

Presentation to the Select Committee
on Ontario Hydro Affairs

BASIS FOR LIMITING EXPOSURE TO IONIZING RADIATION

W.R. Bush, Manager
Radiation Protection Division
Atomic Energy Control Board
Ottawa, Canada

July 6, 1979

BASIS FOR LIMITING EXPOSURE TO IONIZING RADIATION

Presentation to the Select Committee on Ontario Hydro
Toronto - July 6, 1979 by

W.R. Bush, Manager
Radiation Protection Division
Atomic Energy Control Board

Early limits for exposure to ionizing radiation were aimed at preventing injury to X-ray workers, and were set at a fraction of the dose required to produce an observable effect (skin reddening), which was the same basis as used for setting limits for other industrial hazards. This threshold basis for radiation limits began to be questioned in the 1930's when the possibility of genetic effects was considered, and in the 1940's when animal studies in the U.S.A. under the atomic bomb project suggested that cancer and genetic effects might be produced at levels below the existing limits. Ever-increasing attention was given, and continues to be given, to determining the probability of long-term effects (cancer and genetic effects), and to developing radiation protection concepts for minimizing radiation exposures.

Cancer and genetic damage occur naturally, and any radiation-induced increase above the natural incidence can not be detected directly, but can only be inferred from estimates of the probability of the harmful effect per unit dose. The vast majority of persons exposed to small doses of radiation will suffer no ill effects whatsoever, but a very small fraction of the exposed persons might develop cancer several years after the exposure. The fraction of the exposed persons who might develop cancer is not known accurately because the fraction is so small that any increase above the natural cancer incidence is virtually imperceptible.

It is known that the probability of radiation-induced cancer is very small: of the order of one chance in 6000 of fatal cancer for every rem of exposure. Ontario Hydro's nuclear workers receive

an average dose of the order of 1 rem per year. If they received 1 rem every year for 40 years, the average chance of developing fatal cancer as a result of the occupational exposure would be about 40 in 6000. In other words, for every 6000 occupationally exposed persons (each receiving 1 rem/yr for 40 years), 40 might develop fatal cancer as a result of their exposure. Fifteen to twenty per cent of them (900 to 1200 of the 6000 workers) would die from cancer even if not occupationally exposed to radiation. The 40 radiation-induced cancers would not be detectable amongst the 900 to 1200 naturally-occurring cancers, and this is the reason for the uncertainty about the effects of low doses of radiation. The uncertainty exists because any radiation-induced cancer or genetic effects that might occur are so infrequent that they are indistinguishable from naturally-occurring cancers and genetic effects.

In view of the uncertainty about the exact magnitude of the risk from small doses of radiation, it is assumed for radiation protection purposes that all doses are potentially harmful, with the probability of harm being directly proportional to the dose, without threshold. The probability of cancer and genetic effects per rem of exposure is determined from observations of large groups of people who have been exposed to large doses of radiation (of the order of 100 rems) during the atomic bombings of Japan and during medical treatment. For example, one study of 14,109 ankylosing spondylitis patients, who received an average dose of about 320 rads to their bone marrow, showed 31 cases of leukemia whereas only 6 to 7 cases would have been expected in the absence of the radiation treatment. The probability of radiation-induced leukemia indicated by this raw data is 5.4 cases per million persons per rad of exposure. A more sophisticated analysis of the data indicates a probability of 7.5 to 16.4 (average 11.4) cases of leukemia per million persons exposed to one rad. Note that in this study of 14,109 patients, 14,078 did not develop leukemia even though exposed to doses more than 60 times higher than the current dose limit (5 rems per year).

.../

The foregoing example is taken from a report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)¹. This committee was established by the United Nations in 1955 for the purpose of receiving, compiling, assembling, reviewing, evaluating and summarizing reports on radiation levels and effects, and indicating areas of research that require further study. UNSCEAR maintains a continuous review of all relevant world literature and so provides an up-to-date source of information on radiation sources and effects. Canadian participation in the work of UNSCEAR has included experts from the National Research Council, Environment Canada, National Health and Welfare, Atomic Energy of Canada, and the Atomic Energy Control Board.

It is known that the body can repair at least a portion of radiation-induced damage, especially the damage produced by gamma and beta radiation, which are the major types of radiation encountered in nuclear power plants. The smaller the dose, the greater the chance of repair and recovery, and therefore it is likely that radiation risk estimates derived by linear extrapolation from effects observed at high doses will overestimate the risk from the low doses received in nuclear power plants. Consequently, it is thought that such risk estimates provide a conservative basis for setting radiation dose limits. In this sense, the risk estimates based on observations at high doses are considered realistic for radiation protection purposes.

Given the assumption that all doses of radiation are potentially harmful, with the effect being directly proportional to the dose, it follows that the setting of a dose limit is tantamount to setting a maximum acceptable risk of harm, which raises ethical problems. Fortunately, a rational methodology for dealing with this socio-scientific problem has been evolved by the International Commission on Radiological Protection (ICRP). A description of the ICRP is given in Attachment I. An insight into the evolution of radiation protection philosophy can be gained by tracing the history of the ICRP's system of dose limitation over the last 50 years:

.../

- 1928 formation of the ICRP (then called the International X-ray and Radium Protection Committee) by the International Congress of Radiology. The first recommendations concerned shielding requirements and cautioned as follows: "An X-ray operator should on no account expose himself unnecessarily to a direct beam of X-rays", and, "An operator should place himself as remote as practicable from the X-ray tube".
- 1934 first limit: 0.2 R per day (equivalent to about 60 rem per year).
- 1950 (first meeting since 1937); name changed to ICRP and membership increased from seven to twelve, to be selected on basis of radiation protection expertise, without regard to nationality; expert committees established; maximum permissible dose set at 0.3 R per week (equivalent to 15 rem per year).
- 1958 reduction to 5 rem per year; first limit for members of the public: 0.5 rem per year.
- 1965 ICRP publication 9 introduced concepts of justification of practices and optimization of radiation protection.
- 1977 ICRP publication 26; increased emphasis placed on justification of practices and optimization of radiation protection, with dose limits considered as upper boundary for the optimization process.

The ICRP in its 1977 recommendations has avoided the contentious issue of specifying an acceptable risk by showing that the average risk occurring when working under a 5 rem limit is comparable to the risk of working in an industry with a high standard of safety, and by placing its primary emphasis on keeping exposures as low as reasonably achievable, economic and social factors being taken into account (ALARA). The objective of ALARA is to achieve an optimum balance between low collective detriