nuclear industry to the proposed reduction in the permissible dose is illustrated in a letter to Taylor from Parker, a

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98 ICRP/ICRU (1956) Minutes of Joint ICRP/ICRU Meeting, November 6th 1956, In PRO:AB 12/287

99 Sievert R (1957) Letter to Taylor, October 26th 1957, In Taylor L.S (1979)

colleague on the U.S NCRP. Parker was also the director of Radiological Sciences with the General Electric Company[100].

> "I was horrified to discover in one of the circulating news letters on atomic energy that L.S Taylor recommended that the permissible exposure to radiation be reduced to one-third of its present value. I hope you were misquoted!
>
> If this means a reduction to 0.1 r or 0.1 rem per week, the effects on the atomic energy programme could be extremely drastic. In our telephone conversation this week, I thought we had established that no change from 0.3 r per week was in sight".

This letter reveals the degree of regular and informal contact between members of the protection committees and their colleagues in industry. This implies a common view was held over the practical problems of industry.

Like Sievert, Parker considered that genetics could not justify this reduction. He stated that the money industry would have to spend to meet the new limit would be needlessly wasted:

> "We cannot over emphasise the needless waste of funds that would do to meet a 0.1 r per week limit, compared with the present 0.3 r per week. The move should be strongly resisted, unless of course there should be technical evidence indicating its necessity. Provided these low limits to age 30 rest solely on genetic needs, there can be no such evidence"[101].

(III) Peer Group Pressure for an Announcement on the Changes

The Commission also came under pressure from other sections of the scientific community. The radiology profession were also concerned over the implications of the MRC and U.S NAS reports. When Taylor returned from the Mexico meeting he wrote to Rock Carling.

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[100] He had also worked on the Manhattan Project.
[101] Parker H.M (1956) Letter to L.S Taylor, June 19th 1956, In Taylor L.S (1979)

"Both before and after the presentation of the ICRP, I was besieged with questions regarding the information that would be released. It seems to be generally known that some changes will be made and there was high interest in the nature of the changes in view of the reports released by the Medical Research Council and the National Academy of Sciences. Also it appears that at least one or two copies of the reports distributed to the ICRP and to the IEC were in circulation.

I think it highly important that the ICRP release as quickly as possible some general statements regarding the nature of the changes to be made in permissible exposure levels. I think this is particularly important from the point of view of the prestige of the ICRP. After all, our recommendations were made in advance of the other reports. In addition, there is considerable confusion, at least on our side, as to whether radiologists are to be guided by the Council and Academy reports or by the recommendations of the ICRP. With some effort, several of us have persuaded some of our radiological groups in this country not to start blasting at the National Academy report until they at least know some more of what the situation is. I think the release by the ICRP will give the radiologists a feeling that their Commission is providing some degree of leadership"[102]

On the other hand, some members of the Commission did not believe that a delay in publishing new recommendations would harm the Commission. In his 1957 letter to Taylor, Sievert stated:

"I have earlier worried very much about the delay of the revised recommendations decided upon in Geneva in 1956. However, I have, during the last time, come to the conclusion that our position is better just because we have not officially taken a definite position as to the problems of lowering the permissible dose according to the ideas of geneticists. If the ICRP in the new issue of its recommendations makes careful investigation on the basic philosophy of radiation protection and gives the reasons for the different levels to be adopted for occupational work as well as for people near the controlled area and fore whole populations we still remain the control body in our field".[103]

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[102] Taylor L.S (1956) Letter to E Rock Carling August 1 1956, In Taylor L.S (1979)

[103] Sievert R (1957) Letter to Taylor, October 26th 1957, In Taylor L.S (1979)

(IV) Publication of Interim Recommendations on Changes in the Permissible Dose

The amendments agreed during 1956 were not published until 1958, two years after the publication of the reports from the U.K MRC and the U.S NAS. Furthermore, these, were only interim recommendations. The Commission aimed to publish its fully revised recommendations later that year.

(a) Occupational Permissible Dose

The interim recommendations did not reduce the value of the weekly permissible dose:

> "The recommended maximum weekly doses and the modified values for special circumstances permit a desirable degree of flexibility for their application. In practice it has been found that, in order not to exceed these maximum limits and also to comply with the general recommendation of the Commission 'that exposure to radiation be kept at the lowest practicable level in all cases', a considerable factor of safety must be allowed in the design if protective devices and operating procedures"[104]

If the Commission's advice was followed it expected

> "that the average yearly occupational dose actually received by an occupationally exposed person would be about 5 rems and the accumulated dose in the employment period up to thirty years of age would be about 50 rems".

The Commission recommended the continuation

> "of the present conservative practice as regards doses actually received by occupationally exposed personnel, to keep the accumulated dose as low as practicable, especially up to age thirty".

The Commission's interim statement was discussed at the Second United Nations Conference on the Peaceful Uses of Atomic Energy in 1958. At

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[104] ICRP (1958) 'Report on 1956 Amendments to the Recommendations of the International Commission on Radiological Protection (ICRP)', Radiology 70 261-262

this conference, Taylor stated that the recommendation had obvious drawbacks, namely that the average of 5 rems per would quickly become a maximum of 5 rems per year. He was concerned that this

> "would be intolerably restrictive in some atomic energy operations and go beyond the bio-medical necessity"[105]

He then discussed a formula devised by NCRP that enabled workers to receive up to 12 rems in a year. He concluded that

> "the introduction of lowered MPD levels and the age-proration principle for distributing the dose, should not introduce any insurmountable problem in the United States"[106]

(b) Public and Population Exposure

Two other categories of person were discussed in the 1958 statement. Previously the Commission had recommended that for "large" populations the maximum permissible levels should be reduced by a factor of ten. The Commission now stated that this applied to anyone not in a controlled area[107]. The size of this group was much smaller and included people living near a nuclear installation.

The Commission also commented on, but did not recommend a value for, the population permissible dose. It also observed that this issue was causing difficulties for the nuclear industry. Industry needed regulatory stability in order to plan for the future. The uncertainty over genetics meant that planning was difficult:

> "Designers of nuclear power plants, and others concerned with the peaceful application of atomic energy, cannot plan for

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105 Taylor L.S (1959) 'The Influence of Lowered Permissible Dose Levels on Atomic Energy Operations in the United States', In Progress in Nuclear Energy Series XII Vol 1 Ed Marley W.G and Morgan K.Z London: Pergamon Press

106 MPD is an addreviation of Maximum Permissible Dose.

107 This was defined as an area in which the occupational exposure was under the supervision of a radiation safety officer.

the future in the present state of uncertainty as to what the genetic problem may mean in terms of a permissible level for the whole population".

Instead of recommending a value for the population permissible dose the Commission stated:

> "Scientific data derived from human as distinct from experimental animal populations are so scanty that no permissible dose for the population can, at present, be set. The available information is being assessed by the Commission and other groups including geneticists. Until general agreement is reached, it is prudent to limit the dose of radiation received by gametes from all sources additional to natural background to an amount of the order of the natural background in presently inhabited regions of the earth"[108]

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4.7: REDUCTION OF THE PERMISSIBLE DOSE

The Commission met to discuss the final form of its revised recommendations in New York in March 1958. Failla submitted a report to the meeting that proposed the exclusion of background radiation and medical exposures from the Commission's limits. Failla did not dispute that background radiation would produce a biological effect. He simply stated:

> "If permissible limits recommended by ICRP included background radiation the contributions from man-made sources would have to be correspondingly lower. The present state of knowledge does not warrant this restriction"[109]

The implications of including background and medical radiation in the permissible dose had previously been discussed by Morgan[110]

Failla did not consider that Commission was competent to consider the risks and benefits of medical exposure:

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[108] ICRP (1958) 'Report on 1956 Amendments to the Recommendations of the International Commission on Radiological Protection (ICRP)', Radiology 70 261-262

[109] Failla G (1958) Permissible Limits of Exposure, In Taylor L.S (1979)

[110] See Section 4.6 I (b).

> "For the purpose of setting up permissible limits of exposure, the ICRP must assume that medical exposure is necessary and that it is not within its competence to restrict it".

This meant that

> "medical exposure should not be included in the permissible limits recommended by ICRP".

He also recommended that the ICRP adopt the NCRP's formula for accumulated dose.

Following this meeting the Commission's recommendations were drafted and by the end of 1958, after several minor revisions, they were ready for publication. They were published in 1959 as ICRP Publication 1.

(I) The New Permissible Dose

ICRP 1 commented that the permissible dose had not been reduced in response to evidence that deleterious effects had been caused by exposure at the old level. Instead the reduction had been introduced:

> "partly with the intention of limiting the genetically significant radiation exposure of the population, and partly to limit the probability of somatic injury by reducing the lifetime dose"[111]

The main somatic effect of concern to the Commission was leukaemia. It observed the incidence of leukaemia in radiologists was significantly greater than amongst other physicians who had not been exposed.

The risks of leukaemia had not been a feature of the Commission's discussions over the reduction in the permissible dose. The year before, in 1958, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) published its first review on the effects of

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[111] ICRP (1959) 'Recommendations of the International Commission on Radiological Protection', ICRP Publication 1 Health Physics 2 1-20

ionising radiation[112,113]. It had reported that there was a higher incidence of leukaemia among the atomic bomb survivors. UNSCEAR did not quantify the leukaemia risk[114] but referred to a study by Lewis that had attempted[115,116]:

The Commission did not quantify the leukaemia risk but judged that:

> "most conservative approach would be to assume that. . . . even low accumulated doses would induce leukaemia in some susceptible individuals, and the incidence might be proportional to the accumulated dose"[117,118].

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112 This committee had been formed in 1955 in response to concern about the hazards of atmospheric nuclear weapon testing.

113 UNSCEAR (1958) Report of the United Nations Scientific Committee on the Effects of Atomic Radiation, General Assembly Official Records: Thirteenth Session Supplement No 17 (A/3838) New York: United Nations

114 Estimates of the doses received by the survivors were not available in 1957.

115 Lewis E.B (1957) 'Leukemia and Ionising Radiation', Science 125 963-972

116 This had estimated doses for the survivors based upon the mean radiation dose in a number of zones from the centre of the blast. From this Lewis had calculated an estimate of the probability of leukaemia induction following exposure to a unit dose of radiation. For the atomic bomb survivors this ranged from 0.7 - 0.9 x 10^{-6} per rem.
Using an average figure the UNSCEAR report derived an estimate of 12 x 10^{-6} per rem based upon an assumed expression period for the total number of leukaemia's of 15 years.
This risk estimate means that if a million persons were to receive a dose of one rem then twelve would eventually develop leukaemia.

117 Lewis had argued that the incidence of leukaemia fitted a linear dose response relationship and that there was no threshold. UNSCEAR applied his method to the "latest" data on leukaemia incidence to illustrate that the incidence was not linearly related to dose and that a threshold might apply. They argued that the data was too uncertain to state which was correct.

118 This assumption was considered to apply to induction of bone cancer by internally deposited radionuclides as well. Radiation induced life-shortening was also considered to be another possible effect.

(a) Permissible Doses and Acceptable Risk

ICRP Publication 1 differed from the Commission's previous recommendations as the permissible dose was defined as producing an acceptable risk.

> "Any departure from the environmental conditions in which man has evolved may entail a risk of deleterious effects. It is therefore assumed that long continued exposure to ionizing radiation addition to that due to natural radiation involves some risk. However, man cannot entirely dispense with the use of ionizing radiation, and therefore the problem in practice is to limit the radiation dose to that which involves a risk that is not unacceptable to the individual and to the population at large. This is called a "permissible dose"[119]

However, the Commission also commented:

> "that the setting up of maximum permissible limits of occupational and non-occupational exposure (especially the latter) requires quantitative information not yet available about the risks and benefits of an expanded use of 'atomic energy'"

(b) The Permissible Dose for Individuals

Three main categories of exposure were considered in the recommendations: (1) Occupational Exposure; (2) Exposure of Special Groups[120] and (3) Population Exposure.

The Commission emphasized that the:

> "maximum permissible doses recommended. . . are *maximum* values; the Commission recommended that all doses be kept as low as practicable and that any unnecessary exposure be avoided".

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[119] ICRP (1959) 'Recommendations of the International Commission on Radiological Protection', ICRP Publication 1 Health Physics 2 1-20

[120] This category was further subdivided into (i) Adults who work in the vicinity of controlled areas - but who are not radiation workers; (ii) Adults who may enter controlled areas - but who are not radiation workers and (iii) members of the public living near controlled areas.

The Commission did not define "as low as practicable". However, this advice was different to that recommended in 1950 when the Commission had recommended that exposures be kept "as low as possible".

The recommended "maximum permissible total dose" for occupational exposure was limited by the use of the NCRP's formula for relating an individuals permissible dose to his/her age[121]. This allowed a maximum annual exposure of 12 rems, with a maximum of 3 rems in a period of thirteen consecutive weeks. The Commission added:

> "For a person who is occupationally exposed at a constant rate from age 18 years, the formula implies a maximum weekly dose of 0.1 rem. It is recommended that this value be used for planning and design"[122].

A permissible dose of 1.5 rems was recommended for special occupational groups, i.e non-radiation workers. For members of the public a value of 0.5 rem per year was recommended for the purposes of planning and design[123].

(c) The Permissible Dose for Populations

The Commission's discussion on population exposure illustrates the extent of social judgements in the adoption of a population permissible dose:

> "Proper planning for nuclear power programs and other peaceful uses of atomic energy on a large scale requires a limitation of the exposure of whole populations, partly by limiting the individual doses and partly by limiting the number of persons exposed.
>
> This limitation necessarily involves a compromise between deleterious effects and social benefits".

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121 The formula was D=5(N-18), where D was the dose in rems and N the age in years.

122 ICRP (1959) 'Recommendations of the International Commission on Radiological Protection', ICRP Publication 1 Health Physics 2 1-20

123 It was also suggested that the occupational maximum permissible concentrations for radionuclides in air and water be reduced by a factor of ten when applied to special groups.

However, the Commission also commented

> "that a proper balance between risks and benefits cannot yet be made, since it requires a more quantitative appraisal of both the probable biological damage and probable benefits than is presently possible".

The Commission recommended the genetic dose to the whole population, additional to background, should not exceed 5 rems plus the "lowest practicable" contribution from medical sources.

The report describes how this figure was chosen and explains why medical and background radiation were excluded. It emphasised that this the choice was justifiable in view of the benefits that would arise from nuclear energy:

> "Estimates made by the different national and international scientific bodies indicate a per capita gonad dose of 6-10 rems accumulated from conception to age 30 from all man-made sources, would impose a considerable burden on society due to genetic damage, but that this additional burden may be regarded as tolerable and justifiable in view of the benefits that may be expected to accrue from the expansion of the practical applications of 'atomic energy'".

The Commission emphasised the uncertainty in this judgement:

> "There is at present considerable uncertainty as to the magnitude of the burden and, therefore it is highly desirable to keep the exposure of large populations at as low a level as practicable, with due regard to the necessity of providing additional sources of energy to meet the demands of modern society".

It commented that the practical needs of industry meant that medical radiation had to be excluded from the population permissible dose:

> "A genetic dose of 10 rems from all man-made sources is regarded by most geneticists as the absolute maximum and all would prefer a lower dose. In some countries the genetic dose from medical procedures has been estimated to be about 4.5 rems. Therefore, if the limit for the genetic dose from all man-made sources was set at 6 rems, the contribution from all sources other than medical procedures, would be limited

> to 1.5 rems in these countries. This would impose unacceptable restrictions on these countries. Accordingly, as a matter of practical necessity the Commission recommends that medical exposure be considered separately and that it be kept as low as is consistent with the necessary requirements of modern medical practice . . . In view of these considerations the Commission recommends a limit of 5 rems for the genetic dose from all man-made sources of radiation and activities, except medical procedures"[124,125]

The Commission considered

> "that this level provides reasonable latitude for the expansion of atomic energy programmes in the foreseeable future"

In terms of population exposure the Commission hoped that if a thermonuclear reaction could be utilized as a source of power

> "the problem of radiation protection may be greatly simplified".

(d) The Commission's 1959 Statement

Amendments to ICRP Publication 1 were discussed during the 1959 Munich meeting, held prior to the Ninth International Congress of Radiology. These were included in a brief statement issued for publication in the scientific press, and published in 1960[126]. This statement introduced two new topics that had not been previously mentioned. These were (i) the occupational exposure of pregnant women[127] and (ii) population exposure

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[124] ICRP (1959) 'Recommendations of the International Commission on Radiological Protection', ICRP Publication 1 Health Physics 2 1-20

[125] The Commission presented an "illustrative" apportionment of this figure:

(A) Occupational Groups	1.0 rem
(B) Exposure of Special Groups	0.5 rem
(C) Exposure of the Population	2.0 rems
(D) Reserve	1.5 rems.

[126] ICRP (1959) 'Report on Decisions at the 1959 Meeting of the International Commission on Radiological Protection (ICRP), Addendum to ICRP Publication 1 (1958 Recommendations)', Health Physics 2 317-320.

[127] The discussions on this issue had been prompted by a request for a statement from the International Labour Organisation (ILO). The Commission concluded that the available biological information did

arising from nuclear accidents[128]. Recommendations were not made for either of these.

(II) Reactions of Industry to the New Permissible Dose

Even though the new ICRP recommendations had recommended an apparent reduction in the permissible dose, they were considered by the nuclear industry to be fairly generous in most respects. They allowed the industry to plan for expansion and provided greater operational flexibility in the application of protection procedures, particularly for those occupationally exposed.

Some countries, such as the U.K, had already adopted the change in specifying the permissible dose as 3 rems in thirteen weeks, as opposed to the old weekly value, even before the recommendations were published. This change meant that the old weekly figure could be exceeded, on occasions, as long as the accumulated dose did not exceed 3 rems in thirteen weeks. As already remarked most radiation workers had been exposed to well within the old limits.

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not allow quantitative estimates or numerical expressions of risk to be attached to situations involving pregnant women. It simply commented that "pregnant women present a 'special-risk problem' in case of occupational exposure".

[128] In 1957 a major nuclear accident occurred at the Windscale No 2 Pile that led to a large release of radioactivity and contamination of the environment. Several British members of the ICRP were involved in the emergency response and in the subsequent investigation. The 1959 Statement did not refer to the Windscale accident by name. It simply noted the subject of emergency exposure of populations was "extensively" discussed during the Munich meeting and commented that British "constitutes a useful and sound approach to the problem".

The issue of dietary contamination and what action should be taken when food was found to be contaminated above any limit was a subject that the ICRP discussed on a number of occasions during the early 1960s. No recommendations were made.

The use of the NCRP's accumulated dose formula also provided greater flexibility. For instance, it enabled workers in their early twenties to accumulate a dose of 60 rems by age thirty instead of the 50 rems previously recommended by the MRC.

The greater flexibility also applied to the permissible doses for extremities. In the case of non-uniform exposure to the skin, hands, feet, forearms and ankles the permissible dose did not change. The rate at which it could be accumulated did[129].

For population exposure, the ICRP had suggested that for planning purposes 2 rems could be accumulated in thirty years. The UKAEA calculated that if one rem of this was assigned to occupational exposure, 1.7% of the population could receive the maximum occupational dose. This figure would permit about 850,000 radiation workers in the U.K. This was considered to allow for ample growth of the nuclear industry[130].

The UKAEA also calculated that this special group category could apply to about three percent of the population. In the U.K this meant that around 1,500,000 people could be exposed as a result of discharges from nuclear installations. Again this was considered sufficient to allow for enough latitude for all ordinary reactor and processing sites, but would discourage the sitting of reactors "in the middle" of large towns.

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129 The 1953 ICRP recommendations had specified a weekly figure of 1.5 rems for exposure of the skin. This was equivalent to 75 rems per year (on a 50 week year). The 1958 recommendations replaced the old weekly limit with a figure of 20 rems in 13 weeks, or 75 rems per year.

130 UKAEA reactions are contained in the public record office file MRC Committee on Protection Against Ionising Radiation (1958-61) Reports and Papers.

(III) Reactions from the MRC

The MRC PIRC were more critical[131]. It endorsed the change in accumulated dose up to age thirty, provided that this only applied to one sixtieth of the population. If the exposed population was any greater than this the MRC considered that the proposal would be unacceptable. Its previous recommendation, of 50 rems up to age thirty, had applied to one fiftieth of the population.

The MRC PIRC were concerned that the ICRP's explanation of the thirteen week rule would, in effect, result in a reduction in the permissible dose to 3 rems in twenty six weeks. It recommended changing the averaging period to a calendar quarter, as opposed to thirteen consecutive weeks.

The PIRC also expressed concern over the ICRP's suggested population exposure that could be accumulated by age thirty. It considered if the actual dose was 5 rems per capita per thirty years then this would result in considerable genetic damage. One the other hand, if this figure were used for planning purposes then actual doses would be much less:

> "the Committee is prepared to accept the suggested figure as the upper limit. It considers, however, that the operative figure should in fact be determined by considering the levels which should be allowed for different sources of radiation. . . Subject to a maximum value of 5 rems, this operative figure would thus be ascertained by adding the figures regarded as permissible for individual sources, the contribution from each being held to the lowest practicable value".

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131 Committee on Protection Against Ionising Radiation (1960) 'Comments on the Recommendations of the International Commission on Radiological Protection', In MRC (1960) The Hazards to Man of Nuclear and Allied Radiations, A Second Report to the Medical Research Council London: HMSO

(IV) Scientific and Social Judgements in the Derivation of the Permissible Dose

The Commission had made a number of social judgements in its 1958 recommendations, which some considered were outside the scientist's competence. Prior to the completion of its 1958 recommendations, Sievert had circulated to Commission members an excerpt of a paper that voiced this concern. This was by a World Health Organisation Study Group on the Mental Health Aspects of the Peaceful Uses of Atomic Energy.

The WHO Study Group considered that the establishment of permissible doses was a process that involved non-scientific and policy judgements which were outside the competence of scientists. This meant that decisions on the level of risk, that others could face, were "moral" judgements that should not be presented as science. Sievert described this view as "alarming". The Study Group had commented:

> "Scientists do not make the task easier when they vacillate between statements which are limited to their scientific competence and statements which have the mantle of science but which are actually expressions of value and even policy decision. Some pronouncements which have appeared with regard to the 'maximum permissible dose' of radiation illustrate this. It has been pointed out that it is the right, even the duty of scientists, to give an opinion on a scientific matter, but they must do it in a way that will avoid any confusion between facts and judgements on facts.
>
> In the example of the maximum permissible dose, it will be the duty of scientists to find out and make known what risks the public and the workers in the atomic industries will suffer from present and foreseeable plans. They must also describe the probable effects of doses of radiation of whatever size, and under whatever circumstances, upon workers, the population of other countries that might conceivably be affected. But to indicate a maximum permissible dose is entirely another matter. It is doubtful if this is a proper question to put to scientists for it appears to the Study Group to be a moral problem of extremely wide and important implications as to what risks and dangers

perhaps quite unconnected people may be forced to undergo as a result of human actions"[132]

Rock Carling also rejected this view. He considered that the WHO Study Group statement was

> "just a quibble about words - semantic confusion and not worth the paper it is printed on. The moment 'morals' come into scientific nomenclature they evoke nonsense"[133]

Binks considered that the ICRP's authority depended on its membership. It was composed of two types of experts:

> "those who are studying the somatic and genetic effects of ionising radiation and those who in their respective countries are responsible for framing protective measures and for operating laboratory services to ensure adequate radiation control and safety"[134]

This view implies that he judged that these scientists with industrial experience were the appropriate people to make judgements on the risks that others could face.

Holthusen, a biologist, considered the criticism

> "would be justified if the International Commission for Radiation Protection consisted exclusively of scientists, who were competent to discover and make public the hazards to which those employed in the nuclear energy industry are exposed under present conditions and those that can be foreseen in the future. You know my point of view that these problems largely represent a radiobiological problem in the broader sense of the word. Those participating in the "Study Group" seem to assume that the International Commission for Radiation Protection consists exclusively of persons whose competence is confined to the judging of the problem. That would be a fundamental misunderstanding. I should rather assert that in our commission, especially when its subcommittees are included, representatives of all aspects are present and it must be admitted that they are very

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[132]World Health Organisation (1958) Report of a Study Group on Mental Health Aspects of the Peaceful Uses of Atomic Energy, WHO/MH/AE/2 1 April 1958, Extracts in Taylor L.S (1979)

[133]Rock Carling E (1958) Letter to Sievert, 27th May 1958, In Taylor L.S

[134]Binks W (1958) Letter to Sievert, 30th May 1958, In Taylor L.S (1979)

different in evaluating the problem of radiation protection"[135]

He believed that in deriving maximum permissible doses the ICRP had been "quite conscious" of its "moral aspects". He considered that there were three kinds of experts who should be involved establishing the permissible dose:

> "1) Radiobiologists in the broader sense of the word who are qualified to handle problems of somatic-genetic effects of radiation. 2) Persons who possess practical experience in the use of ionising rays in science and technology in their entire field of application. 3) Technical experts who feel that they are qualified to problems of the feasibility of the radiation protection measures considered necessary".

To these, he suggested that another group of persons could be included. These would consider the question of permissible doses from a "public health" view point. This suggestion illustrates that Holthusen recognised the existence of an alternative view, on the risks of radiation, which was not represented on the Commission. However, he did not discuss how this viewpoint could be adequately expressed on the Commission.

In an earlier letter to Sievert, Holthusen had argued that the establishment of permissible doses involved a compromise between biological considerations and the inevitable exposure that would result from the "peaceful" uses of radiation. A term that can be interpreted as referring to the nuclear industry and medical exposures:

> "I have always been of the opinion that the task of carrying out radiation protection procedures is a function of applied physics. On the other hand, fixing the maximum permissible level is a problem in medical biology and has to be based on biological considerations. From the point of view of the biologist and geneticist, the levels of these maximum

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[135] Holthusen H (1958) Letter to Sievert on Position and Future Policy of ICRP May 24th 1958, Translation In Taylor L.S (1979)

> permissible doses can never be low enough. However, one has to deal with reality, and therefore must find a compromise between the radiation burden above natural background desired by the physicians, the geneticists, and the biologists and the burden that in our age and civilisation is inevitable, even in the solely peaceful use of ionising radiation. It is therefore only logical that physicists, physicians and biologists cooperate in the work of the ICRP"[136]

Although Sievert had described the WHO Study Group view as alarming he accepted that the establishment of permissible doses was a non-scientific task

> "which must be primarily based on scientific knowledge and judgement".

He also considered that this task must

> "be carried out independently of the demands of persons or organisations who are responsible for the increase of ionising radiation in the world, but nevertheless in close contact with them"[137]

While this view acknowledges the problem of the close relationship between the nuclear industry and the Commission, it is clear that it did not mean that scientists with experience of the practical problems of industry should be excluded from the ICRP. This experience was judged to be essential in establishing permissible doses. Sievert also considered that the Commission was fulfilling its role as objectively as possible:

> "The only way to arrive at useful and well-balanced maximum permissible levels seems then to be to bring people together representing extensive knowledge and experience on the one hand of the relevant biological effects, and on the other, on the working conditions and protection possibilities. Such a

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136 Holthusen H (1958) Letter to Sievert, January 21 1958, re Recommendations of ICRP, In Taylor L.S (1979)

137 Comments made at the Second United Nations Conference on the Peaceful Uses of Atomic Energy. He addressed the conference as the Chair of the Commission.
Sievert R.M (1959) 'The Work of the International Commission on Radiological Protection (ICRP)' In Progress in Nuclear Energy Series XII Vol 1 Ed Marley W.G and Morgan K.Z London: Pergamon Press

> group is capable of discussing the fundamental protection problems from the various aspects relevant for establishment of sound principles in the assessment of maximum permissible levels. This is what ICRP is trying to do as objectively as possible".

These statements from Commission members clearly acknowledge that practical considerations are important in establishing permissible doses. However, this is a regulatory approach, rather than an independent scientific advisory approach, to the problems of radiation safety.

4.8: SUMMARY

The events of the 1950s were extremely important in shaping the development of the ICRP's protection philosophy. The Commission's 1950 recommendations reflected a compromise between scientific evidence and the practical needs of industry. However, the extent of this compromise was not explicitly recognised in the recommendations. In particular the issue of genetics and population exposure had been ignored.

Nevertheless, the Commission had judged, in 1953, that

> "the values proposed for maximum permissible doses are such as to involve a risk which is small compared to the other hazards of life".

This judgement was made without any means of quantifying the risk from exposure to radiation.

During the 1950s the Commission came under increasing scientific and social pressure to make recommendations on population exposure. Biological scientists, and geneticists in particular, were concerned over the possible hazards of fall-out. This concern was not shared by physical scientists. The physicist members of the Commission were extremely reluctant to take action merely on the concern of geneticists.

The Commission was heavily influenced by the needs of the nuclear industry. This influence was expressed directly through members with affiliations to the industry and through other scientists who shared a common view that nuclear energy was desirable.

Considerable scientific uncertainty existed in the assessment of the biological hazards of radiation exposure. The benefit of this uncertainty was given to industry. The Commission initially responded to this pressure by changing the definition of the maximum permissible dose. The word "maximum" was dropped from the definition, and the Commission allowed the permissible dose to be averaged over a thirteen week period. Thus providing industry with greater flexibility in the application of the permissible dose.

The Commission continued to ignore population exposure until it was forced to take notice of the problem in the mid 1950s, fearing that if it did not other bodies, "weighted with geneticists", might make more restrictive recommendations. The Commissions consideration of population exposure was also motivated by a recognition that the scientific uncertainty made industrial planning difficult. This meant that stability, as well as flexibility, in the application of protection recommendations was required by industry.

The widespread concern over fall-out had led the British and American Governments to conduct full reviews of the extent of population exposure and the evidence on the biological effects of radiation. Although, these did not recommend a change in the Commission's weekly permissible dose, it was apparent the results of the investigations would mean some

restriction on cumulative exposures, particularly during the first thirty years of life.

These reports also drew attention to another biological effect of radiation that had not featured in the Commission's discussions. This was the risk of leukaemia induction. As with genetics it was likely that the incidence of this effect was directly proportional to the dose received. In other words there was not a threshold dose beneath which harm did not occur. This also meant that the Commission's 1950 recommendations were in need of change.

The manner in which the Commission responded to the new biological evidence illustrates the extent to which social judgements formed a major part its derivation of radiological protection standards. The Commission strived to ensure that stability was maintained by causing as little disruption as possible to its system of protection.

Most of the scientific reports published in this period suggested that for population exposure the additional dose above background should be severely limited. Consequently, the amount of population exposure from nuclear operations was dependent on the value of the background dose and from medical procedures. Following pressure from the nuclear industry these were excluded from the Commission's limits.

Nevertheless, the permissible dose the Commission adopted for population exposure still implied a one third reduction in maximum annual exposures of workers. This fact was recognised by some ICRP members who considered it:

"intolerably restrictive in some atomic energy operations".

In response, the Commission maintained stability by allowing higher exposures to result and adopted a formula devised by the U.S NCRP that allowed some workers to receive up to 12 rems per year. Its old maximum permissible dose had been equivalent to 15 rems per year.

The final form of the Commission's 1958 recommendations was not considered to present "insurmountable" problems for the nuclear industry. Most workers were exposed to levels beneath the old permissible dose.

By the late 1950s the Commission had gradually changed its attitude to the biological effects of radiation. It now accepted that any level of exposure would involve some risk. However, the risk from exposure at the permissible dose was considered to be "not unacceptable". This risk was further justified by judgements over the importance of continued expansion of the nuclear industry. The benefits of nuclear power were a common feature of its discussions during the mid to late 1950s. These judgements were explicitly stated in its 1958 recommendations.

The Commission had begun to adopt a more regulatory approach to the problems of radiation safety. It clearly accepted that the derivation of permissible doses involved non-scientific judgements framed by its view that the expansion of the nuclear industry was desirable. Radiological protection involved a compromise between biological considerations and "reality". The Commission rejected the view that these considerations were outside its competence.

This chapter has described the main changes in the Commission's recommendations and philosophy during the 1950s. During this period dual pressures were exerted on the Commission. First, there was social and

scientific concern over the issue of population exposure leading to demands for reductions in the maximum permissible dose. Second, the was pressure from industry for greater flexibility and stability in the application of the Commission's recommendations. The resolution of these conflicting influences reflected the ICRP's view that the risk of nuclear energy was justifiable by the benefits produced. The value of the maximum permissible dose was reduced satisfying the biological concern. It was renamed the permissible dose thus allowing greater flexibility and maintaining stability in the Commission's system of protection.

CHAPTER 5: FROM PERMISSIBLE DOSE TO ACCEPTABLE RISKS

By the end of the 1950s the Commission had started to adopt a more regulatory framework to its recommendations, which were based upon an explicit balance between biological considerations and the practical needs of industry. An important factor in its adoption of the permissible dose, instead of the maximum permissible dose, was the need to provide stability and flexibility in the application of its recommendations. Considerable scientific uncertainty existed over the risk of exposure to radiation within the Commission's permissible doses. Nevertheless, these risks were viewed as "not unacceptable" in view of the benefits arising from expansion of the nuclear industry.

Throughout the 1960s and 1970s many advances were made in the understanding of the biological effects of radiation which allowed a more precise assessment of risk. In particular, more complete epidemiological surveys of exposed populations, such as the atomic bomb survivors, were published. Although such sources of data were subject to a large number of uncertainties, particularly over the shape of the dose-response model, the Commission was able to estimate the risk from exposure at the permissible dose. The Commission responded to the new data by developing an elaborate system of radiological protection based around the notion of acceptable risks. The main risk of concern was the induction of cancer. Genetic damage was judged to be less important. This system was published in 1977 as ICRP Publication 26. How these recommendations evolved from the Commission's 1959 recommendations is discussed in this chapter.

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5.1: IMPLICATIONS OF A LINEAR DOSE-RESPONSE MODEL

Three main reviews of the biological data were conducted in the early 1960s that were to influence the Commission's thinking during this period. The first was a meeting organised by the ICRP in July 1959 and attended by twelve nonmember "experts" on the somatic and genetic effects of radiation. The proceedings of this discussion were not published[1]. Secondly, there was the second report by the MRC Committee on Hazards to Man of Nuclear and Allied Radiation[2]. This was published in 1960 and was followed two years later by the 1962 UNSCEAR report.

These reviews are particularly important because of the prominence they gave to a series of experiments, conducted by Russell between 1956 and 1960[3], which suggested that the assumption of a linear dose-response model for genetic effects may have been unduly cautious[4]. Russell had observed that less effect would be produced by a dose of radiation given at a low dose-rate, than if it had been given at a high dose-rate.

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[1] Taylor does not discuss the contents of this meeting. However, the conference abstracts are held at the Public Records Office.

[2] Pochin was now the Vice Chair of the Committee.

[3] A geneticist who worked for the U.S Atomic Energy Commission.

[4] Russell W.L (1956) 'Lack of Linearity between Mutation Rate and Dose for X-ray-induced Mutations in Mice', (Abstract) Genetics 41 658-659
Russell W. L, Russell L.B and Kelly E.M (1958) 'Radiation Dose Rate and Mutation Frequency', Science 128 1546-1550
Russell W.L, Russell L.B and Cupp M.B (1959) 'Dependence of Mutation Frequency on Radiation Dose Rate in Female Mice', Proceedings National Academy of Science, United States 45 18-25
Russell W.L and Kelly E.M (1960) 'Mutation Frequency at Low Radiation Intensity', Science 131 1320
Russell W.L and Kelly E.M (1961) 'Mutation Frequency in Mice Exposed to Radiation of Intermediate Dose Rate', (Abstract) Genetics 46 894
Russell W.L (1961) 'Effect of Radiation Dose Rate on Mutation in Mice', Journal of Cell and Comparative Physiology 58 Supplement 1 183-187

These experiments were quickly accepted by bodies such as the MRC Committee[5] and UNSCEAR; who also considered them relevant to the induction of somatic effects.

In its second report, the MRC Committee stated:

> "If these experimental findings are extended and can be taken to be applicable to man, previous estimates of the effects of radiation at low dose-rates based on the assumption that such effects are directly proportional to the total accumulated dose, irrespective of the rate at which it is received, may prove to be too high"[6].

Nevertheless, the Committee considered it "prudent" to continue to assume:

> "that even the lowest doses of radiation may involve a finite, though corresponding low, probability of adverse effect. This may prove to be an unduly cautious attitude, but, in our opinion, it is the only justifiable one in the present state of our knowledge".

UNSCEAR commented that while this data had not disproved the "assumed" proportional relationship between dose and effect, it had

> "in fact made it apparent that such a relationship may not hold at doses lower than those which have been investigated. It is also now more fully recognised that somatic effects are less likely to occur at low dose rates than at the high dose-rates employed in many experiments"[7].

In 1962, ICRP Committee I, now called the Advisory Committee on Biology, recommended that the Commission's recommendations needed revising in the light of the most recent biological information.

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[5] On the Hazards to Man of Nuclear and Allied Radiation.

[6] MRC (1960) The Hazards to Man of Nuclear and Allied Radiations, A Second Report to the Medical Research Council, London: HMSO

[7] UNSCEAR (1962) Report of the United Nations Scientific Committee on the Effects of Atomic Radiation, General Assembly Official Records: Seventeenth Session Supplement No 16 (A/5216), New York: United Nations

Committee I was concerned with several main areas: (i) the implications of a linear dose-response model (ii) dose-rate effects and (iii) the recommendation that exposures should be kept as low as practicable[8].

The revisions were discussed by the Commission during its 1962 and 1963 meetings and published in 1964.

(I) Use of a Linear Dose-Response Model for Somatic Effects.

Committee I had discussed whether a linear dose-response model applied to all somatic effects. It concluded that this was a reasonable assumption to make:

> "This assumption is implicit in past recommendations and although confirmatory proof is lacking, we think it is a reasonable basis for assessment"[9].

This statement was repeated in the Commission's revised recommendations, published in 1964[10].

This assumption implied that even very low doses of radiation produced a proportional level of risk. Committee I recommended that the definition of the permissible dose be further clarified with the following statement:

> "the risk is very small even at the maximum permissible level for occupational exposure"[11].

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[8] Taylor L.S (1979)
[9] ICRP Committee I (1962) Report to the Main Commission, In Taylor L.S (1979)
[10] ICRP (1964) Recommendations of the International Commission on Radiological Protection (As Amended 1959 and Revised 1962), ICRP Publication 6 Oxford: Pergamon Press
[11] ICRP Committee I (1962) Report to the Main Commission, In Taylor L.S (1979)

Muller objected strongly to this suggestion as he did not accept that the risk was small[12]. However, his objection was on genetic grounds. He was not concerned with somatic effects.

Taylor also had expressed reservations over this statement. However, unlike Muller he considered that it was an overstatement; he argued that it had not been proved that there was any risk at all. He suggested that the Commission should state:

> "The basis of the Commission's recommendations is the unproven but conservative assumption that any exposure to radiation may carry some risk"[13].

The statement from Committee I was only slightly amended before publication:

> "The basis of the Commission's recommendations is that any exposure to radiation may carry some risk. The assumption has been made that, down to the lowest levels of dose, the risk of inducing disease or disability in an individual increases with the dose accumulated by the individual, but is small even at the maximum permissible levels recommended for occupational exposure"[14].

The Commission's previous judgement, that this level of risk was considered "not unacceptable", was expanded to include a comparison with other occupational risks:

> "the risks of somatic effects are comparable with or less than those of the majority of other trades and professions, and would therefore be considered as not unacceptable".

Taylor has also objected to this type of comparison:

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[12]Muller H.J (1962) Letter to all Members of the Commission, August 13 1962, In Taylor L.S (1979)

[13]Taylor L.S (1979)

[14]ICRP (1964) Recommendations of the International Commission on Radiological Protection (As Amended 1959 and Revised 1962), ICRP Publication 6 Oxford: Pergamon Press

"As far as I am aware, there has not yet been established any causative relationship between any radiation exposure and any injury. Therefore, we have no basis for saying that the risks are comparable or less than those of other trades"[15].

(II) Dose-Rate Effects

The Committee I discussed the evidence for a dose-rate effect and stated that because of the limited nature of the evidence general conclusions could not be drawn. The revised recommendations simply referred to the evidence and stated that the Commission did not "at present" intend to modify its recommendations[16].

(III) As Low as Practicable and Exposure of the Public

Committee I had also discussed the requirement to keep doses as low as practicable. It considered that this was a reasonable requirement for occupational exposure, but not for exposure of the public. In this case measures to reduce exposure may be *practical* but could not be considered *reasonable*. Committee I recommended that in such situations the risk from exposure to

"radiation should be balanced against the 'social cost' of its avoidance which will vary widely depending upon local conditions"[17].

This meant that it was "inappropriate" to describe any recommendations by the Commission on public exposure as maximum permissible levels.

Committee I considered it essential

"for the Commission to give guidance to national and regional authorities who have responsibilities in this field. For this purpose, limits of exposure should be defined which the

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[15] Taylor L.S (1979)
[16] ICRP (1964) Recommendations of the International Commission on Radiological Protection (As Amended 1959 and Revised 1962), ICRP Publication 6 Oxford: Pergamon Press
[17] ICRP Committee I (1962) Report to the Main Commission, In Taylor L.S (1979)

> Commission recommends should not be exceeded unless careful consideration has been given to the practicability of control measures"[18]

This statement concerned Muller as he believed it implied that the Commission would cease to recommend limits for population exposure. The 1962 Amendments did not discuss this requirement. However, they did note that for accidents and environmental contamination the concept of a fixed maximum permissible dose ceased to have any meaning.

(IV) Exposure of the Foetus

Another subject discussed by Committee I was exposure of the foetus. The Commission's discussions of this are particularly interesting as they illustrate the divisions that existed amongst members of the Commission, particularly between the radiologists and the geneticists.

The Commission had referred to this subject in its 1959 statement, but had not made any specific recommendations. Committee I considered that this statement should be amended:

> "Surveys of leukaemia in children have led to somewhat conflicting conclusions. From the latest material, however, it seems probable that exposure of the fetus in utero to X-rays from medical purposes could somewhat increase the incidence of leukaemia within the following seven years"[19,20]

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[18] ICRP Committee I (1962) Report to the Main Commission, In Taylor L.S (1979)

[19] ICRP Committee I (1962) Report to the Main Commission, In Taylor L.S (1979)

[20] The link between X-ray exposure of the foetus and childhood leukaemia had first been reported by Alice Stewart in 1958.
Stewart A, Webb J and Hewitt D (1958) 'A Survey of Childhood Malignancies', British Medical Journal i 1495-1508
However, by 1962 both the MRC and UNSCEAR had reported that a study conducted by Court Brown and Doll cast doubt on the conclusions reached by Alice Stewart. The Court Brown study had been sponsored by the MRC and had found no evidence of an excess of leukaemia.
Court Brown W.M, Doll R and Hill A.B (1960) 'Incidence of Leukaemia after Exposure to Diagnostic Radiation', British Medical Journal ii 1539-1545

These findings had implications for the medical profession that meant that the

> "direct benefit to the mother of the fetus of any radiological examination"

should be balanced against the "possible hazards" to the child[21].

Committee I recommended that once a pregnancy had been reported to the employer

> "the woman must be regarded as the carrier of a member of the population at large. . . who should not receive a radiation dose in excess of 0.5 rem per year".

This requirement would mean that

> "the woman's duties should be arranged so that the radiation dose to the fetus from internal and external exposure of the mother from occupational exposures does not exceed 0.05 rem per month".

The Commission did not accept this suggestion; it considered that practical difficulties would arise in some areas of work. The radiologist members of the Commission were particularly against the proposal. Stone, a radiologist and former director of the Manhattan Project Health Division, commented:

> "Until we have more positive evidence that real damage may be done, we should not upset the whole nuclear sciences and industry by putting the level of exposure for pregnant women so low that we cannot monitor the exposure accurately to say nothing of the absorbed dose to the fetus! Any woman worker whose baby is born deformed in any way or develops a childhood malignancy could sue her employer for over-exposure and claim that his monitoring was not accurate enough to detect the radiation received by the child - if we put through the proposed recommendation"[22].

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[21] ICRP Committee I (1962) Report to the Main Commission, In Taylor L.S (1979)

[22] Stone R.S (1962) Working Paper for ICRP 1962 Ottawa Meeting. - ICRP/62/16 - Appendix 1, August 8th 1962, In Taylor L.S (1979)

The final wording of the revised recommendation stated:

> "The Commission now recommends that women of reproductive age should be occupationally employed only under conditions where the exposure of the abdomen is limited to 1.3 rems in a 13 week period, corresponding to 5 rems per year delivered at an even rate. Under these conditions the dose to an embryo during the first two months of pregnancy would normally be less than 1 rem, a dose which the Commission considers to be acceptable"[23].

When a pregnancy has been diagnosed the Commission recommended:

> "arrangements be made to ensure that the exposure of the woman be such that the average dose to her fetus during the remaining period of the pregnancy does not exceed 1 rem".

This requirement would be met if the exposure of the woman was limited to rates equivalent to 1.5 rems per year.

This issue was also discussed concerning the exposure of the foetus to medical irradiation and what was to become known as the ten day rule. This required that radiological examinations, involving abdominal or pelvic exposure, be limited to the two weeks following the onset of menstruation. In this period it was considered unlikely that the woman would be pregnant and so irradiation of the foetus would be avoided[24].

This suggestion provided a source of conflict between some of the Commission members. This conflict has been described by Taylor as "running argument" between members with different professional or disciplinary affiliations. On one side, were the practising radiologists, Stone and Holthusen. On the other, were "scientists",

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[23] ICRP (1964) Recommendations of the International Commission on Radiological Protection (As Amended 1959 and Revised 1962), ICRP Publication 6 Oxford: Pergamon Press

[24] ICRP (1963) Exposure of Women of Reproductive Age, Appendix 1 ICRP 63/MC/11, 16 January 1963, In Taylor L.S (1979)

especially Muller, a geneticist, and Morgan, a physicist. Taylor describes himself as "in between", a radiological physicist.

Stone opposed the proposal on the grounds that it was unduly restrictive. He did not consider it likely that damage would be caused. Conversely, Morgan considered that if the ICRP did not make any recommendations it would be shunning its responsibilities:

> "Most of the radiation exposure of the population derives from medical sources and if the ICRP is to concern itself solely with sources that contribute only a few percent of this dose and to the offering of very general and useless advice to the physician, I cannot believe we have carried out our responsibility as we should and, in such case, we should move aside and turn over this responsibility to some other organisation"[25].

Muller agreed with Morgan:

> "The excessive delay and negligence of the medical profession in matters of radiation protection, until with the advent of nuclear weapons hysterical public pressure was applied throughout this field, demonstrates clearly the need for reasonable advice on the subject, from outside as well as inside medical circles. In this connection it should also be remembered that the ICRP has been commissioned by the radiologists themselves to advise them in this field, and that it therefore owes the radiologists an especial responsibility to provide them with adequate guidance. The fact that to some of them this guidance seems impalatable serves rather to increase than to lessen this responsibility on our part"[26].

Stone agreed that it was the Commission's responsibility to offer advice to the medical profession. However, he also considered that the "vituperative attacks" made on the profession increased its resistance to change. He wrote to Muller stating:

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[25]Morgan K.Z (1963) Letter to F.D Sowby, Scientific Secretary ICRP, January 15th 1963, In Taylor L.S (1979)

[26]Muller H.J (1963) Letter to F.D Sowby, January 17th 1963, In Taylor L.S (1979)

"I would go even further and say that your attacks on the medical profession to lay audiences have probably resulted in the prolonged suffering and even death of many people. Your interest in future generations has outweighed your consideration of the present generation"[27].

Stone later wrote to all members of the Commission and stated that:

"I am not against making recommendations to the medical profession, but if we make recommendations that result in more troubles rather than getting away from troubles, then we will lose their respect"[28].

In an attempt to reconcile the different opinions Pochin suggested that the ten day rule only apply when this can be done

"without loss of the necessary and urgent clinical information".

The final recommendation stated that radiological examinations should only be delayed if they were

"not of importance in connection with the immediate illness of the patient"[29].

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5.2: ASSESSING RISKS FROM EXPOSURE TO RADIATION

At the beginning of 1963 the Commission and its Committees[30] began planning the next set of recommendations; although at this time the 1962 amendments were still being discussed. The new recommendations were redrafted several times and were published in 1966 as ICRP Publication 9.

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[27] Stone R.S (1963) Letter to H.J Muller, 21 February 1963, In Taylor L.S (1979)

[28] Stone R.S (1963) Letter to E.E Pochin and all Members of the Commission March 19, 1963, In Taylor L.S (1979)

[29] ICRP (1964) Recommendations of the International Commission on Radiological Protection (As Amended 1959 and Revised 1962), ICRP Publication 6 Oxford: Pergamon Pres

[30] These had been reorganised into four Committees: Committee 1, Radiation Effects; Committee 2, Internal Effects; Committee 3, External Exposure and Committee 4, Application of Recommendations.

As part of this process Pochin[31] and Sowby[32] prepared a list of subjects that the Commission need to consider. This included the need to assess the risk of radiation and compare it with other hazards.

(I) The Magnitude of Risk for Somatic Effects

In 1963 Committee 1 prepared a report for the Commission setting out its views on radiation protection. This reemphasised its earlier suggestion that a linear dose-response model be adopted for somatic effects.

When this was discussed several members of the Commission objected to its contents. Stone objected to the statement that no dose of radiation is without risk and that a threshold cannot be assumed to occur for radiation injury[33]. He considered that both statements would be proved incorrect.

(a) Methods of Expressing the Risk

A year later a revised version of the report was circulated for more detailed discussion. This discussed how estimates of risk could be expressed; suggesting that risks should be stated in orders of tens. A risk of death to one person in ten would be called a first order risk, whereas a risk of death to one person in a hundred thousand it would be called a fifth order risk. This proposals had been present in the first report. As an illustration the risk of leukaemia was compared with the risk of motoring:

> "Data from Hiroshima suggest that 100 rem would give rise to about 1 case per 10,000 exposed to this dose each year up to 15 years. On this basis the risk would be about $15/10^4$ per

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31 A medical doctor who was chair of the Commission. Pochin was also chair of the MRC PIRC.

32 Scientific Secretary of the Commission.

33 Stone R.S (1963) Letter to Members of Main Commission October 18, 1963, In Taylor L.S (1979)

lifetime, ie a risk of the third order. This might be contrasted with the risk of death to motorists, which in some countries appears to be of the second or third order, ie, an average of $7/10^4$ for each year of a lifetime"[34]

Committee 1 judged that the risk faced by radiation workers was not greater than the fourth order:

> "If we accept the ICRP statement on the level of risk for occupational workers, and there is at present no evidence against it, the risk of severe somatic injury at maximum permissible occupational levels is such that it would be detectable only by statistical methods applied to large groups, which may be taken to mean the risk is not greater than 1/10000, ie of the fourth order. For exposure from environmental sources the radiation-doses will in most cases be less than occupational values by an order of magnitude and the associated risk can therefore be stated then as no greater than the fifth order".

The second draft of the Commission's recommendations was discussed at the London meeting of the ICRP in January 1964. The 1962 amendments still had not been published. This meeting formally approved a proposal from Loutit, chair of Committee I, that a Task Group be formed to consider questions of risk estimation. The terms of reference of this group were:

> "to consider the extent to which the magnitude of somatic and genetic risk associated with exposure to radiation can be evaluated and to study the relevance, to protection measures, of the number and category of individuals exposed"[35]

The second draft of the recommendations suggested that the risk from radiation exposure could be illustrated by calculating the number of somatic effects that would occur in a population of one million exposed to a dose of 0.5 rems. Morgan agreed that the Commission should attempt

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[34] ICRP Committee 1 - Advisory Committee on Biology (1962) Advice tended to International Commission on Radiological Protection, (A revision of ICRP 62/S-16 and ICRP/63/MC-28), May, 1962, ICRP/64/MC-1, 6 January 1964, In Taylor L.S (1979)

[35] ICRP (1964) Minutes of the Commission Meeting in London, January 1964, ICRP/64/MC-7 13th February, 1964, In Taylor L.S (1979)

to quantify the risk. However, he did not accept Taylor's estimate of ten cases per million and considered that the Commission

> "might be subject to some criticism if we use the lowest figure published in the literature relating leukemic incidence to dose"[36].

Morgan suggested alternative values not for publication, but as "a sobering thought" for the Commission's discussions:

Table 2: "Possible Consequences to Large Population if Permitted to Receive on an Annual Basis the Maximum Permissible Dose (0.5 Rad Per Year) as Recommended by the ICRP"[35]

Type of Radiation-Induced Death	Radiation Deaths per million	Radiation Deaths in World Population
Leukaemia	10-100	$3 \times 10^4 - 3 \times 10^5$
Bone Tumours	10-100	$3 \times 10^4 - 3 \times 10^5$
Genetic Death	50	1.5×10^5
Life Shortening	30	9×10^4
Total	100-300	$3 \times 10^5 - 10^6$.

The response of the Commission to Morgan's concern is not known. Its 1965 recommendations repeated the statement that the expected incidence was 10 cases per year per million exposed to 0.5 rads.

(b) Comparing Radiation Risks with other Hazards

The draft recommendations also further developed the notion that the risk from radiation could be compared with that faced in other occupations. Taylor was against this, as he considered it represented a shift in the ICRP's philosophy, since

> "In the past it has been based upon 'no deleterious effects'. Now it appears to be based on risk no greater than for other occupations. This carries quantitative limitations which I am afraid will be baffling. . . the implication is that the

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[36]Morgan K.Z (1963) Untitled comments on draft ICRP recommendations, In Taylor L.S (1979)

Commission has really made a quantitative study of other occupational risks but I do not think it has done so"[37].

(c) The Necessity of a Philosophy Based Upon Acceptable Risks

A third draft of the Commission's recommendations was circulated to all members of the Commission and its Committees for comment. The comments of Forest Western, a member of Committee 4[38], were based upon discussions with his colleagues at the U.S Atomic Energy Commission.

Taylor has commented that Western's criticisms were particularly interesting; as through working for both the U.S Federal Radiation Council and the Atomic Energy Commission

> "he had developed a high sensitivity and sense of objectivity relative to the concepts involved in radiation protection"[39].

Western considered that it would be "unfortunate" if the Commission allowed readers to draw the conclusion that a linear dose-response existed at low dose rates. He wished to avoid giving the impression that the risk at low doses was "much larger" than "we have reason to believe". Consquently, he argued, the Commission should emphasise that it was an assumption. He accepted that the Commission could not assume that there were threshold doses for somatic effects; but he doubted if

> "any considerable fraction of the Commission would believe that the best estimate of the probability of leukemia from a whole body dose of one rad, received over a period of months as the result of cesium 137 in the body, could be best estimated by linear extrapolation from observations made in any of the well-known leukogenic studies. The rapidly increasing evidence of the importance of dose rate provides a

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[37]Taylor L.S (1963) Untitled comments on Draft ICRP Recommendations, In Taylor L.S (1979) On the Application of the Commission's Recommendations.
[38]Taylor L.S (1979)

strong contribution to the incredibility of such an assumption"[40].

On the other hand, Western emphasised that the development of the concept of acceptable risk was a necessary consequence of the assumption that no threshold exists. This required the Commission to consider carefully what makes a risk acceptable.

(d) Accumulating Higher Risks

Western had also discussed the accumulated dose formula. He considered that it was

> "completely out of line with the principles and objectives described in this report. It is not, of course, designed to protect the employee but for the advantage of the employer. But, unless one assumes the existence of some threshold above the dose specified by the equation, it cannot be supported. Perhaps the best that can be said for it is that employers seldom use the advantage that it purports to give them".

He gave the example of a man employed at age 28 with no previous occupational exposure:

> "under the formula his employer is privileged to expose him to radiation at a rate of from 10 to 12 rems per year for a period of 5 years. The formula contemplates an average exposure of 5 rems per year. There can be no justification for permitting an employer to increase the risk under which an employee works simply because in the past year he has worked at a lower risk".

Taylor, who had originally devised the formula, disputed this. He considered that the reasoning behind the dose formula was "perfectly sound" and that its primary objective was to prevent "radiation exposure abuse"[41].

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[40] Sowby F.D (1965) Survey of Comments on Draft of 1965 Recommendations, ICRP/65/MC-11, In Taylor L.S (1979)

[41] (ICRP (1965) Additional Comments on Third Draft of 1965 Recommendations, ICRP/65/MC-13, In Taylor L.S (1979)

(II) The ICRP's 1965 Recommendations

The final draft of the Commission's recommendations was agreed at the Fiuggi meeting in September 1965 and were published as ICRP Publication 9. A second report was also published in 1965 on the Evaluation of Risks from Radiation. This was the report of the Task Group established under Committee 1.

The new recommendations of the ICRP redefined the objectives of radiological protection as to prevent acute radiation effects and to limit the risks of late effects to an "acceptable level"[42].

(a) The Concept of an Acceptable Dose

ICRP 9 recommended the use of a linear dose-response model as a "practical alternative" did not exist. However, it emphasised that this assumption was conservative. The Commission redefined the term permissible dose as an *acceptable dose*:

> "unless man wishes to dispense with activities involving exposures to ionising radiation, he must recognise that there is a degree of risk and must limit the radiation dose to a level at which the assumed risk is deemed to be acceptable to the individual and to society in view of the benefits from such activities. Such a dose might be called an acceptable dose, with the same meaning as was implied by 'permissible dose'"[43]

The Commission noted that the concept of Maximum Permissible Dose had involved a considerable element of judgement. Nevertheless, it proposed until there was a better understanding of the risks of radiation, to retain the term for occupational exposure. For "planned exposures" of

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42 In 1959 the ICRP had stated that the objectives of radiation protection were to prevent or minimize somatic injuries and to minimize the deterioration of the genetic constitution of the population.

43 ICRP (1965) Recommendations of the International Commission on Radiological Protection (Adopted September 17, 1965), ICRP Publication 9 Oxford: Pergamon Press

individual members of the public, and of populations, the Commission recommended the use of the term *dose limit*.

As any exposure may involve some risk, the Commission recommended that unnecessary exposure be avoided and that

> "all doses be kept as low as is readily achievable, economic and social considerations being taken into account".

(b) Hazards of Occupational Exposure

For occupational exposure, under non-emergency conditions, the Commission explained that it was "desirable" and "reasonable" to set specific dose limits so that,

> "the associated risk is judged to be appropriately small in relation to the benefits resulting from the practice".

For those occupationally exposed the Commission judged that the

> "hazard should not exceed those that are accepted in other industrial or scientific occupations with a high standard of safety".

The Commission recommended an annual maximum permissible dose of 5 rems per year; up to one half of this could be accumulated in any quarter of the year. The Commission further stated:

> "It may sometimes be necessary to provide flexibility for the Maximum Permissible Dose. . . In such cases. . . It will be justifiable to permit the quarterly quota to be repeated in each quarter of the year".

This statement was qualified with the requirement that the accumulated dose was limited in accordance with the Commissions formula, $D=5(N-18)$[44].

However, the Commission did not consider that there was any "justification" for any additional limitation on the accumulated lifetime

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[44]See Chapter 4 Section 4.6 (IV) a and Section 4.7 (I) b.

dose; even though it recognised that any worker annually exposed at the permissible dose could accumulate a lifetime dose of "hundreds" of rems.

The Commission also recommended maximum permissible doses for individual organs[45]. No explanation was given for how the different permissible doses, for the whole body and individual organs, had been derived.

(c) Justification for Exposure of the Public

The Commission considerably simplified its categories of non-radiation workers. These were simply described as members of the public:

> "It is not desirable to expose members of the public to doses as high as those considered to be acceptable for radiation workers; members of the public include children who might be subject to an increased risk and who might be exposed during the course of their lifetime; members of the public (in contrast to radiation workers) do not make the choice to be exposed, and they may receive no direct benefit from the exposure"

For "planning purposes" the Commission considered it "appropriate" to set the dose limits a factor of ten below those for radiation workers. It emphasised that dose limits for members of the public had to be recognised as

> "a some-what theoretical concept, intended for planning purposes, and that it will seldom be possible to ensure that no single individual exceeds the dose limit".

The Commission also judged that the

> "risk to members of the public from man-made sources of radiation should be less than or equal to other risks regularly accepted in every-day life, and should be justifiable in terms of benefits that would not otherwise be received".

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[45]These were: For the gonads and red bone marrow (the *critical organs*) 5 rems per year; Skin, thyroid and bone 30 rems per year; Hands and forearms, feet and ankles 75 rems per year; All other organs 15 rems per year.

The U.S members had opposed the adoption of the term *dose limits* for members of the public but had been overruled by a vote of the Commission[46].

(d) Population Exposure

For exposure of populations the Commission retained its "provisional limit" of 5 rems per generation for the genetic dose to the whole population. It stated that it believed that;

> "this level provides reasonable latitude for the expansion of atomic energy programs in the foreseeable future".

The Commission also emphasised that:

> "the limit may not represent a proper balance between possible harm and probable benefit, because of the uncertainty in assessing the risks and the benefits that would justify the exposure".

(III) The Evaluation of Risks from Radiation Exposure

The report of the Committee I Task Group on the "Evaluation of Risk from Radiation" was published in 1966 as ICRP Publication 8[47]. Several members of this Task Group were also national delegates to UNSCEAR[48], so it is not surprising that both groups produced similar discussions on radiation carcinogenesis. However, there were some "discrepancies"

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[46] Taylor L.S (1979)

[47] ICRP (1966) The Evaluation of Risks from Radiation, A Report prepared for Committee 1 of the International Commission on Radiological Protection, ICRP Publication 8 Oxford: Pergamon Press

[48] The members of the task group were: Russell R.S*; Doll W.R.S (epidemiologist); Dunster H.J (physicist with UKAEA); Eldjarn L; Koller P; Lamerton L.F*; Lindell B* (physicist with Swedish National Institute of Radiation Protection); Loutit J.F (medical doctor with MRC Radiobiological Research Unit, AERE); Newcombe H.B* (geneticist with Atomic Energy of Canada Ltd); Pochin E.E* (medical doctor, academic and MRC PIRC); Sowby F.D (ICRP Scientific Secretary) and Stevenson A.C.
Member marked * were also members of national delegations to UNSCEAR.

between the draft Task Group report and the UNSCEAR 1964 report[49] that were "removed" before publication[50]. The nature of these discrepancies is not known.

(a) Estimate of the Leukaemia Risk

Both reports cited the findings of the Atomic Bomb Casualty Commission up to the end of 1958[51]. It had been concluded that the annual leukaemia incidence was 1-2 cases per million per rad, a figure supported by studies of the ankylosing spondylitics. This led the ICRP Task Group to suggest that the total leukaemia risk was about 20 excess cases per million persons per rad.

This estimate was clarified with the statement:

> "Longer periods of observation may suggest that this is an underestimate for high dose rates. However it may be an overestimate for low dose rates"[52].

For other adult malignancies the epidemiological data was insufficient to enable an estimate to be made, although the Task Group suggested it would approximate to the leukaemia rate.

The Task Group considered that the rate of leukaemia arising from in utero exposure would be five times this. This conclusion was also

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[49] UNSCEAR (1964) Report of the United Nations Scientific Committee on the Effects of Atomic Radiation, General Assembly Official Records: Nineteenth Session, Supplement No 14 (A/5814) New York: United Nations

[50] Taylor L.S (1979)

[51] This was conducting the studies of mortality among the atomic bomb survivors.

[52] ICRP (1966) The Evaluation of Risks from Radiation, A Report prepared for Committee 1 of the International Commission on Radiological Protection, ICRP Publication 8 Oxford: Pergamon Press

supported by the UNSCEAR report: since the 1962 report several studies had been produced that supported Stewart's findings[53].

(b) The Risks of Radiation Work Compared

The Task Group also attempted to compare the risk of radiation work with that in other industries. The comparison was not based upon the risk at the occupational permissible dose, but at a dose five times lower:

> "some basis of comparison is provided by the fact that occupational accidents cause annually some 100 - 200 deaths per million males in the age group 20 to 64 employed in all occupations in England and Wales, ie a fourth order risk; in certain occupations the risk is of the third order. These risks of death may be compared with the fifth order risk of death from somatic injury estimated from exposure to 1 rad per year".

(IV) Deriving Permissible Doses from Assessments of Risk

The Commission's 1966 recommendations, and Publication 8, were its first attempt to quantify the risk from radiation exposure. Its permissible doses, although defined as producing an acceptable risk, had not been derived from an analysis of risk. Equally, there was no relationship between the permissible dose for whole body exposure and that for the critical organs. The organ limits for the gonads and the red bone marrow was the same as the permissible dose for whole body exposure.

This contradiction was addressed in a conference paper by Pochin, the chair of the Commission, in 1966. Pochin commented:

> "One of the most important functions of the International Commission on Radiological Protection, and certainly one of the most difficult, must be its assessment, quantitatively, of the maximum levels of dose or dose rate that can be regarded as permissible, but which should not be exceeded,

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[53] UNSCEAR also observed that in 1962 Dr Alice Stewart's data was considered "controversial".

under various particular circumstances of necessary exposure to ionising radiation"[54].

Pochin considered that this judgement was "central" to all protection requirements. He added

> "Yet is doubly difficult to make if we need to envisage the possibility of occasional radiation damage even at the lowest doses and doses rates, since we must then review, not only the numerical level of risk from various possible injuries at low doses, but also levels of risk that could be regarded appropriate for various circumstances of occupational or other exposure".

The first was

> "a radiobiological judgement that has to be made in the absence, fortunately, of any direct statistical evidence as to the harmfulness to man of radiation at low doses or dose rates".

Whereas, the second was

> "a sociological judgement as to the right criteria of safety and limitation of hazard, a subject on which the community offers remarkably little direct opinion, at least in the necessary quantitative terms, although it is evident in principle that the risks should be minimized, or eliminated if practicable".

Pochin discussed the lack of a direct relationship between the whole body permissible dose and the organ limits. If the two were to be related in a quantitative system the following question had to be answered:

> "what dose rates for each tissue will ensure a degree of safety to the worker equal to that involved when *all* the organs or tissues are equally exposed at 5 rem/year?".

He considered that this question was difficult

> "to resolve in the necessary quantitative way".

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[54] Pochin E.E (1968) 'Permissible Doses for Critical Tissues', In Proceedings of the International Congress of Radiation Protection, Rome, Italy September 5-10, 1966, Part 1 11-14, Edited by Snyder W.S et al Oxford: Pergamon Press

He suggested that three assumptions "might be appropriate" for relating individual organ limits to whole body exposure:

> "Firstly, that the hazard of whole body irradiation is simply the total of the hazards of the radiation of its constituent tissues. . .
>
> Secondly, that within the range of doses or doses rates applicable to permissible dose limits, the frequency of harmful effects is about proportional to the dose or dose rate. . .
>
> Thirdly, that dose limits for individual tissues, when irradiated singly, or for the whole body, when uniformly irradiated, are set so that the risk from any of the these modes of exposure is equal in magnitude".

He suggested that if these assumptions were accepted, the first problem would be to consider "the relative total importance" of somatic effects and genetic damage. He judged that this question "could never" be answered by a simple quantitative comparison; adding that "some opinion" must be expressed.

These issues were also addressed by two Task Groups formed in 1965 under Committee 1[55] as

> "part of the Commission's continuing review of information intended to provide scientific bases for its recommendations"[56].

Draft reports from the Task Groups were discussed in 1967, approved for publication in 1968 and published together in 1969. The nature of the discussions is not known. However, both reports made several suggestions for how the permissible dose could be related to the risk it produced.

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[55] These were the Task Groups on the "Relative Radiosensitivities of Different Tissues" and on the "Spatial Distribution of Dose".

[56] ICRP (1969) Radiosensitivity and Spatial Distribution of Dose Reports prepared by two task groups of Committee 1 of the International Commission on Radiological Protection, ICRP Publication 14, Oxford: Pergamon Press

The report of the Task Group on the "Spatial Distribution of Dose" was concerned with exposure of individual organs[57]. This took Pochin's arguments further and suggested that any system based on risk would need to equate the different types of effect. This implied

> "the acceptance of some common scale of 'hurt or suffering'".

However, such a scale did not exist.

This Task Group considered that the limitations in the available biological information meant that it was

> "evident that at the present time risk considerations can at best play only a very general role in specific recommendations such as those for non-uniform exposure, and that operation and administrative convenience must of necessity often be of equal importance"[58].

The Task Group considered that the current ICRP recommendations did not provide a self-consistent scheme. If the recommendations were based upon assumptions of risk, it would be logical to assume that whole body exposure would produce a greater risk than when the same dose was received by single organs:

> "Yet the dose limit of bone marrow is the same as that for the whole body".

This contradiction was also addressed by the second Task Group on the "Relative Radiosensitivity of Different Tissues"[59]. Its report disregarded the "historical" reasons for a particular "dose limit" and

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[57] The members of this Task Group were: Lamerton L.F; Barendsen G.W; Brues A.M; Dolphin G.W; Müller J; Smith E.E and Vaughan J.

[58] ICRP (1969) Radiosensitivity and Spatial Distribution of Dose Reports prepared by two task groups of Committee 1 of the International Commission on Radiological Protection, ICRP Publication 14, Oxford: Pergamon Press

[59] The members were Mole R.H; Betz E.H; Cottier H and Upton A.C.

attempted to derive a "rational system" based upon the radiosensitivities of individual tissues. It commented that it

> "seems to be the implicit intention of ICRP recommendations that the damage resulting from exposure of one organ or tissue to its dose limit should be approximately the same as the damage of comparable importance resulting from exposure of a second organ or tissue to its dose limit"[60].

This Task Group also suggested a common scale of damage was required:

> "One common scale of quantitative measurement for all cancers might be the amount of life-shortening and on this scale one case of leukemia would be equivalent to several cases of thyroid cancer"[61].

This scale was not considered a satisfactory basis of assessment:

> "But length of life with cancer is no measure of the quality of life or of the amount of suffering experienced by the individual or his family".

It considered that the "inescapable" conclusion was that the

> "only common scale against which all kinds of somatic and genetic damage might be quantified is a scale of hurt or suffering".

The Task Group considered that the concept of "the critical organ" used in ICRP 9 did not allow for the summation of risks from exposure of different parts of the body. Such a summation was "surely" necessary if a proper assessment of the risk of radiation exposure was to be made.

The Task Group hesitated in making "concrete" suggestions for change. Insufficient biological data were available to devise a system completely based upon the risk of deleterious effects occurring in each tissue; although it suggested than an alternative to leaving the system as it was

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60 ICRP (1969) Radiosensitivity and Spatial Distribution of Dose Reports prepared by two task groups of Committee 1 of the International Commission on Radiological Protection, ICRP Publication 14, Oxford: Pergamon Press

61 Not all thyroid cancers are fatal.

would be to make a partial change and revise it as new information became available.

It considered that the choice between these two options depended

> "not only on a scientific assessment of evidence, but also on practical considerations, such as the general desirability of stability in the recommendations over a period of years".

This statement confirms the Commission's implicit objective of maintaining stability in its recommendations in response to scientific uncertainty[62].

The balance between practical considerations and incomplete scientific evidence was outside the Task Group's terms of reference.

In an Appendix to the report it suggested a scheme where the whole body dose limit was derived from the frequency of somatic effects occurring in individual organs. For this system, the dose limit for the red bone marrow was taken as the reference limit[63]. All other dose limits were stated as multiples or fractions of this figure.

In the assessment all malignancies were regarded as equally "hurtful" except for skin cancer and thyroid cancer; both of which were predominantly non-fatal. In deriving dose limits in absolute terms, the levels were

> "set by the acceptable risk as measured by amount of hurt or suffering".

Acceptability, or the "balance between harm and benefit" was not considered.

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[62] See Chapter 4.
[63] The task group considered that the risk of leukaemia induction per rem in red bone marrow was the "best established" at that time.

The table below shows the derived limits compared with the limits in ICRP Publication 9. The later figures were divided by 1/5th to allow direct comparison:

Table 3: Comparison of Derived Limits from ICRP Publication 14 with the Permissible Doses in ICRP Publication 9

Tissue	Derived Limit	ICRP 9 Limit/5
Red Bone Marrow	1	1
Thyroid	3	6
Group II[64]	3	3
Group III[65]	10	{Others 3 {Bone 6
Skin	100	0.6
Group IV[66]	10	3

The Task Group considered that its derived limits, except for the skin, agreed with the current values to within a factor of two or three. On the other hand the limit for the skin was high. This illustrated an important point; that where the sensitivity of a particular part of the body to tumour induction was low, the risk of cancer was not the most important somatic effect.

The Task Group calculated that the dose limit for whole body exposure should be about five times less, or 0.14-0.17 of its notional units, than red bone marrow exposed on its own. The Task Group also commented that it was impossible, due to limitations in the biological data, to include genetic effects in this scheme.

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[64] Organs classified as either having an "apparent" sensitivity to radiation ie Lymph nodes and reticular tissues; or organs with "uncertain" sensitivity ie Pharynx; Bronchus (lung cancer); Pancreas; Stomach; Large Intestine.

[65] Organs classified as having a low sensitivity to radiation. These include Larynx; Oesophagus; Small intestine and Bone.

[66] Organs not classified including Ovary; Uterus; Breast; Prostate and Bladder.

This scheme was not put forward as a definite recommendation, but to provide an example, for discussion, of the derivation of dose limits from the available information. The exact magnitude of the dose limit could not be decided because of insufficient "empirical evidence" on hereditary effects and the lack of "extra-scientific judgements" about the relative importance of hereditary effects and cancer.

The Task Groups suggestions implied either a reduction in the whole body limit, compared to the limit for the bone marrow, or an increase in the red bone marrow limit.

In May 1970 the Commission established another Task Group to consider the proposals in ICRP Publication 14. This Task Group was to produce a report for consideration by the ICRP only and was not for publication[67].

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5.3: SOCIAL AND SCIENTIFIC JUDGEMENTS IN ASSESSMENT OF RISK

The incomplete nature of the biological data and the element of "judgement" involved in making recommendations posed many problems for those with responsibilities for devising radiological protection standards. These standards were widely viewed as scientifically determined.

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[67]This task group consisted of Beninson D.J (Task Group Chairman, a medical doctor working for the Argentine Atomic Energy Commission); Dunster H.J (a physicist working with the Radilogical Protection Division of the UKAEA); Mechali D; Mole R.H (a radiobiologist); Pochin E.E (Chair of ICRP and MRC PIRC and Director of Clinical Research, University College Medical School); Snyder W.S and Sowby F.D (Scientific Secretary of ICRP).

(I) Scientific Basis of Safety Standards

These problems were discussed in a memorandum prepared by ICRP Committee 1 in April 1969. This commented that in the formulation of previous standard the main difficulty had been the lack of quantitative data. However, it was considered evident that some problems

> "cannot be overcome by research and that the further proliferation of data could create an unrealistic impression of reliability in protection methods"[68].

The Committee considered that it was impossible to estimate many quantities required for protection. This meant that

> "now and in the future we must rely on intelligent guesses or 'value judgements'".

The estimation of risk was an "obvious" example of this problem. The Committee was concerned that the Commission had implied that future research would resolve these uncertainties. For instance, ICRP 9 had stated that the relationship between dose and risk was not known with precision, "at present"; implying that in time it would understand the relationship with more certainty. The Committee considered that the ICRP 8 had been more realistic in its approach to risk assessment. This had stated it was unrealistic to expect, in the foreseeable future, that the limitations in estimating risks at very low doses would be resolved.

This led the Committee to ask if the Commission should

> "consider whether it is desirable to acknowledge openly . . . That protection criteria especially when applied to individuals, which are capable of practical implementation, can never have a completely scientific basis".

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[68] ICRP Committee 1 (1969) Uses and Limitations of Further Refinements of Data for Purposes of Protection, ICRP Committee 1, 17th April 1969, ICRP/69/0:C-13, In Taylor L.S (1979)

The Committee also judged that a major difficulty in discussing these problems was the "personal-bias" of the members of the ICRP. It was felt that many members were too closely involved in particular areas of research to be able to judge the extent to which further refinement of the biological data was advantageous. It was thought that scientists from other disciplines "might" have a useful contribution to make.

The Commission rejected this document as the basis of its future work. Many members felt it implied a too passive and negative role for the Commission. Taylor comments, that it was also pointed out that rather than refinement of existing data, there was still a real need for basic quantitative data[69].

(II) Alternative Social and Scientific Judgements in Assessment of Risk

Soon after the publication of ICRP Publication 14 the Commission became involved with a controversy over the risk of exposure to radiation at low doses. This took place in the United States between Drs Gofman and Tamplin and the Atomic Energy Commission. Gofman and Tamplin believed that the U.S Federal Radiation Council (FRC) standards underestimated the risk from radiation at low doses. These standards were based upon and the recommendations of the NCRP and ICRP. The FRC had recommended an average dose limit for the population of 0.17 rads. Gofman and Tamplin considered that this should be reduced by a factor of ten.

Gofman and Tamplin's claims were not based upon new data but on their interpretation of the data in ICRP Publication 14. This was noted in a circular sent to all Commission members by the ICRP's scientific secretary, F.D Sowby. This stated that information in ICRP 14 had been

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[69]Taylor L.S (1979)

used to calculate a risk estimate, for leukaemia induction plus other malignancies, of 598 to 944 per million per rad. This value was considerably higher than the figure recommended either by UNSCEAR or the ICRP.

The implication of this risk estimate meant that a worker receiving an occupational lifetime dose of 200 rems (whole body exposure) would incur a 12-19% risk of developing cancer. This meant that for workers exposed at the Commission's limit, between one and eight and one in five radiation workers could be expected to develop cancer.

Sowby considered that was an

> "astoundingly high occupational risk, only approached by the risk of accidental death among nineteenth-century coalminers (15%) or present-day deep-sea fishermen (10%)"[70].

He commented that the risk was also high for workers exposed within the limit:

> "At the present time, actual occupational exposure are perhaps about one-tenth of the dose limit, but, according to the above risk estimates, even this involves a risk of about 1-2%, which itself is rather high in comparison with the risks of "safe" occupations".

Sowby did not accept that these risk estimates were realistic. He concluded that:

> "if the cancer risk from a lifetime exposure of 200 rems was really as high as 19%, this would surely have been evident by now".

This debate ran for several years and became increasing acrimonious with both sides making attacks and counter attacks on the others reputation.

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[70] Sowby F.D (1970) Letter to Commission Members, 31st March 1970. In Taylor L.S (1979)

The Commission was not directly involved as an organisation, and in 1970 chose not to become involved in issues that were regarded as national controversies. Several of its members, including Taylor and Dunster, were involved and appeared at U.S Senate hearings to testify against Gofman and Tamplin[71].

One member of the ICRP, Bo Lindell, was concerned with the way the ICRP had responded to Gofman and Tamplin and its other critics. In 1971 he wrote to Sowby complaining:

> "we react like mechanical puppets or like insects shown a stimulus triggering aggressive reactions, when we are faced with statements or ideas which are not branded with the mark of the old truth. Should we not instead be curious and appreciative?"[72]

Lindell clearly recognised the importance of the public perception of ICRP. The social circumstances under which the ICRP functioned were rapidly changing; support for the nuclear industry was beginning to be questioned. If the ICRP was to maintain its reputation it could not afford to simply dismiss all criticism as irrelevant.

While he did not agree with Gofman or Tamplin over their proposal for a nuclear power station moratorium, or for a permissible dose of "zero", he did not consider that this was totally ridiculous:

> "Those who have listened know that the Gofman-Tamplin proposal is meant to be a radical shift from the present situation where everything is permitted as long as the MPD is respected, even if the use of radiation is entirely unnecessary (unless paragraph 52 is enforced) or against the

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[71] Taylor's account of this period makes plain his dislike of Gofman and Tamplin. For instance, he described their testimony before the Subcommittee on Air and Water Pollution of the Senate Committee on Public Works as "a masterpiece of obdurate obfuscation and a strange mixture of facts used out of context and employing calculations based on unproven assumptions".

[72] Lindell B (1971) Letter to F.D Sowby, November 25 1971, In Taylor L.S (1979)

> interest of most other people, to a new situation where nothing is permitted until the prospective user of a radiation source has convinced the society that the benefits outweigh the risks. In that system there would be no room for MPD's, the authors feel, MPD's being licenses to kill".

Paragraph 52 was the requirement, in the ICRP's 1965 recommendations, that

> "any unnecessary exposure be avoided, and that all doses be kept as low as is readily achievable, economic and social considerations being taken into account"[73].

Lindell added that he had

> "heard many proposals which have been more stupid and I am ashamed on behalf of the established radiation protection club that we have not been willing to engage in a constructive discussion. I think that the G-T proposal is a beautiful thought but I also think that it is naive and premature in the present world where nothing is governed by such philanthropic rules. And further, I think that it is partly met by the Commission's general philosophy and paragraph 52".

(III) Implications of As Low as Readily Achievable

The Commission had already formed a Task Group under Committee 4[74], during their April 1971 meeting, to discuss the implications the *as low as readily achievable* requirement[75]. This requirement implied that exposures should be reduced to levels beneath the permissible dose. However, at this time this was not a central requirement in the Commission's system of protection. Compliance with the permissible dose was viewed as a measure of good practice.

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[73]ICRP (1965) Recommendations of the International Commission on Radiological Protection (Adopted September 17, 1965), ICRP Publication 9 Oxford: Pergamon Press

[74]On the Applications of the Commission Recommendations.

[75]The members of this Task Group were Rogers L (Chair); Dunster H.J; Polvani C and Stevens D.J.

The first draft of the Task Group report was discussed in November 1972 and the final version was agreed in May 1973, just after the Commission's Brighton meeting. No information is available on these discussions. The report was published as ICRP Publication 22[76].

In deciding whether a dose reduction was "readily achievable" the Task Group judged it necessary to consider the "social gain" arising from the reduction, and the "social costs" of achieving it. Social gains, it considered, would be overestimated by a linear dose-response model. The estimation of "social gain" required that the collective or population dose be calculated; this was the product of the magnitude of individual doses multiplied by the number of people exposed.

The Task Group proposed that very small individual doses could be ignored. Although the Commission published this recommendation not all members of the ICRP agreed with it. Lindell believed that the collective or population dose should be the sum of all doses, however, small[77]. His comments were discussed by the Commission in 1972, but no action was taken[78].

The Task Group also considered it "helpful" to express the population dose in social and economic terms; so that the advantage of a dose reduction could be directly compared with the cost of achieving it.

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[76] ICRP (1973) Implications of Commission Recommendations that Dose be kept as Low as Readily Achievable, A Report of ICRP Committee 4, Adopted by the Commission in April 1973, ICRP Publication 22 Oxford: Pergamon Press

[77] Lindell B (1972) A criticism of the concept of "collective dose" and a plea for the proper assessment of population doses, 8th November 1972, ICRP/1972/MC-31, In Taylor L.S (1979)

[78] Taylor L.S (1979)

In an Appendix the Task Group reviewed values for a unit population dose (expressed as person-rads); these ranged from between $10-$250 per person-rad. The report comments that the higher figures

> "have generally been associated with the more cautious methods of assessing the dose-risk relationship at low doses and low dose rates"[79].

Of the different figures considered, the value proposed by Dunster, a member of the Task Group, and Mclean, another member of the ICRP, was the lowest. This ranged between $10-$25 per person-rad. On the other hand, Lindell had suggested a range of $100-$250.

The report concluded that the Commission's system of dose limitation was aimed at the following objectives:

> "(a) to ensure compliance with the dose limits; (b) to avoid the use of unnecessary sources of exposure; (c) to provide for operational control of specific procedures, both individually and in combination, so that the resulting doses are as low as is reasonably achievable, economic and social considerations being taken into account; and (d) to provide a more general framework to ensure that these doses are justifiable in terms of benefits that would not otherwise have been received".

The report commented that the adverb *readily* had been replaced by *reasonably* because

> "it now appears to the Commission that 'reasonably' more closely describes their intentions".

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[79] ICRP (1973) Implications of Commission Recommendations that Dose be kept as Low as Readily Achievable, A Report of ICRP Committee 4, Adopted by the Commission in April 1973, ICRP Publication 22 Oxford: Pergamon Press

5.4: RELATING DOSE LIMITS TO ACCEPTABLE RISKS

The use of risk estimates to assess the impact of radiation exposure was discussed by the Commission in April 1971. While details of these discussions are not available, the draft statement from the meeting reiterated that the Commission's recommendations were based "upon the cautious assumption" of linearity. This was considered a prudent assumption for planning purposes as it enabled the assessment of an "upper limit" of the radiation hazard would could be compared with other occupations. One the other hand, the Commission judged that the actual risk would be much lower:

> "the more cautious such a procedure is, the more important it becomes to recognise that it may lead to an overestimate of the radiation risks, which in turn could result in the choice of more hazardous alternatives to practices involving radiation exposures. Thus, in the choice of alternative practices, radiation risk estimates should only be used with great caution and with explicit recognition of the possibility that the actual risk maybe much lower than that implied by deliberately cautious assumptions"[80].

The month before the meeting R.H Mole, a member of the Task Group formed to review the Commission's recommendations, had produced a report for the Commission on risk estimation for somatic effects. This had concluded that because of the long latency period for the development of malignancies other than leukaemia it was not possible to estimate, with any precision, what the total risk would be. He suggested that it could be between 250 and 500 cases per million per rad if the linear hypothesis was accepted. This was similar to Gofman's estimate. However, he considered that this range would overestimate the true detriment due to cancer, as he did not accept that there was any

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[80] ICRP (1971) Report on the 1971 Meeting of the ICRP (Draft), ICRP/71/NC-18, In Taylor L.S (1979)

> "real radiobiological justification for assuming that a linear dose-effect relationship must hold at low levels of dose for all kinds of radiation"[81].

The "adequacy" of its recommendations and the risks of exposure were discussed during its 1972 meeting. Following this meeting, the Commission commented:

> "As result of this review the Commission does not see any grounds for making any reduction in its dose limits for exposures of the body or of individual organs, either for workers or for members of the public"[82].

This statement referred to the proposals in ICRP 14 and commented:

> "the limits for red bone marrow and gonads might appropriately be raised to a moderate extent to become consistent with the levels adopted for the whole body and for other tissues".

The Commission, however, did not consider it necessary to recommend an immediate increase in these limits; it would consider the need for a replacement of its current limits during 1973. It aimed to publish new recommendations in 1976.

The final report of the Task Group on Dose Limits, was discussed by the Commission at its 1973 Brighton meeting[83]. In 1974 the Commission agreed that it was necessary to prepare a new set of recommendations and formed a drafting group to prepare them[84]. These were published in 1977 as ICRP Publication 26.

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[81] Mole R.H (1971) Somatic Risks of Public Exposed to Ionizing Radiation, March 1971, ICRP/71/MCT-2/1, In Taylor L.S (1979)

[82] Sowby F.D (1973) 'Statement Issued by the International Commission on Radiological Protection After its Meeting in 1972', Radiology 106 713

[83] Taylor has stated that this was largely written by Beninson.

[84] This consisted of Beninson D.J (medical doctor with the Argentine Atomic Energy Commission); Jammet H (physicist with the French Atomic Energy Commission); Lindell B (physicist with the Swedish National Institute of Radiation Protection); Pochin E.E (a clinician who was chair of ICRP 1965 - 1973, member of U.K National

Unfortunately, there is no information available on the ICRP's discussions of the Beninson report or on the drafting of its 1977 recommendations. Taylor has commented that the Beninson report contained many points of "great philosophical interest" and a "considerable amount" of its recommendations were adopted by the Commission. Consequently, as the Beninson report is the last documented source of information on the ICRP's thinking on dose limitation from this period it will be discussed in some detail here[85].

(I) ICRP Task Group Report on Dose Limits

The report of the Beninson Task Group considered that it was possible to derive a dose limitation system based upon risk. The basis of a "risk equivalent dose limit" would be a "defined level" of acceptable risk, related to the dose limit by a "quantitative consideration" of the dose-effect relationship.

(a) Defining an Acceptable Risk for Occupational Exposure

In Publication 9 the Commission had stated that decisions about the acceptability of risk need to consider the balance between risk and benefit. The Task Group did not consider this to be practical. Instead, its value for an acceptable risk was based upon consideration of the level of risk in other industries:

> "The Task Group did not base its recommendations on any balancing of risks and benefit. It considers that, for the foreseeable future, a practical alternative method for identifying the order of magnitude of an acceptable risk is by examining the risk involved in organisations recognised as having a high standard of safety".

Radiological Protection Board Advisory Board and MRC PIRC) and Sowby F.D (ICRP scientific secretary).

85This was an internal ICRP document and it had not been published outside of Taylor's archive account of the ICRP and NCRP.

This level of risk was measured by statistics on occupational fatal accident rates. This was judged a

> "valuable criterion for selecting a level of safety desirable in work involving radiation exposure".

The Task Group considered that industries with a high standard of safety were those where the average annual death rate did not exceed 1 in 10,000 per year (100 per million workers). Industries with "substantially higher" fatality rates were regarded as 'unsafe'. A risk of 1 in 20,000 per year was considered acceptable for radiation work:

> "It is likely that the risks of fatal accidents from causes unrelated to radiation are in general low in occupations involving radiation exposure, and probable that rates in the region of 10 to 40 deaths per million per year would apply. If the risks of fatal radiation effects do not exceed 50 per million per year, the total risk of occupational fatality would thus ordinarily be clearly below the value of 100 per million per year discussed above. The Task Group therefore selected the value of 50 deaths per million per year as the acceptable risk for occupational exposure"[86].

This corresponded to a lifetime (40 years) risk of 2×10^{-3} from radiation exposure. The Task Group commented that some workers would be exposed to higher levels of risk:

> "in most installations where radiation work is carried out, the average annual doses of all those who are individually monitored are about 1/10th of the recorded doses of the most highly exposed individuals. The distribution of values is very skewed, with a high preponderance of low values".

Higher than average exposures were considered to arise randomly, or as a result of a particular type of work that regularly lead to high exposure. For random exposure the Task Group believed that there was a "negligible probability" that a particular worker will regularly receive such doses

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[86] ICRP (1974) ICRP Task Group on Dose Limits - Report to Main Commission. In Taylor L.S (1979)

through their working life. For those workers who regularly received higher doses the Task Group stated that it would possible

> "to ensure compliance with the average risk limit of 2×10^{-3} for a lifetime by imposing an upper limit of 2×10^{-2} on the lifetime risk to an individual".

This was equivalent to an annual of risk death of 1 in 2000, and would correspond to the risk at the dose limit. This procedure was considered highly conservative if the dose-response relationship was not linear.

(b) Defining an Acceptable Level of Risk for Members of the Public

Radiation hazards were judged by the Task Group to represent a "very minor fraction" of the total number of environmental hazards to which the public may be exposed. Therefore, it considered it reasonable to assess the magnitude of risk from radiation exposure

> "in light of the public acceptance of other risks of every day life".

The acceptance of risks, which could be reduced or avoided entirely was believed to be

> "motivated by the benefits that would not otherwise be received, modified by an assessment of the social cost of achieving a possible reduction of risk, or by an implicit judgement of negligibility".

To derive a value for a level of risk that could be considered acceptable the Task Group stated it had reviewed

> "some available information related to risks regularly accepted in everyday life and of a nature that could be assumed to be understood by the public and which are not readily avoidable"[87].

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[87] The single reference quoted for this was Sowby F.D (1970) Some Risks of Modern Life Vienna: IAEA.
Sowby was the scientific secretary of the ICRP and a member of the Task Group.

From this review an acceptable risk limit for an average member of the public was calculated as 5×10^{-6} per year (1 in 200,000). Over a 70 year lifetime this corresponded to a lifetime risk of about 4×10^{-4} (1 in 2500). The Task Group added that the

> "population is clearly not homogeneous in regard to exposure to risks, but there is scanty information on the distribution of many risk parameters. It is very likely that risk to individuals may differ from the average by more than an order of magnitude".

Dose limitation for members of the public was seen as a "somewhat theoretical concept" as it would "seldom be possible" to ensure that an individual had not exceeded the limit. Compliance with dose limits could be achieved by applying dose limits to the mean dose received by the most exposed members of the population in a particular locality[88]. The selection of such a group was considered to imply

> "a selection of individuals expected to be at the high end of the risk distribution caused by the practice under consideration".

This meant that the dose limit for a 'critical group' should correspond to a higher level of risk than acceptable for an average member of the population:

> "Accepting that some individuals in everyday life exceed by an order of magnitude the nominal average acceptable risk, the lifetime risk incurred by a well selected and very homogeneous small 'critical group' could be considered acceptable if it does not exceed 4×10^{-3}".

It was also noted that some members of the critical group could be exposed to even higher levels of risk. Therefore

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[88]This was defined as a "critical group". A typical critical group would be comprised of members of the public living near a nuclear installation whose habits resulting in them receiving a higher dose. An example would be sea-food consumers near a source of radioactive discharge into the sea.

"For the present, and probably for the next few decades, the setting of a risk limit of 4×10^{-3} for the generality of critical groups ensures that the risk to the average member of the public is much below the proposed limit of 4×10^{-4}".

(c) The Radiobiological Basis of the Dose Limit

The Task Group commented that the lifetime risk for cancers other than leukaemia might be a magnitude higher than suggested in ICRP Publication 8. This posed the question:

> "Are the risks of induction of malignant disease after irradiation at the currently recommended dose limits (ICRP Publication 9) such that these dose limits are no longer applicable".

Besides forming a judgement on acceptable levels of risk, answering this question required

> "(a) an examination of the data about dose and cancer induction and other kinds of radiation damage, and especially of any new information which has become available since the publication of ICRP Publication 14. (b) consideration of the methods of inference from data on high brief exposures to expectations for low-level protracted exposure".

The main source of new information were from the studies of the mortality of the atomic bomb survivors[89]. The Task Group also examined the data on lung cancer induction by Radium-226 and Radium-224[90] and on in utero exposure[91].

The Task Group commented that the use of a linear dose-response model provided an upper limit of risk:

> "The linear relationship thus gives the upper limit of risk and is usually held to imply a large, if undetermined, factor of safety because when it is used for protection purposes no

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[89] It cited studies on mortality up to 1970, 25 years after exposure, from Beebe, Kato and Land 1970, and Jablon and Kato 1972.

[90] Citing studies by Rowland, Failla, Keene and Stehney 1970, Spiess and Mays 1970, 1971.

[91] Citing studies by Stewart and Kneale 1970, 1970, Jablon and Kato 1970 and MacMahon 1962.

allowance is made for protraction, dose rate or the possibility that the true dose response relation is sigmoid, factors which would all reduce the expected risk below that derived from linearity".

Therefore, the Task Group judged that there was

> "room for a great variety of opinion about that true level of risk at the dose-limits recommended by the ICRP and about the proper attitude to take when setting dose-limits to which only some individuals will be exposed, when an overriding recommendation of the ICRP is to keep all exposures as low as is readily achievable. Moreover it has to be admitted that there is considerable confusion amongst the interested public as to exactly what the ICRP really thinks the risk is".

The Task Group considered that dose-rate had to be taken into account. It recommended the use of a factor to reduce the risk estimate derived at high dose for use at low doses. It justified this with the statement:

> "that a linear dose response relationship derived from observations after doses of 100 rads and upwards could not be taken as representing the true relationship between cancer induction and dose".

The magnitude of the protraction or dose-rate reduction factor was based upon experimental data. The Task Group recommended:

> "for a given degree of damage, somatic or genetic, the ratio of dose for protracted exposure as compared with brief, high dose rate exposure, should be taken as 3 for the purpose of radiation protection".

The Task Group also emphasised that the term "linear hypothesis" could be used in two very different contexts. Firstly, it could be used for deriving risk estimates from data at high doses for application at low doses. Secondly, it could be used to refer to a "presumed linear and non-threshold" relationship at low doses. It concluded that there were

> "no grounds for using anything but a linear relationship in making decisions in radiation protection at levels of dose at or below the dose limits of ICRP Publication 9 or of this report".

The Task Group considered it reasonable to suggest a risk estimate for all malignancies except leukaemia of 150 cases per million per rem. If leukaemia was included this was increased to 200 per million per rem. This figure was derived using a linear relationship

> "while recognising that the data for spondylitics and for the Japanese could justify a judgement that the total might be larger".

For all stochastic effects the Task Group recommended a risk estimate of 300 per million per rem[92]. This included an estimate of 100 per million per rem for genetic damage. Use of the protraction factor of three reduced this estimate to 100 per million per rem, or 10^{-4} rem.

(d) Derivation of a Dose Limit for Occupational Exposure

Using these risk figures the Task Group derived the dose limits for radiation workers emphasising that

> "Radiation work should be among the safer occupations even if not necessarily the safest".

The application of the derived risk estimate to the risk target of 1 in 2000 implied an annual dose limit of 5 rems, the current value[93].

> "It can be said therefore that the present practice with a maximum permissible dose of 5 rem and involving average annual doses of about 0.5 rem implies an upper limit of risk well within the range for safe industry".

For individual organs the Task Group recommended, that because of uncertainties in the data, it was reasonable apply a single value for the dose limits that would apply to all organs. A limit of 30 rem was chosen.

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[92]Fatal and non-fatal cancers, and genetic damage.
[93]Without the protraction factor the limit would have been 1.5 rems.

The Task Group concluded that there was

> "no need for a drastic revision of the present recommended dose limits".

(II) The ICRP's 1977 Recommendations

The Commission's revised recommendations were published in 1977. While they do not appear to be totally based upon the suggestions of the Task Group on Dose Limits, many ideas expressed by Beninson have been incorporated into them.

(a) The System of Dose Limitation

The Commission did not publish any judgements concerning the desirability, or otherwise, of nuclear energy. Instead it simply stated that radiological protection was

> "concerned with the protection of individuals, their progeny and mankind as a whole, while still allowing necessary activities from which radiation exposure might result"[94].

The aim of its system of radiological protection was to:

> "prevent detrimental non-stochastic effects and to limit the probability of stochastic effects to levels deemed acceptable. An additional aim is to ensure that practices involving radiation exposure are justified"[95].

To achieve these aims the Commission recommended a new system of dose limitation in which the ALARA principle had assumed a central role. The

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[94] ICRP (1977) 'Recommendations of the International Commission on Radiological Protection', ICRP Publication 26, Annals of the ICRP 1 No 3

[95] Non-stochastic effects are those for which the severity of the effect is dependent on the dose-equivalent, and for which a threshold dose occurs, below which the effect will not occur. Examples include cataract induction, non-malignant damage to the skin and the various forms of acute radiation syndrome (radiation sickness). Stochastic effects are those where it is the probability of the effect occurring, rather than the severity which is related to the dose equivalent. For such effects a threshold does not occur. Examples are carcinogenesis and genetic damage.

system had three main requirements: (a) no practice shall be adopted unless its introduction produces a net positive benefit; (b) all exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account (the ALARA principle); an (c) the dose received by individuals shall not exceed the limits recommended for the appropriate circumstances by the Commission.

(b) Risk Estimates and Dose-Response Relationships

The Commission emphasised that while linearity between dose and effect was a basic assumption it would "probably" lead to an over-estimation of the risk; particularly if the true relationship was a quadratic one. Its preferred model, chosen on "radiobiological grounds", was a linear-quadratic dose-response one. It also commented that it was

> "likely that the frequency of effects per unit dose will be lower following exposure to low doses or to doses delivered at low dose rates, and it may be appropriate to reduce these estimates by a factor to allow for the probable difference in risk. The risk factors discussed later have been chosen so far as possible to apply in practice for the purposes of radiation protection".

No further reference was made to such dose-rate reduction factors. The Commission also warned that the assumption of linearity would not only overestimate the risk, it could also

> "result in the choice of alternatives that are more hazardous than practices involving radiation exposures".

For "radiological protection purposes" the Commission recommended the use of a risk estimate for fatal cancers of "about" 10^{-2} per Sievert (Sv)

(10^{-4} Rem $^{-1}$) as an average for both sexes and all ages. The report did not elaborate on the source of this estimate[96,97,98]

(c) Basis of the Commission's Occupational Dose Limits

The Commission did not change the numerical value of its dose limit for workers; this was retained at 50 milli-sieverts (mSv) (5 rem) per year. However, it did change its meaning. In ICRP 9 the recommended permissible dose was intended as a guide for planning and design; it was considered permissible to work up to the limit. In Publication 26 the dose limit meant a limit in absolute terms, it was not a target to be aimed for. The extent of dose limitation within the Commission's limits would be determined by a cost-benefit analysis and the ALARA principle.

In addition, the Commission replaced the critical organ concept and adopted the principle of risk equivalence as suggested by the Beninson

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[96] This means that for every 100 people exposed to 1 Sv of ionising radiation 1 can be predicted to die of a fatal cancer.

[97] In a statement issued following its 1978 meeting the ICRP stated that the risk estimates contained in Publication 26 were based on advice received from its Committee on Radiation Effects, although this were consistent with data contained in the UNSCEAR 77 report.

ICRP (1978) Statement from the 1978 Stockholm Meeting of the International Commission on Radiological Protection

[98] The UNSCEAR 1977 report had stated that several sources of information, primarily the studies of the atomic bomb survivors and the ankylosing spondylitics, indicated that the "average" risk of inducing a fatal malignancy was in the region of 10^{-2} per Sievert (10^{-4} per rad). This estimate was based upon the assumption that solid cancers were likely to occur at a rate five times the observed leukaemia rate. The report emphasised this estimate was based upon leukaemia rates observed following high doses of radiation, the actual risk at low doses may be "substantially" less.

The derivation of this risk estimate was discussed further in the report's technical annexes. These noted that from studies of the atomic bomb survivors the total rate for fatal solid cancers was estimated to be about 2 x 10^{-4} per rad for "moderately high doses", and at low doses of about 10^{-4} per rad.

UNSCEAR (1977) Sources and Effects of Ionising Radiation United Nations Scientific Committee on the Effects of Atomic Radiation, Report to the General Assembly, with annexes New York: United Nations

Task Group. An organ based limit for non-stochastic effects of 0.5 Sv (50 rem) was recommended for all tissues except the eye, for which a non-stochastic limit of 0.3 Sv (30 rem) was recommended. Under this system implied organ stochastic limits can be obtained by dividing the whole body limit by the appropriate organ weighting factor[99].

The Commission did not explain how the dose limit was derived. However, it commented that for the "foreseeable" future a valid method of judging the acceptability of radiation risks work was by comparisons with other occupations

"recognised as having high standards of safety".

These were industries with an average annual mortality rate of 1 in 10,000 per year. The Commission also noted that in making comparison with other industries the emphasis was on the average risks faced by workers; the risk for individual workers would vary according to their job within an industry.

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[99]The adoption of this system allowed increases in the permissible exposure of individual organs, in line with the Beninson recommendations that the present limits were unnecessarily restrictive. However, the scale of the increase was larger than that suggested by Beninson. The change in method of accounting for internal exposures also led to increases in permissible intakes of many radionuclides, particularly for plutonium.

Table 4: Comparison of Dose Limits for Radiation Workers (mSv) in ICRP Publication 26 and ICRP Publication 9

Organ	ICRP 9	ICRP 26	Increase
Whole Body	50	50	-
Gonads	50	200	4x
Breast	150	320	2x
Red Bone Marrow	50	420	8x
Lung	150	420	3x
Thyroid	300	500	2x
Bone Surfaces	-	500	-
Skin	300	-	-
Remainder	150	170	-

The Commission observed that UNSCEAR had shown that average radiation doses tended to be around one-tenth of the annual limit. At this level of exposure the Commission considered that the risk was comparable with other safe industries.

For those workers exposed near the dose limit the Commission considered that they were

> "unlikely to receive such doses each year of their occupational life and it would be their expected lifetime dose equivalent that would indicate their total individual risk. In this sense they are comparable with individuals who are exposed randomly to higher risks in 'safe' occupations. Exposures consistently near the limits would be comparable with a situation where a higher-than-average risk has been identified for certain individuals in non-radiation industries".

There are some important differences between the treatment of this subject by Beninson and ICRP 26. ICRP 26 does not refer to lifetime risk targets, or individual risk targets. However, the risk at its dose limit and 1/10th of the limit, is equal to the Beninson target of a maximum risk of 1 in 2000 per year and an acceptable risk of 1 in 20,000 per year, *if fatal cancers only are considered.* If the Commission had followed the practice recommended by Beninson, and derived the dose limit using a risk estimate for all stochastic effects, a limit of 3 rems would have been recommended.

The Commission also introduced the concept of *detriment* and discussed whether all components of harm should be accounted for in the derivation of the dose limit. It suggested that this assessment could be based upon the amount of time lost through detriment:

> "It should be mentioned however, that an accidental death appears to involve an average loss of about 30 years of life in many industries, and to be associated with an

> approximately equal total loss of working time from industrial accidents. A fatal malignancy induced by occupational exposure to radiation wold be expected to involve the loss of about 10 years of life, owing to the long latency in the development of such a condition, without appreciable associated time loss from accidents".

This type of comparison was explored further in ICRP Publication 27, also published in 1977[100].

(d) Dose Limits for Members of the Public

ICRP 26 repeated the judgement made by the Task Group that radiation risks represented only a small fraction of the total number of environmental hazards to which the public were exposed. It considered that an acceptable level of risk for public exposure could be inferred from consideration of risks that an individual can only modify to a small degree and that are also subject to national regulation. It stated that

> "a risk in the range of 10^{-6} to 10^{-5} per year would likely be acceptable to any individual member of the public"[101].

Its risk estimate for fatal cancer induction

> "would imply the restriction of the lifetime dose to the individual member of the public to a value that would correspond to 1 mSv per year of lifelong radiation exposure".

The public dose limit was not reduced from its previous 5 mSv level. Instead, the Commission commented that this had been found to provide a high degree of safety. Its continued application was expected to result in average doses to members of the public of 0.5 mSv, provided

> "that the practices exposing the public are few and cause little exposure outside the critical groups".

The actual value of the average dose would depend

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[100] ICRP (1977) 'Problems Involved in Developing an Index of Harm', Publication 27, Annals of the ICRP 1 No 4 Oxford: Pergamon Press

[101] This is a risk between 1 in 1,000,000 and 1 in a 100,000.

"upon both the result of the optimization process of a large number of justified practices causing radiation exposures and the value selected to limit the individual doses. If at some time in the future the combined exposure resulting from optimized exposures resulted in average dose equivalents higher than 1 mSv per year, the situation might still be justifiable, even though the average risk for members of the public would be higher than the range 10^{-6} to 10^{-5} per year".

For the general population, the Commission did not specify a limit.

"It has become increasing clear that the previously suggested level is not likely to be reached, and it is very improbable that responsible authorities would permit the average dose equivalent in a population to reach values that are more than small fractions of the former genetic dose limit of 5 rem in 30 years. Therefore, continuance of the former genetic dose limit could be regarded as suggesting the acceptability of a higher population exposure than is either necessary or probable, and a higher risk than is justified by any present or easily envisaged development. Furthermore, knowledge gained over the past two decades indicates that genetic effects, while important, are unlikely to be of overriding importance, and would need to be related to the sum of all other effects".

(III) Practical Implementation of the New Recommendations

One of the first countries to endorse the new recommendations was the United Kingdom; where in 1978 the National Radiological Protection Board (NRPB) stated that the ICRP's system of dose limitation provided a "satisfactory basis" for controlling exposure to radiation[102,103] Two years later, the European Economic Community (EEC) issued a directive requiring its member states to incorporate the recommendations into national law.

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[102]Within the U.K the National Radiological Protection Board (NRPB) has a statutory function to advise the Government on the suitability of ICRP recommendations for application in the UK. It was formed in 1971 as a result of the Radiological Protection Act 1970. Before its formation this function was the responsibility of the MRC's PIRC.

[103]NRPB (1978) Recommendations of the International Commission on Radiological Protection (ICRP Publication 26): Statement by the National Radiological Protection Board on their acceptability for application in the UK ASP1

Other countries, on the other hand, took much longer to adopt the new recommendations. The U.S did not replace its recommendations, based upon ICRP 9, until 1987; whereas the Canadians are still discussing ICRP 26. These delays were not because of a fundamental disagreement with the ICRP, but simply because some of the recommendations involved changes to established practices. The change to accounting for both internal and external exposures is the main example.

(a) Controversy over Radiation Risks

The endorsement of ICRP 26 by the regulatory authorities cannot be taken as a sign of universal acceptance of the ICRP position. Following the publication of ICRP 26 the Commission became directly involved in a major controversy over the magnitude of risk from exposure to radiation. The validity of the Commission's risk estimates and dose limits formed the central issue in this controversy.

This controversy had its origins in the late 1970s, when a number of scientific studies were published that suggested the ICRP had underestimated the risk from low level exposure to ionising radiation. The most well known of these were the analysis by Alice Stewart and her colleagues of the mortality of nuclear workers at the U.S Hanford facility[104] These studies attracted a considerable amount of scientific and popular attention. However, these were not the only sources of data suggesting that the risk was higher than acknowledged by the ICRP. Many

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[104] Mancuso T.F, Stewart A.M and Kneale G (1977) 'Radiation Exposures of Hanford Workers Dying from Cancer and other Causes', Health Physics 33 369-385
Kneale G.W, Stewart A.M and Mancuso T.F (1978) 'Re-analysis of Data Relating to the Hanford Study of the Cancer Risk of Radiation Workers', In Late Biological Effects of Ionising Radiation 1 387-411 IAEA-SM-2423/510 Vienna: International Atomic Energy Agency

of the Commission's critics also cited analyses by UNSCEAR and the U.S National Academy of Sciences, which had produced a range of risk estimates, in support of their claims[105].

However, this controversy, like the earlier dispute between Gofman and the AEC, was not just confined to scientific evidence which was open to a variety of different interpretation. It was also conducted on personal grounds with both sides in the dispute attacking the credibility of the other[106].

In 1978, following its Stockholm meeting, the Commission responded to the allegations that it underestimated the risk:

> "In the light of its continuing review of the published information on the epidemiological and radiobiological evidence of radiation risks to man, the Commission has concluded that the information available up to May 1978 does not call for changes in the risk factors given in ICRP Publication 26. These factors are intended to be realistic estimates of the effects of irradiation at low annual dose equivalents (up to the Commission's recommended dose-equivalent limits)"[107].

The Commission repeated this judgement in 1980:

> "The Commission has reviewed the very extensive epidemiological and radiobiological information that has become available up to March 1980. . . the Commission has concluded that the new information does not call for changes

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[105] Table 5: Risk Estimates for Fatal Cancer Induction per 10,000 Person-Sieverts (1,000,000 Person-Rems)

Source	Nos of Fatal Cancers
BEIR II, 1972	15-621
UNSCEAR, 1977	100 (75-175)
ICRP, 1977	125 (No range given)
BEIR III, 1980	167-501

[106] Green P.A (1984) The Controversy of Low Dose Exposure to Ionising Radiation, Msc Thesis Birmingham: University of Aston

[107] ICRP (1978) Statement from the 1978 Stockholm Meeting of the International Commission on Radiological Protection

in the risk factors for stochastic effects or the dose-effect relationships for non-stochastic effects"[108]

(b) Why the Dose Limits were not Reduced

The impact of ICRP 26 was addressed in 1982, at a conference organised by the International Atomic Energy Authority; where Lindell, Beninson and Sowby considered the effect it had on standards of protection and answered some of the criticisms that had been made.

The speakers noted that reaction to ICRP 26 had been generally "sympathetic". However, to many the recommendations were new and different. One area that generated concern was that radiation work could not be presented as "safe" unless the average exposure was a magnitude beneath the dose limit. This idea had

> "disturbed many who were still living with the impression that any work below the limits was absolutely safe"[109]

This raised the question that if

> "the risk assumptions were really valid, would this not mean that the recommended dose limits were too high?".

It was accepted that under the old system the dose limits would probably be too high; with the system in ICRP 9 it was possible to work up to the limit. This was no longer considered permissible. The speakers commented that,

> "with the new system is never a priori permissible to work up to the limit. The highest permissible exposure is that which can still be defended as being as low as reasonably achievable. It is not the intention that competent authorities should relinquish their right to impose authorised operational restrictions in order to keep doses

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108 ICRP (1980) Statement from the 1980 Meeting of the ICRP

109 Lindell B, Beninson D.J and Sowby F.D (1981) 'International Radiation Protection Recommendations: 5 Years Experience of ICRP Publication 26', International Conference on Nuclear Power Experience, Vienna, 13-17 September 1982 IAEA-CN-42 Vienna: International Atomic Energy Authority

considerably lower than the ICRP dose limit. On the contrary, in most circumstances it is reasonable to request a higher degree of safety. Only if all reasonable efforts do not suffice to keep the exposures substantially lower would it be permissible to allow exposures up to the limit. In that case, however, it must be recognised that the exposed persons would run a higher-than-normal risk".

This meant that

> "the ICRP dose limits may be seen as an indication of the lower boundary of an unacceptable region rather than as the demarcation of a region of unchallenged acceptability".

The recommendations in ICRP 26 had been based upon the premise that in practice average annual occupational exposures were less than 1/10th of the dose limit. The members of the Commission explained that if occupational exposures were considered in a "wide sense", and did not include the nuclear industry, there was clear evidence that this assumption was valid. On the other hand

> "Nuclear power production, is a rather heterogeneous occupation, extending from uranium mining and milling through reactor operation to fuel reprocessing and waste management. The average doses in each of these steps vary considerably from country to country. There are examples in each category indicating that the average may be less than 1/10 of the limit, but there are also examples where, in some countries, the average may exceed 1/10 of the limit, eg reach 40 per cent or more, as for uranium mining in the United States and in some reactor operations".

(c) The Need for Flexibility in the Application of Dose Limits

Before the publication of the NRPB endorsement of ICRP 26, the Board had discussed whether it should depart from the recommendations and recommend a lifetime dose limit. A lifetime risk limit had been a main recommendation of the Beninson Task Group on Dose Limits. Mclean, the NRPB Director and a member of the ICRP's Main Commission, considered that it would be undesirable for the Board to reject any of the principal ICRP recommendations; without a careful consideration of the consequences

including the damage that might be done to radiological protection. However, he believed it *was* appropriate for the Board to discuss, in a general context, the Commission's recommendations[110].

Writing in the NRPB's Bulletin in 1979, Dunster, a member of the Beninson Task group and of the Main Commission, explained why a lifetime limit had been rejected[111]. The ICRP's annual dose limit allowed a lifetime dose of 2 Sieverts (200 rems) to be accumulated; this was equivalent to a fatality risk of 2%. Dunster explained that, in practice, few people would receive exposures near this level; nevertheless, formal lifetime limits had been rejected as too inflexible for some operations such as the mining of uranium and other minerals[112]. Workers in these areas would face higher than average risks. However, Dunster considered these were "not out of line" with the more dangerous occupations in safe industries, or with the average level of risk in more dangerous industries. He judged that the effect of the Commission's recommendations would be to reduce the number of workers facing these higher risks.

The need for flexibility in the application of the ICRP's system of dose limitation was echoed in document prepared by the NRPB Director, A.S Mclean, in early 1979. This was circulated to all Board members. Mclean

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110 Extract from National Radiological Protection Board Minutes (1978)

111 Dunster, a physicist, had been a member of the Main Commission since 1977, and member of Committee 4, on the Application of the Commissions Recommendations, since 1962. Between 1959 and 1962 he was a member of Committee V, on the Disposal of Radioactive Waste. He had also been a member of the Task Group preparing ICRP Publication 8, 'The Evaluation of Risks from Radiation', and a member of the Benison Task Group on Dose Limits. In 1979 he was the Deputy Director General and Director of Nuclear Safety with the Health and Safety Executive. Between 1971 and 1976 he worked for the NRPB as Deputy Director (Operations). Before this he worked for the UKAEA and in 1982 he became director of the NRPB.

112 Dunster H.J (1980) 'Some common questions on ICRP Recommendations', Radiological Protection Bulletin 10-13

noted that over a lifetime it was to be expected that most workers would receive a cumulative dose well beneath the possible maximum. However, he argued that this expectation should not be expressed so that it would led to a reduction in statutory limits simply because average doses were lower. The additional flexibility was required as in some years it might be necessary for some workers to receive doses near the dose limit[113].

The Board did entirely reject the need to limit accumulated doses. Another paper produced in 1979 discussed the means of limiting the exposure of those workers who regularly received annual doses of between 10 to 50 mSv[114]. This suggested that if a worker was to be assured that his/her total expectation of harm from all sources of exposure was no greater in occupations regarded as safe, then the average annual dose over a working lifetime should about 15 mSv (1.5 rems)[115].

It was further suggested that this could be achieved by using the formula X(N-18) to limit accumulated dose, where X equals 15 mSv. An alternative approach would be to limit the cumulative dose by the expression, 0.01 N Sv (Nrem). Both methods would allow the accumulated dose to approach 0.6 to 0.7 Sv in a lifetime.

Of the two, the latter method would give more operational flexibility. A more negative point was that this method would also allow younger workers to receive higher doses; these workers were considered more at risk.

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113 NRPB (1979) Points relating to Occupational Exposure Publication of Advice on Standards of Protection (ASP) Note by Director, National Radiological Protection Board NRPB(79)P.2

114 Workers in the nuclear fuel cycle, in the commercial preparation of isotopes and in industrial radiography were mentioned.

115 Corresponding to a dose over a 40 year working life of about 0.6 Sv (60 rems).

This was not considered suitable for inclusion in regulations. It was emphasised that methods of controlling accumulated dose were not limits, but guidance on the cumulative doses that should not be exceeded without reasonable justification[116].

The Trade Union Congress were pressing for a reduction in the dose limit to 10 mSv. As a compromise the Health and Safety Executive had proposed keeping the limit but, where cumulative doses exceeded 30(N-18) mSv and, where annual doses exceeded 15 mSv they would have to be investigated to establish whether ALARA was being applied and protection optimised[117].

(d) Application of ALARA

The Board's formal advice to the Health and Safety Commission, the regulatory authority, was published in July 1979. This emphasised ALARA as the main means of reducing exposures; although it commented that there had been calls for a reduction in the value of the dose limit. For workers consistently exposed at or near the dose limits the Board recommended that the enforcing authority should consider if ALARA was being correctly applied[118].

ALARA was viewed by most regulatory authorities as the main method by which exposures could be reduced. However, the ICRP had not offered any formal guidance on how ALARA should be applied in practice. This was acknowledged by the ICRP chairman, Bo Lindell, in 1978. Lindell

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116 NRPB (1979) The Management of Occupational Control of Occupational Exposure to Ionising Radiation, 2nd Draft, National Radiological Protection Board 14.11.79

117 The 1985 Ionising Radiation Regulations incorporated a 15 mSv investigation level.

118 NRPB (1979) Advice to the Health and Safety Commission from the National Radiological Protection Board on the acceptability of the dose limits contained within the draft Euratom Directive (Document 5020/78), National Radiological Protection Board ASP3

considered that ALARA meant that the purpose of the dose limits had changed. These must now be seen as

> "indicating the region of undisputed unacceptability rather than as guidance on what still might be acceptable"[119].

This, he believed

> "explains much of the criticism for not having reduced the occupational dose limit, even though the implied risk at the limit is relatively high (of the order of 10^{-3} per year in fatal stochastic effects)".

The application of ALARA would ensure that exposures near the dose limit would be rare. He further commented that

> "even with the ALARA requirement satisfied, an occupational situation cannot be classified as 'low risk' unless the average annual dose is about 5 mSv and the distribution towards high doses is of random nature rather than systematically related to any identifiable group of workers".

Consequently, limits for planning and design should be established using the ALARA principle.

(e) Justification of Exposures

ICRP 26 had recommended three main principles of protection. The first was the requirement that exposures should be "justified". Although the Commission had not elaborated what it mean by this in Publication 26, further explanation was provided by Lindell in 1979. He considered that this requirement was identical with a risk-benefit analysis, and could only follow from a balance of risks and benefits.

According to Lindell, the assessments of benefits were outside the remit, or competence of national radiological protection authorities. In

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[119] Lindell B (1979) 'Basic Concepts and Assumptions behind the New ICRP Recommendations', In Application of the Dose Limitation System for Radiological Protection IAEA SR 36 Vienna: International Atomic Energy Agency

general, he considered that such judgements should be left to "others"; thereby raising the question of whom these "others" should be. He answered:

> "They should be political bodies, since the justification decision is basically a political decision. If the practice is of great and nationwide importance, the decision should be taken at the highest political level. Since it is a political decision, it should be based on unweighted facts. Therefore, the information from radiation protection experts should not include any hidden judgements"[120]

In "less important cases", where the radiological protection body is expected to decide on justification, for example where

> "there may be no other legal basis to protect society against a non-justified practice"

the protection authority should still consult with other organisations, such as medical or consumer interest organisations, as it is not the proper authority to decide benefits. He considered, that in only a very few cases, where the radiation protection authority was "so certain about society's attitude" could it take the decision itself, for example by not accepting a radioactive toy on the market. He concluded that,

> "in radiation protection, the justification of a practice is a necessary assumption rather than an expected task in the administration of radiation protection".

On the other hand, he stated that justification should not be confused with optimization of protection and the ALARA concept. Optimization could be described as identical with a cost-effectiveness assessment of radiological protection, to establish how much expenditure was justified to reduce exposures. In simple terms this process involved assessing the

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[120] Lindell B, Beninson D.J and Sowby F.D (1981) 'International Radiation Protection Recommendations: 5 Years Experience of ICRP Publication 26', International Conference on Nuclear Power Experience, Vienna, 13-17 September 1982 IAEA-CN-42 Vienna: International Atomic Energy Authority

monetary value of detriment and balancing this against the cost, and level of protection achieved.

Lindell noted that while the

> "monetarization of human lives has been criticised as being cynical and inhuman. It should be remembered, however, that the procedure is not intended for justification (risk-benefit) assessment because of the value judgement involved. In the optimization of protection, on the other hand, the purpose is to get as much detriment reduction as possible for the limited amount of money that society is willing to set aside for protection. . .".

In 1982, the NRPB considered the publication of a consultative document that discussed the use of cost-benefit analysis in the optimization of protection of the workforce. This echoed the statements made earlier by Lindell that the practical application of radiological protection was concerned with activities that were, already justified, either "de facto" or on broad political, economic, medical or social grounds[121]. This reemphasised that the main objective was to ensure that exposures were "as low as is reasonably achievable".

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5.5: SUMMARY

This chapter has described the main developments in the ICRP's system of protection and philosophy from 1960 up to 1977, and the publication of ICRP 26. During this period many advances were made in the study of radiation effects on populations. By 1977 it was possible for the risk of exposure to be quantified. However, even before this the Commission's philosophy was already expressed around the notion of an acceptable risk.

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[121] NRPB (1981) Cost Benefit Analysis in the Optimisation of Protection of Radiation Workers - A Discussion Document, National Radiological Protection Board November 1981

During the 1950s the Commission's system of protection was based around the concept that a threshold dose existed. By the mid 1950s it was apparent that this was assumption was not correct. The available biological data suggested that a linear dose-response model was more likely. This was first suggested by Mitchell in 1945.

The Commission did not address this until its 1959 recommendations. By 1965 it was already stating that the assumption of linearity was likely to overestimate the risk. A series of experiments conducted by scientists working for the U.S Atomic Energy Commission suggested that dose-rate was important for genetic effects; lower dose-rates were observed to produce less damage than the same dose given at a higher rate. These experiments were conducted between 1956 and 1960. Following the publication of this data the Commission placed less emphasis on genetic damage.

The somatic effects of radiation, and in particular the induction of cancer, were considered to be more important. However, the Commission judged that the dose-rate data was also applicable to this category of radiation effects.

During the 1950s the Commission had judged, without any real supporting evidence, that the risks of radiation were small compared to the other hazards of life. During the 1960s the additional qualification was added that the risks were comparable, or less than in most other professions. A statement that was not based upon a rigourous analysis of risk.

Not all members of the Commission agreed over the emphasis that should be placed on the risks of low level exposure. The physicists, typified by

Taylor, and the radiologists, typified by Stone, argued that the risks were small, if they existed at all. Linearity, they stressed was an assumption. They argued that there was no evidence that damage was done at the Commission's permissible dose. These arguments were echoed by other members of the Commission and its Committees with links with the nuclear industry. On the other hand, Muller, the only geneticist on the main Commission, did not accept this.

These divisions were also expressed over the issue of exposure of the foetus from diagnostic radiology. Some scientific evidence, widely considered as controversial, had suggested that the foetus was particularly at risk from radiation exposure.

The practising radiologists were firmly opposed to any recommendation that would restrict clinical practice. They were opposed by Morgan, a physicist, and Muller who considered that the Commission had a duty to provide recommendations that addressed all sources of radiation exposure; particularly medical radiation as this was a major source of population exposure. This issue was resolved with recommendations that limited non-essential X-rays of women.

A major consequence of the assumption of a linear dose-response model was the concept of acceptable risks. By 1965 the Commission had redefined the permissible dose as an acceptable dose. The Commission explicitly accepted that exposure within its limits was not risk free, but was justifiable in view of the benefits arising from practices causing radiation exposure. No attempt was made to define, quantify or explain what the benefits were.

The level of risk was further clarified as equivalent to that in industries with "high standards of safety". This statement was justified by a limited comparison in Publication 8; this compared the risk of leukaemia at an exposure of 1 rem, with the average mortality rate for all industry. The risk at the permissible dose was not assessed.

However, this was the first time that the Commission had publicly attempted to quantify the risk. Morgan had previously expressed concern that the Commission's estimate of risk were on the low side. ICRP 8 had suggested that the total cancer risk was about 40 excess cases per million per rem. An estimate justified "only by the rather dubious linearity of the relationship" at high doses.

The concept of risk was a major component of the Commission's philosophy. However, risk was only used for comparisons; it was not used to derive the permissible doses. Equally, there was no relationship between the organ dose limits and the whole body permissible dose.

This contradiction was addressed by two Task Groups during the late 1960s. One implication of their reports was that the whole body dose limit could be reduced compared to the individual organ limits; or the individual organ limits could be increased. The decision between the two options was outside the terms of reference of the Task Groups.

The Commission also formally introduced social considerations into its dose limitation system, recommending that:

> "all doses be kept as low as is readily achievable, economic and social considerations being taken into account".

However, no further explanation was given for this in its 1965 recommendations.

The notion of acceptability was developed further in the planning of the Commission's new recommendations during the early 1970s. The Task Group on Dose Limits did not consider the approach suggested in the 1965 recommendations to be practical. This suggested that decisions about acceptability needed to consider both risks and benefits. The Task Group considered that decisions of what constituted an acceptable risk should be based upon the level of risk in industries with "high standards of safety". These were industries with an annual fatal accident rate of less than 1 in 10,000. A value of half this, 1 in 20,000 per year, was selected as an acceptable risk for radiation exposure. On average, radiation workers received annual doses equivalent to 1/10th of the permissible dose.

A risk limit of 1 in 2000 per year was also adopted. This did not imply the need for a reduction in the dose limits. This conclusion could only be justified by deriving a radiation risk estimate that was not based upon linearity; a dose-rate reduction factor of three was used. If a linear dose-response model was used it would have required a three fold reduction in the dose limit to 1.5 rems.

The Commission's new recommendations were published in 1977 as ICRP Publication 26. It did not recommend a reduction in its dose limits, as they were now called; even though the risks of radiation were recognised to be over three times as dangerous as stated in publication 8. Equally, the Commission did not explain how its estimates of risk were derived. It hinted that these were derived by taking non-linearity into account; a reduction factor of two was used and fatal cancers only were considered.

The intention of dose limits was also changed. This was not made clear in the recommendations, but was clarified by members of the Commission after ICRP 26 had been published. Radiation work could not be presented as "safe" unless the average exposure was a magnitude beneath the dose limit. However, the maintenance of the 50 mSv (5 rem) dose limit was important in providing stability for industry. The numbers had not changed but their emphasis had.

The dose limits were now viewed as representing the

> "lower boundary of an unacceptable region rather than as the demarcation of a region of unchallenged acceptability". Compliance with the dose limit was not sufficient.

The Commission did not consider that simple compliance with the dose limits was sufficient. It now required that exposures were also *as low as reasonably achievable*. This requirement explicitly introduced economic and social considerations into the limitation of risk. The application of ALARA required that a cost-benefit analysis be conducted to identify the magnitude of risk, and the expenditure that was considered justified to reduce it.

Not all groups of workers received annual average doses of 1/10th of the limit. Some groups, particularly those involved in uranium mining, some reactor operations and industrial radiographers, consistently received higher than average exposures. This was recognised by the Commission; who did not discuss this in ICRP 26.

The Commission argued that ALARA was sufficient to ensure that the annual doses of the most exposed workers would be brought down. Some national authorities such as the NRPB, while not publicly disagreeing, considered the use of time-averaged restrictions as well. These were not adopted

and a retrospective 15 mSv (1.5 rem) investigation level was introduced in the U.K. ALARA remained the central part of radiological protection philosophy. The high risk workers were effectively overlooked.

Justification, and the assessments of benefits, was also deemed to be outside the responsibility of radiological protection. In the 1950s when the risks were considered small, the Commission made many judgements about the benefits of nuclear energy. In the 1970s social circumstances had changed and universal support for the nuclear industry no longer existed. The biological evidence also suggested that the risks of exposure were larger than previously recognised. Justification of risk and the consideration of benefits was no longer the Commission's responsibility. The Commission considered this responsibility lay with other, unidentified, authorities. Equally, national authorities, such as the U.K NRPB, considered that the practical application of the Commission's recommendations was concerned with activities that were already justified, either "de facto" or on broad political, economic, medical or social grounds.

The Commission and the national authorities were only concerned to ensure that the dose limits and ALARA were complied with. However, the Commission did not ignore the practical needs of industry. The need for flexibility was the main argument against lifetime dose limits and reductions in the annual limit.

The period covered by this chapter marks a significant development in the ICRP's philosophy and system of protection. Biological data indicated that the risk of exposure was greater than previously recognised. The Commission did not responded to the new data by reducing the value of its

permissible dose. Instead, it developed an elaborate system of protection based around the notion of acceptable risks in which the emphasis shifted away from compliance with dose limits to keeping all exposures as low as reasonably achievable.

CHAPTER 6: FROM ACCEPTABLE RISK TO TOLERABLE DETRIMENT

The controversy over radiation risks in the late 1970s and early 1980s did not provide a significant challenge to the ICRP's authority. The scientific data was subject to many uncertainties and was open to a variety of interpretations. The Commission was viewed as the "acknowledged" authority in the field of radiological protection. Its critics were seen as a tiny minority operating outside the realms of science[1].

The main challenge to the ICRP's system of protection was not brought about by its critics but by scientists working within official radiological protection circles. The scientific basis of the Commission's recommendations were its estimates of radiation risk. These were largely based upon analyses of the mortality of the atomic bomb survivors. These analyses depended upon accurate assessments of the radiation doses received by each survivor. Without this information it would have been impossible to relate the observed cancer mortality rate with dose and thus impossible to estimate the risk from exposure to radiation.

The studies of mortality among the atomic bomb survivors had found a higher death rate due to leukaemia in Hiroshima than in Nagasaki. This difference was attributed to the different composition of radiation in the two cities; arising from different mechanisms of exploding the bombs. According to the dosimetry system in use, the tentative-1965 dosimetry (T-65D), nearly a quarter of the dose in Hiroshima was due to neutrons.

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[1]Green P.A (1984) The Controversy over Low Dose Exposure to Ionising Radiation Msc Thesis Birmingham: University of Aston

In Nagasaki, it was believed that there were hardly any neutrons and the carcinogenic effect was ascribed to gamma-rays. Neutrons are more biologically damaging than gamma-rays.

The T-65D system was challenged in 1980 by work conducted by two scientists working with the U.S Lawrence Livermore Laboratory, a nuclear weapons facility. This work, initiated to investigate the hazards of neutrons, suggested that the dosimetry for the two cities was incorrect. Their work suggested that the T65D system: (i) overestimated the neutron dose in Hiroshima by between 6 - 10 times, so that the neutron contribution to the biological effect was very small, and (ii) underestimated the gamma ray dose in Hiroshima and overestimated it in Nagasaki[2].

These findings were first reported in the journal *Science* under the headline; "NEW ATOMIC BOMB STUDIES ALTER RADIATION ESTIMATES THE BASIS OF 15 YEARS OF RADIATION RESEARCH MAY BE IN ERROR: RADIATION TOXICITY MAY BE UNDERSTATED"[3]. This was followed by newspaper reports in several countries.

Following the publication of the *Science* article some scientists speculated that if the Loewe and Mendelsohn research was correct, it would mean that the observed cancer mortality in the two cities was due

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[2]Loewe W.E and Mendelsohn E (1980) Revised Dose Estimates at Hiroshima and Nagasaki and Possible Consequences for Radiation Induced Leukaemia (Preliminary) D-80-14 U.S: Lawrence Livermore National Laboratory

Loewe W.E and Mendelsohn E (1980) Revised Dose Estimates at Hiroshima and Nagasaki, U.S: Lawrence Livermore National Laboratory

[3]Marshall E (1981) 'News and Comment: New A-Bomb Studies Alter Radiation Estimates The Basis of 15 years of Radiation Research may be in Error: Radiation Toxicity may be Underestimate', Science 212 900-903

to exposure to gamma rays[4]. Risk estimates derived from studies of the A-Bomb survivors would have to be increased.

6.1: IMPLICATIONS OF POSSIBLE DOSIMETRY REVISION FOR ICRP STANDARDS

In 1981 work began on the reassessment of the T-65 dosimetry system. This was funded jointly by the U.S and Japanese Governments and was conducted by scientists working for the Radiation Effects Research Foundation in Japan. The consensus that emerged, from "official" circles, was that the dosimetry revision was not expected to result in major changes in the ICRP's dose limitation system.

(I) The Preliminary Response of ICRP

The ICRP first addressed the possible implications of the dosimetry revision in a conference talk by Lindell, Beninson and Sowby in 1982. They did not consider that the dosimetry revision would have a major effect:

> "It has been suggested that the decrease in the neutron dose estimate would make the gamma radiation alone responsible for the observed increase in the cancer incidence among the Japanese survivors, and that the risk factor for gamma radiation would have to be revised upwards to account for this. However, the Lawrence Livermore study indicates that the gamma dose was probably earlier underestimated so that any revision of the risk factor for gamma radiation would probably be minor. The situation is under continued review and the last words have not yet been said"[5].

This view was supported by UNSCEAR in its 1982 report. This stated that it was unlikely that the effect of the revision would be to increase the

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[4]Rotblat J (1981) 'Hazards of Low Level Radiation - Less Agreement, More Confusion', The Bulletin of Atomic Scientists June/July 31-36

[5]Lindell B, Beninson D.J and Sowby F.D (1981) 'International Radiation Protection Recommendations: 5 Years Experience of ICRP Publication 26', International Conference on Nuclear Power Experience, Vienna, 13-17 September 1982 IAEA-CN-42 Vienna: International Atomic Energy Authority

risk estimates by more than a factor of two. UNSCEAR also observed that the data from Hiroshima and Nagasaki was only one source, of several, of information on the risk from radiation[6].

(II) Response of the Nuclear Industry and Regulatory Authorities

This response was echoed by many others working within radiological protection circles. For instance, the issue was addressed during the Public Inquiry held in the U.K in 1982 into the Central Electricity Generating Boards (CEGB) plan to build a Pressurised Water Reactor. Both the Central Electricity Generating Board and the NRPB, who were represented by Sir Edward Pochin[7], considered that the effects of the revision would be small.

The CEGB stated:

> "it must be remembered that the increased incidence of cancer due to exposure to ionising radiation must be measured against a large and fluctuating background, and given the difficulties inherent in estimating the doses received by the atomic bomb survivors and other irradiated populations (e.g those exposed during medical procedures), a precise value of radiation risk will not be obtained by epidemiological studies and agreement within a factor of 2 is good considering the heterogeneity of data sources. . . the protection of the radiation workers and of the public depends not so much on a precise estimate of the risks as on the application of the whole philosophy of radiation protection"[8].

The proof of evidence presented by Sir Edward Pochin only very briefly discussed the atomic bomb dosimetry revisions. Again emphasising that the expected effects were small:

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[6]UNSCEAR (1982) Ionising Radiation: Sources and Biological Effects United Nations Scientific Committee on the Effects of Atomic Radiation 1982 Report to the General Assembly.

[7]By 1982 Pochin was an emeritus ICRP member.

[8]Bonnell J.A (1982) Biological Effects of Radiation and the Medical Supervision of Radiation Workers, Sizewell 'B' Power Station Public Inquiry: CEGB Proof of Evidence CEGB P17

> "the net effect on the risk estimates has yet to be fully evaluated. One preliminary study has indicated that risk estimates for exposure for low LET radiation might be increased by a factor of between 1.3 and 1.7"[9].

(III) Scientific Pressure for a Reassessment of Risk Estimates

The progress of the dosimetry revision were also discussed in 1983 at a conference organised by the International Atomic Energy Agency and the World Health Organisation. However, the dosimetry revision was far from complete and scientists working on the project were unable to predict the final effect on risks estimates[10].

Two other scientists presented an analysis of the derivation of risk estimates based upon the UNSCEAR 77 data, but excluding studies of the atomic bomb survivors[11]. They observed that their mean value was approximately the same as that derived by UNSCEAR in 1977 *before* it applied a factor to account for the influence of dose rate[12]. The authors argued that because of the paucity of human data that could be used to support a dose rate effectiveness factor (DREF),

> "a case can clearly be made for not using a DREF where a conservative and easily defensible risk figure is required"[13].

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[9]Pochin E.E (1983) The Biological Bases of the Assumptions mane by NRPB in the Calculation of Health Effects, Proof of Evidence, Sizewell B Inquiry NRPB/P/2

[10]Maruyama T (1983) 'Potential Influences of New Doses of A-Bomb after Re-evaulation of Epidemiological Research', In Biological Effects of Low Level Radiation, Proceedings of an International Symposium, Venice, 11-15 April 1983, Vienna: International Atomic Energy Authority

[11]This was based upon a paper published in 1981.
Charles M.W and Lindop P.J (1981) 'Risk Assessment without the Bombs', Journal of the Society of Radiological Protection 1 No 3 15-19

[12]A range of 100-440 fatal cancers per 10,000 Person-Sieverts (1-4.4 X 10^{-2} Sv^{-1}) was quoted; with a mean of 260 fatal cancers per 10,000 Person-Sieverts (2.6 X 10^{-2} Sv^{-1}).

[13]Charles M.W, Lindop P.J and Mill A.J (1983) 'A Pragmatic Evaluation of the Repercussions for Radiological Protection of Recent Revisions in Japanese A-Bomb Dosimetry', In Biological Effects of Low Level

A two fold differences with ICRP estimates was not judged to provide strong support for revision of the dose limits; dose limits were only one part of the ICRP's protection system. One the other hand, they did state:

> "We hope the conclusions of our evaluation will encourage an authoritative international body such as ICRP, with access to the most up to date information, to review these data".

They also commented on UNSCEAR's statement that it had postponed a reevaluation of the human epidemiological data and dose-response models until the results of the revised Japanese dosimetry were known:

> "There appears to be little point in waiting for definitive final review of the bomb survivors before reviewing and encouraging improved follow-up of the many other sources of information to which UNSCEAR have referred. Such a review could only add further credibility to the ICRP dose limitation system".

(IV) The Official Response of the ICRP

In 1984 the Commission officially addressed the issues surrounding the revision of the atomic bomb dosimetry. However, it declined to comment until further information had become available:

> "Reports were received of the progress in re-evaluating the doses to which survivors in Hiroshima and Nagasaki were exposed. The implications of this re-evaluation, and of a continuing survey of reports of the cancer incidence and mortality in the survivors, will be reviewed when further information becomes available"[14].

The Commission also stated that they had reviewed several studies suggesting that the risk was higher than they had suggested in 1977.

Radiation, Proceedings of an International Symposium, Venice, 11-15 April 1983, Vienna: International Atomic Energy Authority

[14] ICRP (1984) Statement from the 1984 Stockholm Meeting of the International Commission on Radiological Protection

The evidence in these studies was considered insufficient to warrant a change in the Commission's risk estimates:

> "No reliable evidence could be derived from these reports to indicate that a change is needed in current estimates of overall risk of cancer induction per unit dose, or in estimates for particular organs, these risk estimates being the basis of the Commission's recommendations".

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6.2: IMPLICATIONS OF INCREASES IN RISK ESTIMATES

By the end of 1986 it was apparent that a combination of the reassessment of the dosimetry revision *and* the longer epidemiological follow-up of the atomic bomb survivors, would mean increases in risk estimates. The debate was therefore no longer about whether the ICRP's risk estimates should change, but about how much and when they would be changed.

For instance, within the U.K, the report by the Sizewell B Inquiry Inspector, Sir Frank Layfield, commented that it would be prudent to assume that risk estimates might rise by a factor of two. He therefore instructed the NRPB to publish its justification for its endorsement of the ICRP's recommendations[15].

(I) Possible Revision of the ICRP's Recommendations

In late 1986 John Dunster, a member of the ICRP and director of the NRPB, discussed the basis of the Commission's risk estimate and commented on the changes that might occur in the light of the dosimetry revision. This article emphasised that the dose limit was only one part of the recommended system of dose limitation:

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[15] Layfield F (1987) Sizewell B Public Inquiry Report by Sir Frank Layfield, Summary of Conclusions and Recommendations Department of Energy

"with the requirement to keep all doses as low as reasonably achievable becoming a much more important and much more effective part of the system"[16].

(a) Clarification on the Source of the Commission's 1977 Risk Estimate

Dunster commented that the Commission's 1977 risk estimate was primarily based upon leukaemia data multiplied by a factor to account for the ratio of leukaemias to other cancers. Allowance was also made for non-linearity as it

"seemed sufficiently clear that the dose/effect relationship for these radiations would be somewhat concave upwards".

Consequentially, the Commission adopted a risk estimate for leukaemia based upon results

"at the lower end of the observed ranges and selected a value of 20×10^{-4} Sv".

(b) Possible Future Changes in Risk Estimates

Dunster suggested that it would be interesting, though not very profitable to speculate on the way that risk estimates might change in the next few years. First, he commented that some of the early leukaemias would have been missed because of the "short delay" before the mortality studies were started. To account for this he suggested that current risk estimates could be increased by a factor between 1.3 and 1.5. Secondly, the revision to the dosimetry system was expected to lead to a further increase of about 1.5. Dunster judged that the combined effect of these changes would be to double the current estimate of leukaemia risk to 40×10^{-4} Sv.

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[16]Dunster J (1986) 'Evolution of ICRP Dose Limits', Radiological Protection Bulletin November 1986

On the other hand, he considered that the allowance for non-linearity should be more explicitly expressed. He recommended the use of a dose rate effectiveness factor of 1.5 and an increase in the quality factor for neutrons.

He also judged that an allowance should also be made for "competing causes of death"; that is a person dying of another cause before a cancer can be expressed. This allowance, he argued, would have the effect of reducing risk estimates; a reasonable reduction factor would be 0.7.

In combination of these different factors had the effect of reducing the leukaemia risk estimate back down the current ICRP value (20×10^{-4} Sv). Dunster also commented that the factor of six, for the ratio of leukaemia's to total cancers, was probably too low and might have to be increased to ten. This would serve to increase the risk estimate for all cancers.

Dunster concluded that:

> "by making a selection from this range of possibilities . . . the final estimate of the risk of fatal cancer would be in the range of 100 to 400 x 10^{-4} per Sv".

This suggested a four fold increase in the Commission's risk estimates.

(c) Possible Changes in the Dose Limits

In deriving dose limits Dunster observed that risk estimates

> "have to be combined with social judgements".

Consequently, the Commission's 1977 recommendations had been based on a comparison of the average risks of radiation work with the average risks in "moderately" safe industries[17]. Dunster added that

> "the relationship between the dose limit and the average depends on other features of the protection system and it would be more direct if the comparison could be made between the most highly exposed radiation workers and the workers at highest risk in moderately safe industries. It seems unlikely, however, that adequate data are available for this direct comparison".

The comparisons made by the Commission in 1977 were based upon fatalities only. Dunster discussed the effect of including non-fatal cancers and argued that this would tend to increase the dose limits. He justified this by explaining that non-fatal cancers occurred at a lower frequency that non-fatal accidents.

He concluded that it was not possible to state firmly what action the Commission might take. Dose limits could either go up, ie be made less stringent, or they could be reduced:

> "At one extreme, a more specific use of the expressed rather than the intrinsic risk and the inclusion of non-fatal conditions, could result in dose limits somewhat higher than those currently recommended, though probably not by more than a factor of about two. At the other extreme, the developing biological information, combined with much the same social judgements, might call for a decrease in dose limits by a factor perhaps as high as five. A more central choice would lead to dose limits to about half those values. Time alone will tell".

A further comment on the consequence of the dosimetry revision was put forward by the other U.K ICRP member at a conference in London in November 1986. Professor Roger Berry commented the Commission had decided, "as a matter of prudence", to recommend a reduction in the

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[17] This is an important change of emphasis. ICRP 26 had referred to industries considered as having "high standards of safety".

principal dose limit for members of the public to 1 mSv per year[18]. The Commission's 1985 Statement had commented:

> "The Commission's present view is that the principal limit is 1 mSv in a year. However, it is permissible to use a subsidiary limit of 5 mSv in a year for some years, provided that the average annual effective dose equivalent over a lifetime does not exceed the principal limit of 1 mSv in a year"[19].

This was not a new recommendation, but a change in emphasis from the recommendation in ICRP Publication 26. The 1985 Statement did not provide an explanation why the change was made and did not refer to the dosimetry revision.

(d) Schedule for ICRP Revision of Recommendations

After his talk Berry announced:

> "In 1987 the current ICRP recommendations will be ten years old, and as you would expect the Commission is reviewing whether they need modifying. At the meeting with its Committees in Como in September 1987, the Commission will decide whether the overall system of dose-limitation itself needs to be revamped".

During the following discussion Berry commented that

> "from several independent sources we are coming to relatively consistent estimates in the rate of cancer induction as a function of radiation dose. Now, whether those final figures are a factor of 2, or a factor of 5 different from the current ICRP estimates remains to be determined".

(e) Social and Scientific Judgements in the Acceptability of Risk

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[18]Berry R.J (1987) 'The International Commission on Radiological Protection - A Historical Perspective', In Radiation and Health: the Biological Effects of Low-Level Exposure to Ionising Radiation Eds Russell Jones R and Southwood R Chichester: John Wiley and Sons

[19]ICRP (1985) Statement from the 1985 Paris Meeting of the International Commission on Radiological Protection

Another speaker at the conference, Professor Edward Radford, commented that scientists were not particularly good, or appropriate, at making "social and moral" judgements on the how much radiation exposure was acceptable[20]. Two members of the ICRP agreed with this sentiment. Professor Berry stated:

> "I am going to support Professor Radford on this point. I do not think that the scientist, by virtue of his science, has any right to believe that he is better at making moral and social judgements. By presenting knowledge in a clear and understandable way, he can, however, assist the moral decision".

Professor Wolfgang Jacobi, a German ICRP member, stated:

> "With reference to the ICRP occupational limit, I think the main thing is what risk is acceptable to a worker. Of course, this problem is not unique to radiation workers; it is a problem for all types of industry and I am not sure that industry has resolved this satisfactorily. ICRP proposes a level of exposure which produces a risk of fatality comparable to the risks of dying in other industries. Please note that ICRP can only recommend, and I think it would be a very good idea for ICRP if some other international organisation would advise on what should be an acceptable risk".

These statements represent an implicit criticism of the earlier role of the ICRP.

(II) Review of ICRP Recommendations

Soon after this conference Dunster wrote to several organisations in the United Kingdom informally seeking their views on how the ICRP recommendations could be modified. This letter noted that:

> "The Commission is planning to issue revised recommendations early in the 1990s. The revision will probably be a consolidation of present policies, although more fundamental changes cannot be ruled out. New epidemiological information coming out of Japan may call for changes in dose limits and

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[20] Radford was the former chair of the U.S National Academy of Sciences Committee on the Biological Effects of Ionising Radiation.

radiobiological work may call for changes in the quality factor for high LET radiations"[21].

Dunster's letter outlined several questions that were likely to be discussed by the Commission as part of their review of their recommendations. These included:

> "Should the present scheme of justification, ALARA and dose limits continue?
>
> Are quantitative dose limits proper for ICRP?
>
> What social judgements should be used in their selection?
>
> Should a single set of dose limits and a single standard risk rate be used regardless of age and sex?
>
> Should the quantity to be controlled, take account of non-fatal conditions and, if so how?".

(a) Social and Scientific Pressure for a Reduction in the Dose Limits

One of the organisations that responded to the Dunster's offer was the environmental group Friends of the Earth (FoE). FoE interpreted the available scientific evidence as supporting the claim that the ICRP underestimated the risks from radiation exposure by between two and ten times. This justified, in their opinion, an immediate reduction in the dose limits for both radiation workers and members of the public[22].

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[21]Dunster H.J (1986) Letter to Friends of the Earth
This letter accompanied a letter from Sir Richard Southwood, the NRPB chair, suggesting the formation of an 'Environmental Issues Panel'. This would be comprised of the NRPB and a number of non-governmental organisations, including pressure groups. It would serve as a forum for an exchange of views on matters relating to the Boards work and on radiological protection generally.
It is interesting to note that in 1978 the Board secretary, Dr Roger Clarke, had recommended to the Board that membership of the its Statutory Advisory Committee be expanded to include organisations representing the public, including "Friends of the Earth" and research based scientists from both sides of the nuclear debate.
NRPB (1978) Consultation with Public on Standards NRPB (78)P.1.

[22]Green P.A. (1987) Radiological Protection - The Recommendations of the ICRP and the Case for a Reduction in the Dose Limits, London: Friends of the Earth

This view was expressed in a declaration that was circulated to the scientific community asking for support. This declaration called for

1. An immediate five fold reduction in the dose limits for radiation workers and members of the public, to 10 mSv and 0.2 mSv per year respectively.

2. A further two fold reduction in the dose limits for radiation workers, in a reasonable period, to 5 mSv per year.

3. The limitation of public exposure to ionising radiation by the requirement that all doses must be as low as is technically achievable (ALATA) and not as low as is reasonably achievable (ALARA)[23].

This declaration was signed by over 800 hundred scientists from thirteen different countries and was presented to the ICRP's chairman Dan Beninson[24], with supporting evidence at its Como meeting[25]. The ICRP had previously agreed that this evidence would be circulated at the meeting for discussion.

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[23]Green P.A (1988) 'Scientists declaration organised by Friends of the Earth (UK) and presented to the meeting of the International Commission on Radiological Protection held in Como (Italy), September 8-17 1987', Experientia 44 89-90

[24]These included two Nobel Prize winners, Linus Pauling and George Wald; former Manhattan Project scientist Joseph Rotblat; an Emeritus member of the ICRP and former chair of ICRP Committee II, Karl Z Morgan; a former chair of the US NAS BEIR Committee, Edward Radford and scientists such as Alice Stewart.

[25]Green P.A. (1987) The Effectiveness of ALARA and the Risk to Radiation Workers Exposed within the Dose Limits, Friends of the Earth Evidence to the ICRP, London: Friends of the Earth

Russell Jones R. (1987) The International Commission on Radiological Protection: Time for a Reappraisal, Friends of the Earth Evidence to the ICRP, London: Friends of the Earth

(b) The Response of the ICRP

After its Como meeting the Commission issued a statement for publication in the scientific Press[26]. This commented that the Commission was reviewing its basic recommendations, a process that it expected to complete in 1990. No reference was made to either the scientists' declaration or the evidence presented by Friends of the Earth.

The statement did discuss the effects of the dosimetry revision. It quoted new evidence from the Radiation Effects Research Foundation (RERF)[27], the organisation conducting epidemiological studies of the survivors, as providing:

> "a definitive account of the average changes in organ dose estimates from exposure to the atomic bombs in Hiroshima and Nagasaki, and of the resultant increase in estimated risks of cancer induction".

The Commission commented that this evidence showed that fatal cancer risk would be increased by a factor of 1.4 under the new dosimetry system. When this was combined with the longer follow-up of the survivor population risk estimates had increased by twofold. This was not considered sufficient to warrant a change in the Commission's dose limits.

The Commission acknowledged that further increases in risk could be expected if the excess risk persisted throughout a lifetime. The risk figures it had quoted were the observed risk up to 1985. They also noted that the RERF paper had used a dose-rate effectiveness factor. The

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[26] ICRP (1987) Statement from the 1987 Como meeting of the International Commission on Radiological Protection

[27] Preston D.L and Pierce D.A (1987) The Effect of Changes in Dosimetry on Cancer Mortality Risk Estimates in the Atomic Bomb Survivors Technical Report RERF TR-9-87 Radiation Effects Research Foundation, Hiroshima, Japan

Commission considered that this would require further study. Consequently, the Commission announced that it would wait the results of further reevaluations of the biological data before judging the consequences for the revision of its system of dose limitation.

In the meantime, the Commission argued that,

> "it would be prudent to follow the present recommendations as they were meant to be interpreted. When this is done, the value of the dose limits, in most cases, will not be the controlling factor in the restriction of doses; therefore the final judgement on the choice of dose limits can await full scientific review without any serious consequences.
>
> This is because the requirement to keep 'all doses as low as is reasonably achievable' (optimisation) should in most situations keep the doses far below the limits. The Commission wishes to re-emphasise the view, expressed in Publication 26', that exposure near the dose limits would only be acceptable if a dose reduction is not reasonably achievable and the practice has been found to be justified. The limits are not intended for planning purposes but rather indicate the borderline to risk levels that must be considered unacceptable. Exposures below the limits are only acceptable if they are 'as low as reasonably achievable'".

(c) Reactions of Environmentalists to the Commission's Statement

The Commission's statement was criticised, by some scientists and environmentalists, as they believed it to be inconsistent with the data contained in the RERF paper[28]. Before the Como meeting some observers

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[28]Lambert B.E (1988) 'Radiation-Induced Cancer Risks', The Lancet May 7 1045-1046
Green P.A (1988) 'The response of the International Commission on Radiological Protection to calls for a reduction in the dose limits for radiation workers and members of the public', International Journal of Radiation Biology 53 No 4 679-682
Rotblat J. (1988) 'A Tale of Two Cities', New Scientist January 7 46-50
Russell Jones R (1987) 'Radiation, Cancer and the New Dosimetry', The Lancet November 14

had expected that the ICRP would make some changes to its recommendations[29].

The difference between the Commission's position and its critics was over the interpretation of the RERF study. The Commission had based it's statement on the mortality of the survivors up to 1985. Whereas the Commission's critics had argued that it was correct to use the RERF estimates of lifetime risk[30]. These included a forward extrapolation in time to estimate how many cancers will occur in the future[31]. In this case, the RERF paper had quoted a risk estimate for all cancers including leukaemia of over seventeen times the Commission's 1977 estimate. This assumed a linear dose-response relationship.

The authors of the RERF study had also taken a dose-rate effect into account. Using a range of DREF factors (of 1.5 to 3) this reduced the risk estimate to between 5 and 10 times the 1977 risk estimates. It was emphasised that the use of a DREF was not intended to suggest exclusion of the linear estimates.

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[29]News Item (1987) 'Nuclear Industry Considers Tougher Standards', New Scientist September 3

[30]The studies of the survivors had indicated that the excess cancer risk, with the exception of leukaemia and possibly bone cancer, was not declining even 40 years after the explosions. This indicated that a relative risk, or multiplicative risk model was more correct. This model assumes, that following exposure, a persons excess risk is proportional to their natural risk of developing a cancer. This excess risk continues through life.
The absolute, or additive risk model, used by ICRP and UNSCEAR in 1977 assumed that radiation exposure produces a constant excess risk with a fixed expression period. After this period the excess risk will tail off.

[31]Two thirds of the survivors in the "Life-Span Study" (LSS) of the Japanese bomb survivors were still alive in 1988.

(d) Peer Group Pressure on the Commission

Significantly, criticism of the Commission's interpretation did not just come from its more established critics. The science journal *Nature* published an editorial that coincided with the ICRP's meeting in Como. While this defended the ICRP and rejected claims that the ICRP should immediately change its recommendations, it explicitly stated that the ICRP must change the way it works:

> "If it seeks to retain its influence, it had better change its style. For reasons connected with its constitution, but none the less excusable on that account, ICRP is slower than it should be to respond to changing circumstances, and given to behaving as if its recommendations should be regarded as mosaic tablets, to be accepted by all with only the most laconic explanation. It may have not sought the place on the public stage it now occupies, but being there it should learn to act"[32]

This statement illustrates the changing social context in which advisory groups, such as the ICRP, work. The traditional authoritative stance of expecting automatic support for a closed decision making process is no longer considered appropriate. Consequently, advisory groups now need to seek support for their actions if they are to retain their status.

The medical journal *The Lancet* was critical of the ICRP's Como Statement:

> "It is to be hoped that the ICRP's decision to maintain for the present its recommended dose limits was not tempered by the financial and practical consequences of a reduction. . . The ICRP has in the past formulated recommendations from which national bodies have taken a lead: by vacillating it risks losing that authority"[33]

The U.K NRPB also publicly took a different view to the Commission over the interpretation of the new data. It did not share the Commission's

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[32]Editorial (1987) 'Hard Battles on Radiation Safety', Nature 329 185-186
[33]Editorial (1987) 'Consequences of New Radiation Dosimetry', The Lancet November 28, 1245-1246

judgement that action was not warranted and in mid November 1987 it held a press conference to say guidance was necessary:

> "You will be aware that the International Commission on Radiological Protection (ICRP) has issued a statement, following its meeting in Como in September of this year, which addresses the issues of risk estimates and dose limits. The Commission concluded that the results of a definitive study of the new calculations of doses, allowing for, amongst other things, the relative humidity in air which reduced neutron doses, coupled with the longer follow-up time to 1985 of the survivors, has raised the risk estimate for the exposed population approximately twofold. This, the Commission considers, is not sufficient to warrant a change in dose limits. One of the Board's functions is to advise Government departments and agencies on the acceptability of ICRP statements. We consider that guidance is required and the Board therefore advises in our report NRPB-GS9, published today, Government departments and agencies who have regulatory responsibilities to consider the implications for dose limits of this change in risk factors"[34].

(III) NRPB Recommendation of Increases in Risk Estimates

The Board commented that it would issue formal advice once UNSCEAR had published its conclusions on risk; and when the ICRP had issued its revised recommendations. Meanwhile, the Board stated that it recognised that

> "the new Japanese data raise risk estimates for radiological protection purposes and considers an increase of a factor of two or three should be anticipated"[35].

The NRPB recommended a risk estimate of 3×10^{-2} Sv as applicable for radiological protection purposes[36]. This was derived using a dose-rate reduction factor of three.

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[34] NRPB (1987) Text of Presentation by Dr RH Clarke, Director NRPB at a Press Conference on 18 November 1987 at the British Institute of Radiology

[35] NRPB (1987) Interim Guidance on the Implications of Recent Revisions of Risk Estimates and the ICRP 1987 Como Statement National Radiological Protection Board NRPB-GS9

[36] 300 fatal cancer deaths per 10,000 Person-Siverts.

(a) Impact of New Risk Estimates on Risk Acceptability

To assess the effect of increase the NRPB used a report by a Study Group of the U.K Royal Society[37,38]. The NRPB observed that this Study Group had concluded that an occupational annual risk of death of 1 in 100 "seems" unacceptable. Whereas a risk of in 1000 would not be totally unacceptable if

> "the individual knows of the situation, enjoys some commensurate benefit, and everything reasonable has been done to reduce the risk".

The NRPB judged that workers exposed near the dose limits for a working lifetime would exceed this level; when its new fatal cancer risk was applied. Therefore

> "as long as the legal dose limits remain at their present levels, it would be prudent to adopt some time-averaged restriction on individual occupational exposure. This should ensure that working practices will be adjusted in a way that will accommodate any future reduction in dose limits".

The Board recommended that radiation workers exposure should be controlled so it would not to exceed an average dose of 15 mSv per year. This level of exposure would produce a risk of death from cancer of 1 in 2000 per year; the risk produced by exposure at the dose limit when the old ICRP risk estimate was used. Around 2000 workers in the U.K exceeded the 15 mSv level in 1987.

The NRPB commented that it had deliberately not recommended a change in the dose limit; that was not its function. Although, it did emphasise that exposure near the dose limit produced a risk that

> "verges on the unacceptable".

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[37] Royal Society (1983) Risk Assessment A Study Group Report

[38] The membership of this Study Group included John Dunster and Sir Edward Pochin.

This meant that it was even more important to ensure that all doses were kept as low as reasonably achievable.

For members of the public the NRPB referred again to the conclusions of the Royal Society Study Group; noting that involuntary risks higher than 1 in 100,000 per year were probably unacceptable. The NRPB also commented that it was relevant to consider the variation in natural background levels in determining dose limits for members of the public.

Its new risk estimate implied that members of the public exposed at the 1 mSv level received a fatal cancer risk of about 1 in 33,333 per year. The Board also judged that this level of risk "probably verges" on the unacceptable. The Board advised that exposure of critical groups around nuclear installations should be limited to 0.5 mSv per year for a single site. This is equivalent to an annual risk of 1 in 66,666.

Earlier drafts of the NRPB guidance had taken a more "regulatory" approach. Its new Director, Dr Roger Clarke, had commented that small changes in the risk estimate did not automatically mean a change in the dose limit. He justified this by arguing there was not a simple dividing line to distinguish between levels of risk that were acceptable and those that were unacceptable. Instead there was a broader region in which acceptability could be demonstrated.

This meant that the 50 mSv dose limit for workers could be retained with lower doses being achieved through better management. It was suggested that a 15 mSv target could be achieved by either (i) a lifetime limit, of 600 mSv; (ii) by an age related formula such as 15(N-18) mSv or 15X

mSv[39], or (iii) by existing administrative arrangements such as the 15 mSv investigation level in the Ionising Radiation Regulations[40].

The age related formula and lifetime limits were excluded from the final version to avoid pre-empting Board views on the new ICRP recommendations, when finally published[41].

(b) The Response to the NRPB Guidance

The NRPB guidance was favourably received by environmental groups, such as Friends of the Earth, who viewed it as an important first step in improving safety standards. The Health and Safety Commission, the organisation responsible for drafting regulations, announced that it was establishing a tripartite working group to consider possible amendments to the Ionising Radiation Regulations[42,43].

The nuclear industry were more guarded in their response. The Central Electricity Generating Board (CEGB) were quoted as stating that the

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[39]Where N or X is the number of years as a radiation worker.

[40]NRPB (1987) Advice on the Interpretation of Dose Limits for Workers and Members of the Public Note by Director NRPB (87)P.22 September 29 1987

[41]NPRB (1987) Letter from Sir Richard Southwood to all Board Members on Interim Guidance on the Implications of Recent Revisions of Risk Estimates and the ICRP Como Statement October 23rd 1987

[42]The members of the Working Party were: Ryder E.A (HSE); Clarke R.J (NRPB); Berry R.J (BNF); Gittus J.H (UKAEA; Wright J.K (CEGB); Hill J (MOD); Godfrey B.E (Department of Health); Bernard B, Howell F.J and Cunningham (Trade Unions); Boddy K, Roberts P.J and Ross W.M (Medical Establishments); Davies E.R (Academic) and Shaw G (Local Authorities).

[43]The Working Group issued its first report in 1989. It recommended that an investigation be held where a workers dose reaches 150 mSv in 10 years. This recommendation was accepted by the Health and Safety Commission who issued a draft Code of Practice in 1990.

Working Group on Ionising Radiation on Ionising Radiation (1989) Report 1987-1988, Health and Safety Commission

Health and Safety Commission (1990) Draft Code of Practice, Part 4: Dose Limitation - restriction of exposure, Additional guidance on regulation 6 of the Ionising Radiation Regulations 1985 (IRR85)

guidance would not cause problems at their plants[44]. British Nuclear Fuels (BNF) stated that 90% of its workforce already received doses within the new targets and further measures were being considered to bring the levels of exposure of the remainder down[45].

Minutes from NRPB meetings observe that most of the comments they had received were favourable. They also refer to correspondence received from the chair of the United Kingdom Atomic Energy Authority (UKAEA). This correspondence has not been made available although it is reasonable to assume that it discussed the practical difficulties of complying with the NRPB guidance, especially in older installations[46]. The NRPB have also commented that industries response to its guidance has expressed at meetings "at various levels of formality", rather than by correspondence. The major input from both management and trade unions has been through the HSC working party.

Some industry representative had commented publicly. For instance, Dr Roger Berry, a U.K ICRP member[47] who in 1987 became the Director of Health and Safety for British Nuclear Fuels (BNF), stated that the guide-lines would cost BNF £100 million to meet. He has been quoted as commenting that the guide-lines had forced BNF to change its working

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[44]Guardian 19.11.87
[45]Guardian 19.11.87
[46]The view of industry is hinted at in the following correspondence from the NRPB secretary. The letter discusses the first report of the HSC Working Group:
"the first report of the Group which does, indeed, generally support the line advocated by NRPB but refers to some practical difficulties which need to be resolved. I think this is a fair reflection of the developing attitude to our advice and the likely outcome of the ICRP deliberations in that what seemed at first rather Draconian is becoming more acceptable through familiarity".
Webb G (1989) Personal Communication
[47]Berry left the main Commission in 1989 and became a member of Committee 4 on the Application of the Commission's Recommendations.

practices and reassess the balance between individual and collective doses. Berry also reportedly suggested that the NRPB guidance, if enforced, would cause the U.K tin mining industry to close down[48].

More recently Berry has stated that the nuclear industry regards occupational radiation induced cancer as a "putative" as opposed to a "demonstrated" hazard at the levels of exposure commonly experienced. He has also commented that exposures within the nuclear industry have been steadily reduced since the 1970s; largely as a result of the ALARA principle, and without a reduction in the dose limits. He also judged that a further reduction in individual dose limits would act to increase the collective dose. This, he argues, will increase the total harm resulting from occupational exposure[49].

Nuclear industry spokepersons abroad have been less guarded in their response to the NRPB guidance. This particularly applies to those countries with uranium mining industries where difficulties would be experienced in complying with a 15 mSv target. For instance, at an International Conference on Radiological Protection in Mining, held in Australia in 1988, a representative from the French Atomic Energy Commission was asked whether France would follow the NRPB lead. He replied:

> "Certainly not. . . About 5 years ago we had up to 10-20% of people who have exceeded the limit of ICRP but at the time it was not implemented in our regulation. We have reduced this number to about 5-6 people a year among 1500 people. I don't think that it is realistic to think that we could avoid exceeding individual limits because you have not only to consider routine operations but there is a number of

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[48]Guardian 17.11.88

[49]Berry R.J (1989) 'A View from the Nuclear Industry', In The Effects of Small Doses of Radiation Conference February 7/8th 1989, Cafe Royal, London

situations in a mine, where for instance, say ventilation has a failure during which you get very easily in one shaft very high doses. It is unrealistic to think that it would be possible at the moment with the present situation"[50].

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6.3: INFLUENCE OF FURTHER INCREASES IN RISK

By late 1988 further information from the Radiation Effects Research Foundation had become available confirming that risk estimates had increased[51]. This was discussed in the 1988 UNSCEAR report[52,53,54] The NRPB was the first radiation protection authority to respond to this.

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[50]Comments made by Pierre Zettwoog, of the Nuclear Protection and Safety Institute, CEN/FAR, at the International Workshop on Radiological Protection in Mining April 4-8 1988, Darwin, Australia.

[51]Shimizu Y, Kato H, Schull W.J, Preston D.L, Fujita S and Pierce D.A (1987) Life Span Study Report 11, Part I: Comparison of Risk Coefficients for Site-specific Cancer Mortality based on the DS86 and T65DR Shielded Kerma and Organ Doses, RERF TR12-87 Hiroshima: Radiation Effects Research Foundation

Shimizu Y, Kato H, Schull W.J (1988) Life Span Study Report 11, Part II: Cancer Mortality in the Years 1950-1985 based on the recently Revised Doses (DS86), RERF TR5-88 Hiroshima: Radiation Effects Research Foundation

[52]UNCSEAR (1988) Sources, Effects and Risks of Ionising Radiation, 1988 Report to the General Assembly, with Annexes, New York: United Nations

[53]UNSCEAR derived risk rates applicable to high dose rates of: Total Population 700-1100 excess fatal cancers per 10,000 Person-Sieverts Working Population (aged 25-64) 700-800 fatal cancer deaths per 10,000 Person-Sieverts. These were based upon a multiplicative model for all cancers other than leukaemia. For leukaemia an additive model was used.

[54]The assessment of UNSCEAR differed to that of the U.S National Academy of Sciences (the BEIR V report). This used a modified relative risk model in its assessments. This takes into account the tailing off of risk, for some cancers, over time. The BEIR V committee did not used a DREF: a linear-quadratic dose-response model was used for leukaemia, that implied, the Committee argued, a DREF of two. For other cancers a DREF was not used.

However, the BEIR V committees judgement on the use of a DREF was ambiguous. It also commented that "it may be desirable to reduce the estimates derived here by a dose rate effectiveness factor of about 2 for populations exposed to small doses at low dose rates. It also commented, that high energy gamma rays (the source of exposure at Hiroshima and Nagasaki) are only half as effective as mid energy X-rays. The implication being that this would cancel

(I) The Change from Acceptable to Tolerable Risks

In its evidence to the Public Inquiry into the proposed PWR at Hinkley Point the NRPB Director, Dr Roger Clarke, announced that it had increased its estimates of risk. This increase was based, in part, on the UNSCEAR 1988 report and on its own analysis of the epidemiological data[55,56]. From these sources it derived a risk estimate, based upon a linear relationship, that was twelve times the ICRP's 1977 value. This applied to high dose-rates. The NRPB also produced a separate, and slightly lower estimate, applicable to a working population. This was approximately nine times the ICRP's 1977 estimate.

To derive risk estimates applicable for radiological protection purposes, the NRPB applied a dose rate factor of three[57]. This reduced the risk to

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out the DREF! No further data was presented to support this assumption.

The Committee's risk rates for the general population are equivalent to 714 to 1329 fatal cancer deaths per 10,000 Person-Sieverts, with a mean of 857 fatal cancer deaths per 10,000 Person-Sieverts.

For a a working population they are equivalent to a range of 530-978 fatal cancer deaths per 10,000 Person-Sieverts, with a mean of 650 fatal cancer deaths per 10,000 Person-Sieverts.

BEIR V (1989) Effects of Ionising Radiation, Committee on Biological Effects of Ionizing Radiation, National Academy of Sciences/National Research Council, Washington D.C: National Academy Press

[55]NRPB (1988) Statement of Evidence to the Hinkley Point C Inquiry by R.H Clarke NRPB-1 NRPB-M160

NRPB (1988) Health Effect Models Developed from the 1988 UNSCEAR Report, by Stather J.W, Muirhead C.R, Edwards A.A, Harrison J.D, Lloyd D.C and Wood N.R NRPB-R226

[56]The NRPB's assessment was, like UNSCEAR's, primarily based upon the atomic-bomb survivor data. However, unlike the UNSCEAR assessment which reported the risk in a Japanese population, the NRPB transfer the risks to the U.K population.

This need to use this approach is a consequence of using a relative risk model. The natural cancer rates for the Japanese are different to the rates in Western countries like the U.K. Transference of risk rates across populations does allow population specific risk estimates to be derived. However, it also introduces additional uncertainty into the risk assessment.

[57]UNSCEAR did not recommend a value for DREF. It simply suggested that a value between 2-10 would be applicable. This is slightly different

4.5×10^{-2} Sv^{-1} for a population of all ages, and to 3.4×10^{-2} Sv^{-1} for a working population[58].

In addition, the NRPB judged that account should be taken of non-fatal cancers[59] and of the risk of genetic damage to all generations after exposure[60]. When these factors were combined a risk estimate of 6×10^{-2} Sv^{-1} was calculated for the whole population, and 4.5×10^{-2} Sv^{-1} for a working population.

These estimates were discussed in the light of a Health and Safety Executive Document on the "Tolerability of Risk"[61]. This report had judged that the maximum *tolerable* risk for workers was 1 in 1000 per year. For members of the public the maximum tolerable risk 1 in 10,000 per year. The NRPB commented that its exposure target of 15 mSv, and the principal public limit of 1 mSv produced risks within those considered tolerable by the Health and Safety Executive.

Outside the Inquiry, Clarke has suggested that tolerable is a better word than acceptable

> "with its connotations of being borne or endured rather than happily ignored"[62].

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advice to its 1986 report. This stated that a DREF of "up to five", or a range of 1.5 - 3 could be used.

58 450 fatal cancer deaths per 10,000 Person-Sieverts and 340 fatal cancer deaths per 10,000 Person-Sieverts respectively.

59 Which it weighted to account for, in its judgement, the reduced importance of non-fatal cancers relative to fatal ones.

60 The ICRP only considered the risk to the first two generations in ICRP 26.

61 HSE (1988) The Tolerability of Risk from Nuclear Power Stations London: HMSO

62 Clarke R.H (1989) 'How acceptable has become tolerable', Radiological Protection Bulletin No 99 4-6

At the Inquiry the NRPB did not discuss the implications of its new estimates of risk for the ICRP system of dose limitation. Since the Inquiry, Clarke has commented that its risk estimate for all stochastic effects would imply a dose limit of "about" 12.5 mSv under the system implied by ICRP 26. Alternatively, the HSE guide-lines would mean a dose limit of around 20 mSv[63].

(II) Possible Changes in Radiological Protection Philosophy and Standards

The possible form of future radiological protection standards was the subject of a conference held in 1988. This was attended by several members of the ICRP. John Dunster[64] discussed the position in Europe:

> "The present form of our system of radiological protection in Europe stems from several articles of faith - axioms, if you prefer a less emotive term. They are not provable, so they are not worth discussing. I merely list them here. The first is that the International Commission on Radiological Protection (ICRP) is, with some minor exceptions right. The second is that a unity of protection standards among countries, is of itself desirable. . . The third is that harmonization is best achieved from the top down-by central regulatory and advisory procedures"[65].

This view also dismisses the recent criticism of the Commission.

Dunster discussed the basis of current ICRP policy and stated:

> "The Commission takes the line that the system of dose limitation should be such that radiation work should carry predicted risks of the same general magnitude as those in reasonably safe industries and no individual should be exposed to unreasonably high risks from radiation, either at work, home or elsewhere".

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[63] Clarke R.H (1989) Current Estimates of Radiation Risk and Implications for Dose Limits National Radiological Protection Board Update Course April 1989

[64] Who had retired as Director of NRPB but was still a member of the ICRP Main Commission.

[65] Dunster H.J (1988) 'A View from Europe: Stability, Consistency or Pragmatism', Health Physics 55 No 2 391-393

This statement represents a change of emphasis compared to ICRP 26. This had argued that the average risks of radiation work were comparable to the risks in industries with high standards of safety.

Dunster acknowledged that the Commission would have to respond to the new data on risk. He commented that the

> "Minimum onus on the Commission over the next few years is to consolidate and clarify its present texts, to assess and, if necessary, react to the revisions of the Japanese dosimetric and epidemiological data".

Dunster emphasised that the new biological data had to be balanced against the need for stability and continuity in protection recommendations:

> "The practical achievement of compliance with new dose limits might be costly and might take some time if the changes were downward and considerable. Thus, even simple changes in dose limits will need substantial justification".

Warren Sinclair[66] addressed the changes that were being considered by the US NCRP[67]. In 1987, to curb some of the higher exposures occurring in industry the NCRP had recommended that cumulative exposure should not exceed age X 0.01 Sv[68]. He commented that average exposures in the U.S ranged from 1.2 - 6 mSv per annum; with the higher exposures occurring in the nuclear fuel cycle. The general average was 2.3 mSv, which produced a risk that

> "compares favourably with fatal accident rates in other nominally "safe" industries".

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66 President of the U.S NCRP and a member of the ICRP.

67 Sinclair W.K (1988) 'Trends in radiation protection - A view from the National Council on Radiation Protection and Measurements (NCRP)', Health Physics 55 No 2 149-157

68 NCRP (1987) Recommendations on Limits for Exposure to Ionising Radiation, NCRP Report No 91, Bethesda: NCRP

Sinclair further commented that

> "the trend in radiation exposures during the 25 years from 1960 to 1985 shows that the average exposure has declined steadily by about a factor of 2 during this period. . . even though the number of workers has increased by about a factor of 2".

On the other hand, he argued that while

> "this situation appears very satisfactory and seems to indicate that applying exposure limits plus adopting the as-low-as-reasonably-achievable (ALARA) philosophy is working well, we cannot afford to be smug about it because, over the same period, the statistics for fatal accidents in workers of all other kinds has dropped by a factor of 2"[69].

Sinclair observed that workers who exceed the dose limit on occasion, and who were exposed near the limit for a working lifetime would face a risk of developing a fatal cancer of about 5%.

> "This exceeds the lifetime risk from automobile fatalities and seems an unreasonable increase when compared with the natural risk of fatal cancer: 16-20%"[70].

(III) The Importance of Detriment

While increase in risk estimates have lead to an expectation amongst some scientists and environmentalists, that dose limits would be reduced this view has been contradicted by the regulatory authorities and members of

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[69]This point has been made by others working in the nuclear industry. Scientists from the Bhabha Atomic Research Centre in India have argued that the ICRP's concept of a safe industry, with 1 in 10,000 fatalities per year, needs revising in view of the general improvements in industrial safety. The suggest that this figure should be lowered to 1 in 20,000 per year "or even" 1 in 50,000 per year. This would imply lower dose limits. However, they also argued that that improvements in the diagnosis and treatment of cancer meant that many cancers were now curable. This raised the question: "Will the changing trend in the curability of radiogenic cancers significantly reduce the detriment to radiation workers?". Murthy M.S.S, Madahvanath U and Soman S.D (1988) 'Some Factors that may Influence Future Radiation Protection Policies', In Radiation Protection in Nuclear Energy, Proceedings of a Conference held in Sydney Volume 1, IAEA-CN-51/54 IAEA: Vienna

[70]This was calculated using a risk estimate twice the ICRP's 1977 figure.

the ICRP. The U.K Chief Inspector of Nuclear Installations has argued that a proportional reduction in the dose limit, in line with the increases in risk is

> "not the only option and may be neither feasible, necessary or correct"

as this approach overlooks

> "both the existing and projected effect of the ALARP requirement"[71,72,73]

John Dunster, of the ICRP, has argued that the system of protection should move away from simple considerations of risk alone towards one based upon detriment. The concept of detriment was introduced in ICRP Publication 26, but did not form a central part of the recommendations.

The concept of detriment takes into the account the probability and severity of a deleterious effect such as cancer. On the other hand, risk only considers the probability that the effect will occur. Dunster has argued that detriment takes into account the time of death; cancers are expected predominantly to occur later in life after a long latency. He argues:

> "a death in later years is less detrimental than an earlier one"[74]

Dunster also mentioned the 1988 UNSCEAR report as this had "explicitly" accounted for competing causes of death and the effect of latency on detriment. Detriment had been expressed by estimating the average years

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[71] ALARP, *as low as reasonably practicable*, is the legal form of ALARA adopted into U.K law.

[72] Ryder E.A and Beaver P.F (1989) 'Changes in Risk Estimates and Their Implications: the U.K Legislative Position', Journal of the Society of Radiological Protection 9 No 3 195-196

[73] ALARP is judged to be equivalent to ALARA under english law.

[74] Dunster J.H (1989) 'Setting Radiation Standards', Nature 337 26

of life loss. UNSCEAR had presented risk estimates deriving using both the absolute and relative risk models. Dunster complained that,

> "most commentators on this topic have stressed the increase in fatal risk without considering the decrease in years lost per attributable death"[72].

He also judged:

> "There is a further weakness in using risk alone. The total risk of death cannot be increased: it is unity. Radiation can change the time and cause of death, not the overall probability.
>
> The risk to the individual is thus a poor measure of the consequence of exposure to ionising radiation"[72].

He concluded:

> "We need a multi-attribute approach to take account of the time and nature of death in addition to its probability. This would also make it easier to include explicitly the non-fatal effects such as curable cancer and hereditary effects. It is hoped that those responsible for setting standards, particularly dose limits, will not rush into changes based only on the simple concept of risk. . . the most appropriate immediate reaction is to increase the attention paid to the need to keep all exposures as low as can reasonably be achieved. Quantitative changes in standards should be a more measured response"[72].

The effect of a change to a detriment based system is illustrated by discussions at the Hinkley Point 'C' Public Inquiry. In its design for the PWR the CEGB had applied a maximum annual dose of 10 mSv for its workforce. If the risks of radiation work were compared with fatal accident rates it commented that the annual risk of death at this exposure level

> "lies towards the upper end of the range of risks run by industrial workers"

If the comparison was conducting using detriment, measured as days of life lost

"the overall detriment to the classified workforce at Hinkley Point 'C' would be the same order as may comparable industries, even allowing for the additional risk of "conventional" fatal accidents"[75,76].

In 1988 the Commission issued a progress report on the preparation of its new recommendations. In this the Commission stated that it intended to retain the general form of their system of protection. It was, however, considering a development in the application of dose limits. The report stated:

"As late as the 1950s, there was a tendency to regard the limits as a measure of satisfactory achievement. Since then, much more emphasis has been put on the over-riding requirement to keep all exposures as low as reasonably achievable, economic and social factors being taken into account. This emphasis has resulted in substantial decreases in individual doses and this trend has reduced the importance of the dose limits in the overall system of protection.

The Commission now believes that the dose limit is too crude a device and that it many need to be supplemented by other limits, which might be called dose constraints, and which would be applied more selectively. The dose limit might then be set to correspond to a level of risk above which individuals should never be deliberately exposed. . . If this change were to be made by the Commission, the concept of dose limits would change. Much of their present function would be better achieved by the more specific dose constraint"[77].

Following its 1989 Paris meeting, where a new Commission was appointed, the ICRP issued a statement that provided further details of the form of its new recommendations[78]. This commented that it

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[75]CEGB (1988) Proof of Evidence on Safety Criteria by R.H Taylor Hinkley Point 'C' Power Station Public Inquiry CEGB 8

[76]Also see: Hoaksey A (1990) 'Widening the Discussion on the Tolerability of Risk', Journal of the Society for Radiological Protection, 10 31-37
The author of this paper was from the CEGB Health and Safety Department. He argued that if loss of life expectancy is taken into account "a significant reduction in the dose limits may not be required".

[77]ICRP (1988) ICRP Progress Report on the Preparation of the New Recommendations San Carlos de Bariloche 30-09-88

[78]New members of the Commission included R.H Clarke, the NRPB director and Shigematsu I, from the Radiation Effects Research Foundation.

"sees the need to take into account additional features of the detriment, particularly the long delay between exposure and the expression of the consequence in the individual. The importance of this point will be increased if the Commission uses some form of a multiplicative risk projection model. The Commission is considering adopting an approach to detriment, which allows probability, severity, and time delay to be taken into account in the optimisation of protection and when using detriment in the selection of dose constraints and dose limits".

The Commission also noted that it has not yet decided on the values of the dose limits to be included in the new recommendations.

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6.4: NEW ICRP RECOMMENDATIONS

Just prior to the October 1989 meeting of the Commission the NRPB published an editorial in its Bulletin which acknowledged that the ICRP has come under increasing criticism in recent years:

"Now that we have a new Commission, it is worth reflecting on what the new Commission should have as its first priority in the next year.

For the last 60 years, ICRP has been seen as the pre-eminent body giving authoritative advice which has formed the basis of radiological protection regulation around the world. However, in recent years its has been increasingly criticised for moving too slowing and not explaining itself in the clearest of terms"[79,80].

The NRPB argued that it was important for the ICRP to maintain its status in the field of radiological protection:

"It is important for the future of international harmonisation in radiation protection that the Commission continues to be regarded as the principal source for recommendations. The Trades Union Congress and the International Confederation of Free Trade Unions are calling for a strengthening of IAEA powers to regulate radiation protection internationally. Whether or not the IAEA is the

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[79]The NRPB director was one of the new ICRP members.
[80]NRPB (1989) 'Editorial: A New ICRP', Radiological Protection Bulletin No 103

right body to do this, the proposal underlines the importance of ICRP maintaining its initiative in protection standards".

The Board suggested that the Commission should allow its recommendations to be circulated for comment prior to publication:

> "For most people, the most important thing that ICRP can do is to allow early sight of its proposed new recommendations. Once the Commission has met in October this year and agreed an advanced draft with its committees, it would be beneficial were this to be floated on the international scene. This would give people time to reflect on the ideas before they are finally published as the formal ICRP recommendations. It would also enable anybody who identifies a particular problem in the application of the recommendations to comment to the Main Commission, again before the text is finalised. Finally, it would do a great deal to enhance the Commission's status to let people know that it is not inactive but is tackling a number of philosophical problems which need to be resolved".

(I) Draft ICRP Recommendations

The draft ICRP recommendations were circulated for comment in February 1990[81]. This move indicates the Commission recognised that it had to change its procedures if it was to continue to command support; this also indicates the influence of the NRPB on the new Commission. The draft recommendations were written by a Task Group, set up by the 1985-1989

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[81] By this time other countries had started to follow the NRPB and recommend further restrictions in occupational exposures. . The Swedish authorities new legally binding regulations came into force in January 1990. These maintain the annual ICRP limits of 50 mSv for radiation workers and 1 mSv for member of the public and also apply supplementary limits on the accumulated dose. A lifetime limit of 700 mSv was applied (ages 18 to 65) with a subsiduary limit of 180 mSv up to age 30. These are equivalent to an average of 15 mSv per year.
Statens Stralskyddsinstitut (1989) Dose Limits for Radiation Workers, Press Release 17 March 1989
The Federal Republic of Germany has introduced a lifetime limit of 400 mSv. This is roughly equivalent to an average of 10 mSv per year.
Kaul A, Cosse F, Martignoni K, and Nitschke J (1989) 'Limitation of Occupational Radiation Risk by Radiological Protection Legislation in the Federal Republic of Germany', Journal of the Society of Radiological Protection 9 No 1 85-95

Commission, that consisted of the ICRP Chair and Vice-Chair and the chairs of its four Committees[82].

The introduction to the draft discussed the development of the Commission's recommendations since its formation and commented:

> "The method of working of the Commission has not changed greatly over the last few decades. Since there is little or no direct evidence of harm at the levels of annual dose at or below the limits recommended by the Commission, a good deal of scientific judgement is required in predicting the probability of harm resulting from low doses of radiation from the observed data obtained at higher doses and usually at high dose rates. The Commission's aim is to draw on a broad spectrum of expertise and this to reach a reasonable consensus about the outcome of exposures to radiation. It has never though it appropriate to use either the most pessimistic or the most optimistic interpretation of the available data"[83].

It also commented that the Commission reviews newly published data annually

> "It is not likely that dramatic changes would be necessary, but if new data should show the existing recommendations to be in need of urgent change, the Commission would react rapidly".

The Commission remphasised that its terms of reference were confined to the hazards of ionising radiation:

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[82] The members were: D Beninson (Chair of Commission, from the Argentine Atomic Energy Commission); H Jammet (Vice Chair of Commission, from the French Atomic Energy Commission); W Sinclair (Chair of Committee 1 - Radiation Effects, from the U.S NCRP); C Meinhold (Chair Committee 2 - Secondary Limits, from the U.S Brookhaven National Laboratory); J Liniecki (Chair of Committee - Protection in Medicine, from Medical Academy of Lodz) H.J Dunster (Chair of Committee 4 - Application of the Commission's Recommendations, until 1989, from NRPB) R.J Clarke (Chair of Committee 4 - Application of the Commission's Recommendations, from 1989, from NRPB); B Lindell (Emeritus member of Commission, from Swedish National Institute for Radiological Protection) and H Smith (Secretary of ICRP).

[83] ICRP (1990) Recommendations of the Commission - 1990, Draft Feb 1990, ICRP/90/G-01 1990-02-09

"It also recognises that this concentration on a single one of the many dangers facing mankind may cause an unwanted element of anxiety. The Commission therefore wishes to emphasise its view that ionising radiation needs to be treated with care rather than fear and that its risk should be kept in perspective with other risks".

The primary aim of radiological protection was defined as:

"to provide an appropriate standard of protection for man without unduly limiting the beneficial practices giving rise to radiation exposure".

However, the Commission recognised that this aim cannot

"be achieved by science alone".

and argued that value judgements have to be made as well:

"All those concerned with radiological protection have to make value judgements about the relative importance of different importance of different kinds of risk and about balancing of risk and benefits. In this they are no different from those working in other fields concerned with the control of hazards".

(a) Biological Basis of the Recommendations

The Commission judged that the human epidemiological data "are not sufficiently precise" to confirm or exclude a linear dose-response model. On the other hand, it argued that radiobiological theory and animal experimentation suggest that the

"direct use of epidemiological data obtained at high doses and high dose rates will over-estimate the risks at low doses and dose-rates"[84].

This led the Commission to conclude that

"in the context of radiological protection, there is sufficient evidence to justify its making an allowance for non-linearity when interpreting data".

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[84] In an appendix the Commission explicitly stated:
"most of the human data, on breast and thyroid, while quite imprecise, show no effect of fractionation (ie a DDREF=1). The data for leukaemia in the Japanese survivors fit a linear quadratic better than linear with an equivalent DREF of about 2 but the data on solid tumour mortality vs dose from Japan fit a linear response with dose quite well over a broad dose range".

The Commission adopted a value of 2 for DREF[85].

The Commission assessment of risk was similar to that of UNSCEAR[86]. Unlike its 1977 assessment the Commission derived risk rates for the working population and for the total population[87]. For workers it derived a risk rate of 4×10^{-2} Sv^{-1} and for the total population 5×10^{-2} Sv^{-1}[88]. These figures are approximately four to five times higher than the Commission recommended in 1977. The Commission also calculated that each cancer was associated with a mean loss of life of thirteen years.

(b) "The Conceptual Framework of Radiological Protection"

In a discussion on its general policy aims the Commission repeated its judgement that radiological protection "necessarily" includes both scientific *and* social judgements. It redefined its three point system of protection to:

> "(a) No practice involving exposure to radiation should be adopted unless its use produces sufficient benefit to the exposed individuals or to society to offset the radiation detriment it causes. (The justification of a practice).
>
> (b) In relation to any particular source within a practice, the magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposures where these are not certain to be received should all be kept as low as reasonably achievable, economic and social factors being taken into account. This procedure should be constrained by restrictions on the doses, or the risks in potential exposure situations, to individuals so as to limit the inequity likely to result from the inherent economic and social judgements. (The optimisation of protection).

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[85] The Commission called this a dose and dose-rate reduction factor.

[86] For leukaemia it used an additive or absolute risk model; for cancers other than leukaemia it used a multiplicative, or relative risk model. The relative risks from the Japanese population were transferred to three others; the U.S, the U.K and Puerto Rico. The Commission risk rates represent an average of the risk in these four populations.

[87] In another departure from its previous recommendations, these risk rates took into account competing causes of death.

[88] 400 and 500 fatal cancer per 10,000 Person-Sieverts respectively.

(c) The exposure of individuals resulting from the combination of all the relevant source should be subject to over-riding dose limits, or risk limits in case of potential exposure situations, aimed at ensuring that no individual is deliberately exposed to radiation risks that are judged to be unacceptable in normal circumstances. Not all sources are susceptible to control by action at the source and it is necessary to specify the sources to be included as relevant before selecting a dose limit. (Individual dose or limits)".

The Commission did not discuss the justification of a practice in any detail, other than to comment that it required an examination of the benefits and risks of different options. However, the justification of a practice was considered to go

"far beyond the scope of radiological protection".

The Commission judged that where the justification and optimization of protection had been conducted effectively there would be few cases where dose limits would have to be applied. It intention was to choose a value of the dose limit so that continued exposure just above the limit would result in risks

"that could legitimately be described as unacceptable in normal circumstances".

This judgement involves social considerations and cannot

"be made on health considerations alone".

In an appendix it commented that its basic policy was to

"provide a radiation safety system such that radiation safety is as good as, and preferably better than in other areas currently seen as 'safe'".

(c) Risk Tolerability and Dose Limits

The Commission commented that the basis of choosing a limit on the level of risk that an individual can be exposed "has always been elusive". However, its previous approach, of comparing radiation risks with

industrial fatal accident rates, was not considered satisfactory. It gave several reasons in support of this judgement:

> "For example, standards of industrial safety are neither constant nor uniform world-wide; the mortality data relate to averages over whole industries, whereas dose limits apply to single individuals; the quantitative comparisons were limited to mortality data although the inclusion of non-fatal conditions on both sides of the comparison would have led to higher dose limits; and, finally, there are few grounds for believing that society expects the same standard of safety across a wide range of industries".

The Commission also commented that a simple probability of harm was not an adequate basis for assessing the detriment resulting from exposure to radiation[89]. A variety of other factors, it judged, were also important components of detriment. These included:

> The lifetime probability of death.
>
> The time lost if the death occurs.
>
> The reduction in life expectancy.
>
> The annual distribution of the probability of death.
>
> The probability of dying in a year at any age, conditional on reaching that age.

The notion of risk tolerability was also adopted by the Commission. Its dose limits are now described as representing the

> "border between 'unacceptable' and 'tolerable'".

The Commission defined "tolerable" as meaning a risk was

> "not welcome but can reasonably be tolerated".

It also defined an acceptable risk as a risk that could be

> "accepted without further improvement".

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[89] In an appendix it argued: "The introduction of a new risk source will not change our lifetime probability of death, but only the distribution of the probable causes of death".

Despite introducing such considerations into the analysis of risk the Commission did not explain how it choose the value of its dose limits. It presented a variety of data to illustrate how such a decision could be made.

First, it presented data to show that for each death the average time lost remained constant at 13 years, whether the annual exposure was 10 mSv or 50 mSv. Secondly, it showed how variations in annual exposure did not bring about large changes in average life expectancy[90]. Third, it argued that the annual probability of death did not remain constant but varied throughout life, with the peak risk occurring at age 78. The age of peak risk was "almost" independent of dose. Four, the Commission also considered changes in age-specific mortality. This is the probability of dying in a particular year, conditional on being alive at the beginning of the year. It argued that even for a constant exposure at 50 mSv the change in mortality rate was small compared to the differences in mortality between men and women.

In an appendix, the Commission argued that a risk-free society was Utopian, and that some risk was unavoidable:

> "There seems to be an unspoken convention that we are willing to accept certain levels of risk in order to enjoy the benefits of a modern society, provided that the risks are not unnecessary or easily avoided. The obvious question is: What levels?".

To answer this question the Commission referred to the 1983 Study Group Report of the British Royal Society (see page 295 and its judgement that

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[90]The average loss of life expectancy ranged from 0.23 years at 10 mSv, 0.46 years at 20 mSv, 0.68 years at 30 mSv and 1.11 year at 50 mSv.

a risk of 1 in 1000 could not be called "totally unacceptable". The Commission also argued that its limits in Publication 26

> "were put forward with the implied assumption that an annual occupational death probability of about 10^{-3} to the most exposed individuals would be at the border of being unacceptable"[91].

It commented that the risk of exposure at 30 mSv per year was equivalent to 1 in 900 and at 20 mSv per year 1 in 1300[92].

The Commission concluded that:

> "its dose limit should be set in such a way and at such a level that the total effectance[93] received in a full working life would be prevented from exceeding about 1 Sv received moderately uniformly year by year and that its application of its system of protection should be such that this figure would only be rarely be approached".

It also added:

> "The final choice of limits and the way in which they are expressed are influenced by the way in which the limits will be applied in practice".

The Commission commented that its previous practice of specifying an annual dose limit was "inflexible". It had considered lifetime limits but rejected these as impractical. Instead, it suggest that

> "flexibility might be provided by setting the limit in the form of the total dose accumulated over a period of a few years, while retaining an annual limit higher than the annual average over the longer period".

The Commission judged that a period of five years would not cause too many problems to implement and would also provide "sufficient flexibility". It recommended a dose limit of 100 mSv in five years, with

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[91] ICRP 26 made no reference to this figure. The maximum risk at its dose limit was 1 in 2000 per year. See Chapter 5 Section 5.4 II (c).

[92] In a summary the Commission also referred to annual risk limit. This was quoted as approximately 1 in 1250 per year for workers.

[93] Its new term for dose.

an overriding limit of 50 mSv in any year. Implicit in this was the intention that a limit of 20 mSv should be used for design purposes.

The Commission's discussion of the derivation of dose limits for members of the public was even shorter. It noted that two approaches existed. The first was to decide on unacceptable or tolerable levels of exposure. The second was to consider the variations in natural background radiation. It recommended that its existing limit of 1 mSv, as an average of a five year period, be maintained:

> "The Commission is also aware that its previously recommended long-term limit of 1 mSv has been widely adopted in practice and no gives rise to no serious difficulties of application, except in a few transient situations".

(II) Response to the Draft Recommendations

All of the comments on the ICRP draft that have been seen at the time of writing are critical. The comments from the NRPB and the French Atomic Energy Commission originate from several different perspectives, but are united in their criticism of the regulatory approach adopted by the ICRP. These comments illustrate the extent to which the ICRP has lost the automatic support of peers.

(a) The Response of the NRPB

Within the U.K the NRPB consulted with a number of organisations before publishing its response to the draft recommendations. The Board published its views in May 1990. They were quite critical of the draft recommendations but also commented:

> "the draft represents a substantial advance in the development of radiological protection standards and that many of the ideas, when fully developed, will lead to improvements in radiological protection practice".

The Board considered that the introduction of the concept of unacceptable and tolerable doses was a useful step. However, it commented:

> "there is no clear derivation of what levels of risk are deemed to form the boundaries between 'unacceptable' and 'tolerable' for workers and the public. There is also not a clear relation back to the 1977 recommendations".

The draft recommendations had considered, almost exclusively, the risks of fatal cancer induction. The Board disagreed with this approach:

> "ICRP uses the risk of fatal cancers in setting its dose limits; the reason for excluding non-fatal cancers risk is not sufficiently justified".

The Board judged that the ICRP had only used one aspect of detriment in its assessment of risk, the probability of death from fatal cancer, and considered the Commission should justify this. However, it also commented:

> "One reason why the probability of fatal cancer is the single factor employed may be the lack of a yardstick against which the additional factors can be judged. If so, it should be stated that the multiattribute approach is correct in principle but that there are at yet limited practical and comparative criteria. At present, the best available measure is then the simple death probability, and this can be assessed using the various studies of tolerable risk".

The Board also contradicted the ICRP's judgement that there is little reason to expect the same standards of safety around the world. The NRPB criticised the ICRP for not stating what levels of risk it considered acceptable or tolerable levels based upon studies in western countries. The Board believed that western notions of tolerability should be applied globally:

> "This could be applied globally by noting that, on the grounds of equity, developing countries should also expect this degree of safety".

The NRPB considered that a limit of 20 mSv appeared "sensible". It also stated that the time averaging method adopted by the Commission, and its retention of the 50 mSv limit, was "generous and unnecessary". It judged that:

> "Flexibility is after all a matter for regulators. It is for ICRP to state what is thinks is correct".

The Board also considered that the Commission had failed to answer "a straight-forward question":

> "radiation risk factors have increased by a factor of four to five, why have dose limits not come down pro rata?".

(b) Comments from Industry

The nuclear industry has not published its comments on the draft recommendations. However, unpublished comments from the French Atomic Energy Commission were critical of the Commission's new five year limits. The comments illustrate the pressure that will be exerted on the Commission not to reduce its dose limits.

The Atomic Energy Commission conclude that the ICRP's recommendations would only have "a limited overall impact" in France. However, major problems would be experienced in particular sectors of industry:

> "The main problem is that of uranium mines"[94]

The report explained:

> "It must be realized that the limit of 100 mSv over 5 years would have dramatic consequences for the operation of uranium workings, particularly underground mines. In the period between 1984 and 1988, 410 miners were exposed to radon, out of 1276 who were monitored, ie 32% exceeded the value of 100 mSv. The same problem certainly exists in all mines throughout the world".

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[94]Commossariat à l'Energie Atomique (1990) Analysis of the ICRP Text, 26th March 1990, HBR/BBD-H311

This problem was not only confined to uranium mines, but affected many areas of the nuclear fuel cycle:

> "Certain activities, such as the fabrication of fuel, the maintenance of reactors, emergency action in the event of operating accidents and work associated with the dismantling of facilities result in exposure levels exceeding 100 mSv in five years for small groups of individuals of high technical competence. It is estimated that are some 1,500 persons who exceed the 20 mSv per year threshold in French organisation as a whole".

The French also feared that a reduction in the dose limit would have a knock-on effect on secondary limits. They argued that this would have major consequences for industry:

> "There is considerable uncertainty as to the manner in which the reduction in the individual dose limits will affect the numerous limits and variables derived from its (LDCA, discharges, site boundary dose rates, contents of radioactive material transport packages, marketing of food products in the event of accidents etc, at the very least). If these limits are reduced in the same proportion as the limits for workers, there will be major consequences in many sectors".

The report also discussed the "other consequences" of the recommendations:

> "Although the ICRP mentions the importance its attaches to maintaining a degree of stability in its recommendations to avoid confusion, it had certainly underestimated the psychological, if not the legal consequences of the modifications its proposes. Indeed, the proposal to limit the dose to 100 mSv for a five year period would, in France, automatically result in the practical limit of 20 mSv per year. It should be understood that this reduction would have a disastrous psychological effect on the public and staff of nuclear installations. How could the public be preventing from seeing it as justification for its fears and a disavowal of the technical managers. As for the specialists, most are wondering whether the Commission is not motivated by the desire to satisfy certain pressure groups".

The comments of the Atomic Energy Commission concluded with a criticism of the ICRP's role in recommending dose limits. It considered that this was a regulatory function and not the role of the ICRP:

> "Although we have mainly emphasized the negative aspects of the ICRP document, we nevertheless consider that it constitutes an excellent approach for establishing a rational political basis for radiological protection. Our only regret is that the ICRP should have gone so far in drawing up regulatory recommendations concerning dose limits, as preparation of regulations falls to the political authorities making allowance for aspects of public health, the scale of which varies from country to country".

The French Atomic Energy Commission recommended that

> "in addition to the current 50 mSv per year limit, a regulatory 1 Sv lifetime limit would be introduced, making it possible to make no exceptions, even for uranium miners".

(c) The response of Pressure Groups

Throughout Europe most environmental pressure groups condemned the draft recommendations for failing to recommend a reduction in the dose limits in proportion to the increase in risk. In the U.K the environmental pressure group Friends of the Earth formed an alliance with a several trade unions in the nuclear industry to ensure that the recommendations did not form the basis of U.K legislation[95]. This alliance "demanded" an immediate five fold reduction in the dose limits:

> "The formation of the coalition between FoE and the Trade Unions is a significant step towards reducing radiation risks. It will send a clear signal to the ICRP and industry that further excuses will not be tolerated. The benefit of doubt must now be given to those at risk. The ICRP must radically revise its recommendations".

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[95]Transport and General Workers Union (1990) Nuclear Trade Unions and Friends of the Earth Join Forces to Cut Radiation Risks, Press Release April 6th 1990
The unions involved were TGWU, AEU, EETPU, UCATT and MSF.

(III) The Commission's Response to Comments on its Draft Recommendations

The Commission met in Washington in June to discuss the response to its draft recommendations. Following this meeting it issued a press release announcing the decisions it had reached. This press release noted that the draft recommendations had been circulated for comment to

> "international, regional and national organisations, professional societies and several expert groups"[96].

The press release stated that the increases in risk called for "some quantitative changes" in its recommendations:

> "One such change to be recommended by the Commission is reduction of the dose limit for occupational exposure. The current figure of 50 millisieverts in a year will be reduced to 20 millisieverts in a year, with some provisions to allow year-to-year flexibility".

This statement represents a change of emphasis compared to its draft recommendations as the press release did not state whether the Commission intended to allow workers to receive an dose of 50 mSv in some years. This issue was discussed by the ICRP's scientific secretary in a talk to the Nordic Society for Radiation Protection in August 1990. The scientific secretary, Dr Hylton Smith, stated that the Commission was still discussing the proposal to apply a dose limit of 20 mSv per year

> "averaged over a defined period of 5 years".

Dr Smith also commented that the Commission was meeting in November 1990 to finalise it new recommendations, which would be published in "the first half of 1991.

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[96] ICRP (1990) Press Release, June 1990

6.5: NEW CONCERN OVER GENETICS

The dose limits proposed by the Commission are based upon considerations of the fatal cancer risks to an individual. They do not account for the risk of genetic damage to future generations; the draft recommendations did discuss genetics but commented that:

> "Radiation has not been identified as a cause of such effects in man"[97].

This changed with the publication of an article in the *British Medical Journal* by Martin Gardner in February. This was concerned with the excess of childhood leukaemia near the British Nuclear Fuels operated Sellafield Reprocessing Plant in Cumbria. Gardner's study found a positive correlation between the occupational exposure of the father and the incidence of leukaemia in their children[98].

The Gardner study identified two groups of workers who faced the highest risk of having a child that developed leukaemia. These were those who had received lifetime doses in excess of 100 mSv (equivalent to the Commission new five year limit); or those who received a dose of 10 mSv or over in the six months prior to conception. For these workers there was a six fold increase in risk, amounting to a 1 in 400 chance that the child would develop leukaemia.

The study was accompanied by an editorial in the *British Medical Journal* that stated:

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97 ICRP (1990) Recommendations of the Commission - 1990, Draft Feb 1990, ICRP/90/G-01 1990-02-09

98 Gardner M.J et al (1990) 'Results of a Case Controlled Study of Leukaemia and Lymphoma among people near Sellafield Nuclear Plant in West Cumbria', British Medical Journal 300 423-429

"These findings have important potential implications for radiobiology and for the protection of radiation workers and their children"[99].

This article attracted a considerable amount of national and international media coverage over a period of several almost two months. By the end of February the media were not just commenting on the implications of the article for BNF, it was also commented on the implications for the ICRP and its new recommendations.

The journal *Nature* commented on the findings in an editorial entitled; "UNACCEPTABLE RISK":

> "If there is a causal relationship between radiation exposure and the occurrence of leukaemia. . . it is difficult to believe that the managers of nuclear plants will in future be able to regulate their affairs by yardsticks even as carefully devised as the latest proposals of the ICRP, now in circulation in draft form"[100].

The editorial concluded:

> "It is not that radiation risks have been grossly underestimated in the past, but that the Gardner study points to a weakness in the definition of what risks are acceptable. The principle has been that the consequences of exposure should be so unlikely that they are lost in the noise. If radiation causes leukaemia in offspring, even with a likelihood as small as one in 400, the consequences will no longer seem inconspicuous to those concerned".

The journal *Science* reported the findings in an article entitled; "BRITISH RADIATION STUDY THROWS EXPERTS INTO A TIZZY". The article reported that:

> "Many experts would like to write off Gardner's study. . . but can't, its too well done".[101]

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[99] Editorial (1990) 'Childhood Leukaemia around Sellafield', British Medical Journal 300

[100] Editorial (1990) 'Unacceptable Risks', Nature 344 90

[101] Roberts L (1990) 'British Radiation Study Throws Experts into Tizzy', Science 248 24-25

The radiological protection establishment had expressed surprise at the study; an excess of leukaemia has not been seen in children of the atomic bomb survivors. However, no one, including BNF have questioned the validity of this study. Gardner seems to have found evidence for genetic damage in humans; although he did not speculate on the mechanism by which the damage could occur.

At the time of writing the ICRP have yet to response officially to the study. The Gardner study was not mentioned in its Washington press statement or in the recent talk by its scientific secretary. An unofficial response was contained in a letter to *Nature* from John Dunster. This was written soon after the publication of the Gardner study. It briefly discussed the draft recommendations in light of Gardner's findings and commented that the recommendations will ensure that "almost no workers" will be exposed to the high risk levels identified by Gardner[102]. Significantly he does not say *no* workers.

The NRPB have also not yet commented officially on the study. In an editorial in its June 1990 bulletin it commented:

> "recommendations on dose limits are at present based solely on fatal cancer risks. We appear to lack a satisfactory approach for taking account of risks in future generations. Fatal cancer risks can be compared with risks of fatality in other industries and used as a basis for setting dose limits. There is no similar yardstick with which to compare hereditary disease. Yet it is now clear that there is an *urgent* need for appropriate methods to be developed"[103].

The editorial concluded:

> "The legacy of Gardner is then not then solely in the particular problem of childhood leukaemia. Radiation-induced

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[102]Dunster H.J (1990) 'Review needed of risks', Nature 344 98.
[103]Editorial (1990) 'After Gardner', Radiological Protection Bulletin No 113 4

hereditary disease has always been accepted as a late effect of radiation exposure, but what we do not have, as yet, is a completely adequate system for taking it into account in setting dose limits. The current debate will increasingly direct attention to this important issue in radiation protection".

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6.6: SUMMARY

The cornerstone of the ICRP's philosophy, in ICRP 26, was the notion of acceptable risk. The risks of radiation work, on average, was judged comparable to the risk in industries with high standards of safety. This analysis was dependent on the Commission estimates of radiation risk, which were largely derived from epidemiological studies of the atomic bomb survivors. This chapter has described the response of the Commission to new scientific information showing that it had underestimated the risk.

In the early 1980s it was revealed that past studies of the survivors had relied upon overestimates of their radiation exposure. This implied that radiation risks had been underestimated. As a result work started on producing a new dosimetry system. The Commission initially to suggestions that it would need to revise its dose limits by commenting that the effect of the dosimetry revision was likely to be small. Possible differences of a factor of two, with its 1977 risk estimate, were not judged to require major changes in the magnitude of its dose limit. The Commission announced that it could afford to wait for more detailed scientific information. It justified this by arguing that the ALARA principle would ensure that most exposures were well beneath the limit. Consequently, ALARA provided the Commission with an element of stability in the face of scientific uncertainty.

However, the stability of the Commission's system of protection was questioned by the widespread scientific and media coverage given to the acknowledgement that the dosimetry system was in error. This created a social and scientific *expectation* that the Commission would have to amend its recommendations. This expectation radically changed the nature of the debate during the 1980s. The ICRP were operating in a new social environment in which its actions were carefully scrutinised. To maintain its reputation it had to be seen to respond to the new data.

By the mid 1980s it was apparent that risk estimates would be increased as a result of the dosimetry revisions *and* the longer epidemiological follow-up of the survivors. The debate was no longer about *whether* the Commission would need to revise its recommendations, but *when* and by *how much* it would need to revise them.

The Commission response was informal, through public comments by some of its leading members. Nevertheless, these comments addresses the implications of the new scientific information on the Commissions recommendations. It appeared that the Commission was responding to public demands for openness in its decision making process. Its members statements openly acknowledged the element of social judgement in considerations about the magnitude of dose limits. They also implied criticism of the Commission's previous role for failing to opening acknowledge this.

The Commission indicated that its risk estimate could rise by a factor of four. Considerable scientific uncertainty was attached to this suggestion. It was dependant on judgements about the degree of allowance for non-linearity in the dose-response model and for competing causes of

death. The Commission had taken non-linearity into account in its 1977 recommendations but had not explicitly acknowledged this. The Commission had not previously discussed competing causes of death.

The Commission also announced that it was reviewing the basis of its recommendations. Within the U.K it wrote to a number of organisations, including its critics, inviting comments on how its recommendations could be modified. This action increased the expectation, amongst both the Commission's peers and critics, that it was about to change its recommendations.

It did not, instead, the Commission announced that the review of its recommendations would not be completed until 1990. It further added that it did not consider the new scientific data sufficient to warrant immediate action. This statement attracted widespread criticism, particularly from its traditional supporters indicating that the Commission could no longer expect automatic support for its actions. This criticism also served to increase the social expectation that dose limits had to be reduced. The U.K NRPB broke with past tradition and recommended that risk estimates should be increased. It also recommend that occupational exposures, should be reduced, on average, to one third of the ICRP's dose limit.

By 1988 the NRPB had acted to further increase its risk estimates; these were now a factor of three to four times higher than recommended by the ICRP. One response to this was a suggestion from the U.K Health and Safety Executive, a regulatory authority, that the notion of *acceptable* risk should be replaced by *tolerable* risk. This did not imply biological

tolerability but social tolerability. This move was welcomed by the NRPB.

During the late 1980s the Commission continued to discuss the possible form of its new recommendations. Its statements illustrate the extent to which the new scientific information had to be balanced against the need to provide stability in its recommendations. One British member of the Commission commented:

> "even simple changes in dose limits will need substantial justification".

The Commission and national regulatory authorities also started to argue that the increases in risk did not automatically mean reductions in dose limits. This approach, they argued, ignored the importance of the ALARA principle. Members of the Commission also argued that simple considerations of risk were a "poor" measure of the consequences of any exposure. Instead, the concept of *detriment* was increasing emphasised.

In 1990 the Commission issued it's new recommendations in draft form for consultation. This move implies a recognition of the new social context in which the Commission worked; it needed to gain support for its actions and could not automatically expect it.

The Commission commented that its basic aim was to

> "provide a radiation safety system such that radiation safety is as good as, and preferably better than in other areas currently seen as 'safe'".

Further explanation was for this aim was not provided.

The Commission acknowledged that its estimates of risk had increased by between a factor of four to five; but did not recommend a proportional

reduction in its dose limits. It adopted the notions of tolerability and detriment, but failed to explain the relationship between these concepts, its estimates of risk and its recommended dose limits. It also rejected its previous arguments used to justify its dose limits, comparisons based upon simple measures of fatality were no longer considered adequate. Such comparisons now suggest radiation is one of the most dangerous industries to work in.

The Commission also announced that annual dose limits were too inflexible. It recommended, instead, that limits should be applied over a five year period. A limit of 100 mSv was recommended, this is equivalent to an average of 20 mSv. Stability and continuity with its old recommendations was maintained by allowing workers to receive up to 50 mSv in any year, subject to the five year limit above.

All of the comments on the ICRP draft that have been seen at the time of writing are critical. These comments originate from several different perspectives, but are united in their criticism of the regulatory approach adopted by the ICRP. The NRPB were particularly critical of the Commission's desire to provide flexibility in its recommendations, pointing out that flexibility is "a matter for regulators". On the other hand, the French Atomic Energy Commission considered that the derivation of dose limits was a national political function and not the role of the ICRP.

While these two comments cannot be automatically assumed to be representative of all the views that the Commission will receive, they do indicate the changed social context in which the Commission now operates. It cannot automatically assume that its pronouncements will be supported,

even by organisations that have traditionally supported it. However, this criticism also has to be compared against other statements from the NRPB and the French authorities welcoming the new recommendations as providing a positive contribution to radiological protection.

This chapter ended with the reemergence of concern over genetics. The Gardner study suggests that a measurable genetic risk exists at levels of exposure that are within the Commission's proposed limits. The NRPB have commented that the radiological protection community lacks an adequate means to assess the risks of future generations. This comment is highly significant and illustrates the major challenged facing the radiological protection community.

In the 1940s the concept of biological tolerance was replaced by the maximum permissible dose in response to concern over genetics. In the 1980s the recognition that the risk of fatal cancer had been underestimated meant that acceptable risks could not longer be considered acceptable. Instead the notion of tolerance was readopted. Not biological tolerance but societal tolerance. The theory of tolerability has, however, been challenged again by genetics. The highest level of risk identified by Gardner exceeds that considered to be the maximum tolerable for occupational work.

CHAPTER 7: DISCUSSION AND CONCLUSIONS

There are two common views that describe the establishment of radiological protection recommendations by the ICRP. Neither is supported by the analysis in this thesis. The most widely accepted view, which can be called *scientific determinism*, suggests that the ICRP's recommendations are formed in response to changing scientific data only. In this view, social considerations, such as judgements over the economic achievability of safety standards, are not a determining factor.

The alternate, and contrasting, view is provided by critics of the Commission, who argue that ICRP's recommendations are *politically, or social determined*. In this model the assessment of scientific information is not a determining factor. Instead, it is argued that the Commission's recommendations are deliberately set to allow for the unhindered expansion of the nuclear industry.

Neither of the analyses adequately explains the evolution of the ICRP's philosophy or recommendations. A third view, provided by academic analyses of the source of conflict, suggests that both scientific and social factors are important in the assessment and regulation of risk. This approach has formed the framework for the analysis in this thesis.

Two separate components can be identified in the formulation of protection recommendations by the ICRP. The first is the formulation of philosophy, or the underlying concepts behind the Commission's recommendations. The second process is concerned with the formulation of practical measures to limit exposure to radiation. These can be collectively termed the Commission's system of protection.

This thesis has examined the evolution of the Commission's philosophy and protection recommendations in response to a variety of internal and external social and scientific pressures. The first general observation that can be made is that the Commission's system of protection i neither solely scientifically or solely socially construed. Instead, the Commission's recommendations have been formed in response to a complex relationship between scientific data and social considerations, such as practicality of recommendations and the need to maintain stability in the application of successive recommendations. The relationship between these concerns has been shaped by a combination of disciplinary, professional, and occupational factors and a shared view of the objectives and rationale of radiological protection.

A central component of this shared view has been the belief that nuclear energy represents a technological advancement that offers society many benefits that outweigh its risks. This belief can be described as a *socio-technical commitment* to nuclear energy. This analysis does not support the view, suggested by some critics of the ICRP, that a simple conspiracy exists to allow for the unhindered expansion of the nuclear industry. Such a view suggests that the Commission has deliberately ignored evidence on the risks of radiation. The Commission has not done this. Instead, its interpretation of the scientific data and the expression of its philosophy has been shaped by its socio-technical commitment to nuclear energy.

Previous analyses of the role of the ICRP have examined its recommendations in the context of controversy over radiation risks. The Commission has been viewed as an organisation responding in a united

manner to changing scientific data. This view has ignored examples of internal conflict, within the Commission, over the interpretation of scientific data. This thesis has focused on this conflict, its resolution and the formation of a consensus view as means of maintaining expert authority and influence. The formation of consensus has been an essential element in maintaining the continuity and stability of the Commission's recommendations.

Throughout its history, new scientific information, and the recognition that radiation risks were greater then previously recognised, have not led to dramatic or radical changes in the Commission's dose limits or recommendations. Instead, a major aim has been to achieve an element of continuity and stability in the application of its successive recommendations; particularly in the face of scientific uncertainty. This process has been a determining factor in its response to the practical needs of industry and its interpretation of the scientific data.

The evidence examined by this thesis also suggests that the manner in which the Commission responds to new scientific or social pressures is not static, but continually changing in response to these influences.

The response to new scientific data, and resolution of internal conflict over its interpretation, has been instrumental in leading to changes in the Commission's philosophy and its concepts of assessing risk. It has reduced the value of its numerical limits less frequently. Where limits have been changed this has been accompanied by practical measures designed to maintain an element of continuity with previous

recommendations, and provide flexibility in the application of the new system. This pattern is repeated throughout the Commission's history.

This thesis has identified five separate stages in the evolution of the Commission's philosophy. These are (i) the change from physical protection to biological tolerance; (ii) the replacement of biological tolerance with the notion of the maximum permissible dose; (iii) the replacement of the maximum permissible dose with the permissible dose; (iv) adoption of the notion of acceptable risk and (v) the reintroduction of notions of tolerability; not biological tolerability but societal tolerability.

This framework has formed the basis of the discussion in this thesis. There is clear evolution of the ICRP's philosophy since its formation in the 1920s. The nature of the practical problems, however, have changed considerably in this period.

Before the Second World War the problems of radiological protection were largely confined to the medical profession. This period also saw the first controversy over radiation risks, between physicists and members of the medical profession. There was a considerable amount of professional prestige associated with early X-ray work. Even though the deleterious effects of radiation began to be reported soon after the discovery of X-rays the medical profession were reluctant to take safety seriously. This controversy was resolved through social pressure, in the early 1920s following the deaths of many eminent clinicians, and resulted in the formation of the first safety committees. The membership of these committees was initially limited to radiologists, physicists and X-ray manufacturers; biologists were not involved.

These professional and disciplinary affiliation shaped the nature of the early protection standards. These were concerned with *physical* protection. This was an approach made necessary by the limitations of technical knowledge of the time.

At a very early stage it was recognised that absolute protection was not possible. The weight and costs of the necessary shielding to achieve this had to be balanced against the benefits of medical radiology. Both physician and physicist alike agreed with this compromise view. They judged that while some radiation would reach the operator it would be "innocuous".

This view was justifiable only through a very narrow definition of the biological effects of radiation. The aim of providing shielding was to prevent to the occurrence of the acute and visible effects or radiation, such as skin damage. These were the effects that were identifiable "by the available methods of clinical examination and observation".

This framework also shaped the developing notion of *biological tolerance*. By the 1930s protection recommendations included numerical tolerance doses; the amount of radiation required to produce skin reddening. Within this narrow framework radiology was considered to no more dangerous than other professions.

This framework was questioned in the early 1940s in response to experimental work on genetics. This suggested that biological tolerance did not exist; even low levels of exposure could be predicted to produce a risk. Before the United State became involved in the Second World War the U.S Advisory Committee on X-ray and Radium Protection considered

reducing the value of the tolerance dose in response to the new data. A move that was rejected because of fears that a lowered tolerance dose would make many medical procedures difficult to carry out. Instead, a change in philosophy was considered and the Advisory Committee proposed the adoption of the notion of the *maximum permissible dose*. A concept that implicitly recognised that a safe level of exposure did not occur.

The development of the atomic bomb and the birth of the nuclear industry radically changed the nature of the problems of radiological protection; many more people, including the public were likely to be exposed to radiation.

The key question for the safety committees of the late 1940s was to what extent should safety standard reflect the state of biological knowledge of the effects of radiation. It was known that radiation was a cause of cancer and could also produce genetic damage. The resolution of this question was dominated by the British and the Americans; the two main war time partners in the wartime atomic bomb project.

The standards that were developed were not based upon scientific information alone but were shaped by social judgements and the belief that nuclear energy represented a technological advancement that would produce many benefits. The key issue was not whether the question of risk raised fundamental questions over whether atomic energy should be developed. The aim was to establish how much risk was *permissible*.

This belief was not just shaped by a simple occupational affiliation to the new, and still undeveloped, nuclear industry. The members of the safety committees in the U.K and U.S were drawn from a variety of

scientific and occupational backgrounds. Some of the scientists were closely involved in the plans for developing the industry. Others, however, were specialists drawn from universities.

The interpretation of the scientific data was a source of conflict between members with different disciplinary affiliations. The biologists adopted a more cautious attitude than the physicists. The choice of the value of the maximum permissible dose rested on two biological considerations; genetics and changes in the blood. While the biologists considered that genetics were important, they agreed with the physicists that this were not the limiting factor. A consensus view that depended on a judgement that the exposed population was small compared with the total population.

The evidence for changes in the white blood cell count formed the scientific basis of the maximum permissible dose. The evidence for these changes was subject to a considerable degree of scientific uncertainty. Blood changes had been observed at very low levels of exposure. However, it was not known if these were deleterious or not. The emphasis that should be placed on this evidence was also a source of conflict. This conflict was not resolved on scientific grounds. The scientific uncertainty had to be balanced against the "practical" needs of industry. This formed the determining factor in the decision over the value of the *maximum permissible dose*.

Prior to the reformation of the ICRP in 1950, the Americans and the British collaborated in planning its recommendations and agreed on the size of the maximum permissible dose. This process was organised by Taylor, a physicist and founder member of the pre-war IXRPC, and Mayneord

a British physicist. Neither of these scientists worked for the nuclear industry. However, they clearly held a common philosophy. Taylor argued that scientific uncertainty should not be allowed to imped technological progress. A view that explicitly recognised that evidence of harm would only be provided through the "sacrifice" of workers exposed to radiation.

The Commission did recommend a reduction in the maximum permissible dose, from its pre-war value, but only to a level that could be achieved by the new nuclear industry. It was also expressed as a weekly figure, rather than a daily figure, to provide greater flexibility in its application.

British scientists later explained that a lower figure had not been adopted as it would have involved economic difficulties that could not be justified in view of the scientific uncertainty. The aim was to provide stability in which the new industry could develop.

This stability was challenged by the lack of a maximum permissible dose for population exposure. The issue of genetics became an issue of major popular concern during the 1950s. It also provided a source of further conflict between members of the Commission as it came under increasing pressure to make recommendations on population exposure. Biological scientists, and geneticists in particular, were concerned over the possible hazards of fall-out. This concern was not shared by physical scientists. The physicist members of the Commission were extremely reluctant to take action merely on the concern of geneticists.

The scientific uncertainty over the magnitude of genetic risks posed a dual problem for the nuclear industry during this period. On the one hand, the scientific evidence implied the need for a restriction of

radiation exposure, particularly in the first 30 years of life. This could involve an economic penalty for industry and would serve to increase its costs. On the other, the scientific uncertainty meant that planning for future expansion of the industry was difficult.

The manner in which the Commission responded to this concern illustrates the extent to which socio-technical commitment formed a major influence on its derivation of radiological protection standards. The evidence suggests that the Commission adopted a more manipulative method of selecting scientists to serve on its committees ensuring that this commitment was represented.

The concern over genetics did not immediate lead to the recommendations of a population permissible dose. Instead, in the mid 1950s it published interim recommendation that provided greater flexibility in the application of the maximum permissible dose. The word "maximum" was dropped from the definition, and the Commission allowed the *permissible dose* to be averaged over a thirteen week period.

Most of the scientific reports published in the mid 1950s suggested that for population exposure the additional dose above background should be severely limited. Consequently, the amount of permissible population exposure from nuclear operations was dependent on the value of the background dose and from medical procedures. Following pressure from the nuclear industry these were excluded from the Commission's limits published in 1959.

Nevertheless, the population permissible dose adopted by the Commission adopted still implied a one third reduction in maximum annual exposures

of workers. The new permissible dose was also expressed as a yearly figure. The Commission provided continuity with its previous recommendations by allowing some workers to exceed permissible dose in some years.

The Commission also changed its method of describing the risks of radiation. This was in response to the assumption that a linear dose-response model applied to both genetic and somatic effects, such as cancer induction. It had previously stated that the risk of exposure "was small". Instead the risk from exposure at the permissible dose was judged to be "not unacceptable". This risk was further justified by judgements over the importance of continued expansion of the nuclear industry. However, the Commission did not attempt to quantify the benefits or even state what they might be. It was also unable to quantify the magnitude of risk from exposure to radiation.

The adoption of a linear dose-response relationship was an important part of the ICRP's developing philosophy. However by 1965 it was stating that this assumption was likely to overestimate the risk. A judgement that was based on scientific evidence suggesting that for genetic damage dose-rate was important; lower dose-rates were observed to produce less damage than the same dose given at a higher rate. The Commission responded to this information considerably quicker than it had to the initial concern over genetics. Following the publication of this data the Commission placed less emphasis on genetic damage.

Another source of conflict between members of the Commission was the scientific evidence suggesting that exposure of the foetus from diagnostic radiology was a cause of childhood leukaemia. The practising

radiologists were firmly opposed to any recommendation that would restrict clinical practice. They were opposed by Morgan, a physicist, and Muller who considered that the Commission had a duty to provide recommendations that addressed all sources of radiation exposure; particularly medical radiation as this was a major source of population exposure. This issue was resolved with recommendations that limited non-essential X-rays of women.

During the 1960s and 1970s its main concern were somatic effects and in particular the induction of cancer; this was also assumed to show a linear dose-response relationship. A major consequence of this assumption was the concept of acceptable risks. By 1965 the Commission had changed its philosophy and had confidently redefined the permissible dose as an *acceptable dose*, however its value was not changed.

The Commission explicitly accepted that exposure within its limits was not risk free, but was justifiable in view of the benefits arising from practices causing radiation exposure. Still no attempt was made to define, quantify or explain what the benefits were. However, this judgement closely reflected a prevailing social attitude; nuclear energy still received widespread support.

The level of risk was also further clarified as equivalent to that in industries with "high standards of safety". This statement compared the fatal cancer, risk at average levels of exposure, with the average risk of accidental death for all industry. The risk at the permissible dose was not assessed. However, this was the Commission's first attempt to quantify the risks of radiation exposure.

The 1960s and early 1970s marked a period of considerable stability in the application of the Commission recommendations. A further revision was not published until 1977 by which time it was possible for the Commission to present a detailed assessment of risk. The manner adopted by the Commission to discuss reflected the changing social context and the decreasing level of support for the nuclear industry. Its 1977 recommendations do not refer to this industry.

The notion of acceptability was developed further in the planning of the Commission's 1977 recommendations. However, the Commission now judged that decisions about acceptability did not need to consider both risks and benefits. Instead, it judged that decisions of what constituted an acceptable risk should be based upon the level of risk in industries with "high standards of safety". The risks of radiation work could be justified by the level of risk faced by other workers.

The emphasis of the Commission's dose limits also changed. The Commission assessed that radiation was more dangerous than recognised in 1965. This scientific evidence did not lead to a proportional reduction in its dose limits. Instead, continuity was maintained by changing the emphasis of dose limits and its philosophy of acceptability. Under its old system compliance with the permissible dose was used as an indicator of good practice. In Publication 26 the emphasis shifted to *average* levels of exposure, nominally taken as equivalent to 1/10th of the dose limit.

The Commission's assessment of risk was based upon average levels of exposure. Radiation work could not be presented as "safe" unless the average exposure was a magnitude beneath the dose limit. Some groups,

particularly those involved in uranium mining, some reactor operations and industrial radiographers, consistently received higher than average exposures. This was recognised by the Commission, but not explicitly discussed in ICRP 26. For these groups of workers the implication was that continual exposure near the dose limit produced a risk that verged on the unacceptable. One means of limiting their risk was by the imposition of lifetime dose limits. The Commission rejected the use of lifetime limits fearing that they would introduce practical difficulties.

The Commission resisted pressure, from trade unions and other critics, for a reduction in the dose limit. It argued that ALARA was the most appropriate mechanism to ensure reductions in exposures, not reductions in the dose limit. It also disputed the scientific basis of the evidence used to suggest that it underestimated the risk. Even though the scientific evidence of the late 1970s was more complete and allowed for an assessment of risk to be made it was still subject to large degrees of scientific uncertainty. As a result it was open to a variety of interpretations.

The main challenge to the Commission's authority did not come from its critics but from scientists working inside the radiological protection community. Doubt was cast, in the early 1980s, on the epidemiological basis of the Commission's recommendations when it was suggested that the doses received by the atomic bomb survivors had been overestimated. If this were correct it implied that radiation was more dangerous.

This evidence was widely reported by the media creating a social and scientific expectation that the ICRP would have to amend its recommendations. For the first time the ICRP was not setting the agenda.

This expectation, and the strength of subsequent scientific evidence, gradually changed the nature of the debate during the 1980s. The ICRP found itself operating a new environment where its actions were carefully scrutinised. To maintain its reputation is had to be *seen* to respond to the new data and the demands for change.

However, the Commission's initial response was one of attempting to maintain stability. It argued that the effect of the dosimetry revision would be small and have little consequence on its system of dose limitation. It justified this by arguing that the ALARA principle would ensure that most exposures were well beneath the limit. Consequently, ALARA provided the Commission with an element of stability in the face of scientific uncertainty.

By the mid to late 1980s the strength of the scientific evidence had radically changed the nature of the debate. The debate was no longer about *whether* the Commission would need to revise its recommendations, but *when* and by *how much* it would need to revise them. This in turn increased the pressure on the Commission for changes in its system.

Several leading members of the Commission responded to the new data on its behalf. They openly acknowledged the element of social judgement in considerations about the magnitude of dose limits. They also implied criticism of the Commission's previous role for failing to opening acknowledge this.

The Commission indicated that its risk estimate could rise by a factor of four. Considerable scientific uncertainty was attached to this suggestion. It was dependant on judgements about the degree of allowance

for non-linearity in the dose-response model and for competing causes of death. The Commission had taken non-linearity into account in its 1977 recommendations but had not explicitly acknowledged this. The Commission had not previously discussed competing causes of death.

The Commission also announced, in 1986, that it was reviewing the basis of its recommendations. Within the U.K it wrote to several organisations, including its critics, inviting comments on how its recommendations could be modified. However, in 1987 it announced that its review of its recommendations would not be completed until 1990.

This move attracted widespread criticism, particularly from its traditional supporters indicating that the Commission could no longer expect automatic support for its actions. This criticism also served to increase the social expectation that dose limits had to be reduced. The U.K NRPB took action independently of the ICRP and recommended that occupational exposures, should be reduced, on average, to one third of the ICRP's dose limit.

By 1988 the NRPB had acted to further increase its risk estimates; these were now a factor of three to four times higher than recommended by the ICRP. One response to this was another change in the concepts used to describe risk. This suggestion, however, was not made by the ICRP but by a British regulatory body. It suggested that the notion of *acceptable* risk should be replaced by *tolerable* risk. This did not imply biological tolerability but social tolerability. This move was welcomed by the NRPB.

These two announcements suggested that in the U.K, at least, the actions of the ICRP were becoming increasingly irrelevant. However, this would be an over-interpretation of events. The NRPB's criticism should not be viewed as motivated by a desire to replace the ICRP. Instead, they can be viewed as aiming to change the nature of the way the Commission works. The NRPB has commented on the desirability of the ICRP retaining its status. This, however, requires major changes in the way its works; it cannot automatically assume support, instead it had to win support for its arguments.

During this period the Commission also began to counter the expectation that dose limits should be reduced. It has argued that the new scientific information had to be balanced against the need to provide stability in its recommendations. The Commission and national regulatory authorities have also argued that increases in risk did not automatically mean reductions in dose limits. An approach, they argued, that ignored the importance of the ALARA principle.

Further changes in the methods used to describe risk have also been made. Several leading members of the Commission have argued that simple considerations of risk are a "poor" measure of the consequences of any exposure. Instead, the concept of *detriment* has been emphasised.

In 1990 the issued its new recommendations in draft form and invited comments. It acknowledged that its estimates of risk had increased by between a factor of four to five; but did not recommend a proportional reduction in its dose limits. Instead, its philosophy and method of describing risk was formally changed.

It adopted the notions of tolerability and detriment, but failed to explain the relationship between these concepts, its risk estimates and its dose limits. It also rejected its previous arguments used to justify its dose limits, comparisons based upon simple measures of fatality were no longer considered adequate. Such comparisons now suggest radiation is one of the most dangerous industries to work in.

The Commission also announced that annual dose limits were too inflexible. It recommended, instead, that limits should be applied over a five year period. A limit of 100 mSv was recommended, this is equivalent to an average of 20 mSv. Stability and continuity with its old recommendations was maintained by allowing workers to receive up to 50 mSv in any year, as long as the five limit was not exceeded.

All the comments on the ICRP draft that have been seen at the time of writing are critical. These comments originate from several different perspectives, but are united in their criticism of the regulatory approach adopted by the ICRP. While these two comments cannot be automatically assumed to represent all the views that the Commission will receive, they do indicate the changed social context in which the Commission now operates. It cannot automatically assume that its pronouncements will be supported, even by organisations that have traditionally supported it. However, this criticism also has to be compared against other statements from the NRPB and the French authorities welcoming the new recommendations as providing a positive contribution to radiological protection.

During late 1990 the Commission were finalising the final text of its new recommendations, which were expected to be published in the first half of

1991. The Commission has yet to respond officially to the Gardner study that linked the occupational exposure of the father with childhood leukaemia. This study is highly significant and has provided another challenged to the radiological protection community. The NRPB have commented that methods of assessing genetic risk are *urgently* required. The genetic effects of radiation were first described in 1927.

In the 1940s the concept of biological tolerance was replaced by the maximum permissible dose in response to concern over genetics. In the 1980s the recognition that the risk of fatal cancer had been underestimated meant that acceptable risks could not longer be considered acceptable. Instead the notion of tolerance was readopted. This time it did not mean biological tolerance but societal tolerance. The theory of tolerability has, however, been challenged again by genetics. The highest level of risk identified by Gardner exceeds that considered the maximum tolerable for occupational work.

This thesis has focused on the process of the establishment of radiological protection recommendations by the ICRP. The Commission's system of protection is not solely based upon its scientific assessment of risk. Increases in risk have not led to proportional reductions in its dose limits. Equally, its recommendations are not solely based upon social considerations.

Instead, the Commission's recommendations have been formed in response to a complex relationship between scientific data and social considerations. The relationship between these concerns has been shaped by a combination of disciplinary, professional, and occupational factors and a shared *socio-technical commitment* to nuclear energy.

The Commission has responded to new scientific data by balancing increases in risk with its aim of maintain continuity and stability in successive recommendations. Where scientific data indicates that risks are higher than previously recognised, the Commission has responded by making complex changes to its philosophy and methods of describing risk. Where changes in numerical limits have been applied, they have been accompanied by practical measures designed to limit the impact of the change and maintain stability with old recommendations and provide flexibility in the application of the new.

The Commission has responded to recent social pressures by becoming slightly more open in its decision-making process. However, the publication of the draft recommendations is not sufficient. Until recently, the Commission chose not to emphasise the influence of non-scientific considerations in the formulation of its recommendations and maintained that its recommendations were scientifically determined. It now recognises that the risk is four to five times greater than it recognised thirteen years ago. However, it argues that this needs to be balanced against the need for stability and flexibility. These considerations should not be the function of an "independent" advisory group. This is a national regulatory function.

The ICRP makes judgements on the level of risk that others can face. Its recommendations are used by politicians to justify national policy decisions. Yet the ICRP is not a group of "disinterested" scientists. Its assessment of scientific data and the formulation of recommendations is influenced by the affiliations of its members and a shared socio-technical commitment to nuclear energy. It is questionable whether the

ICRP is an appropriate body to make judgements on the level of risk that others can face.

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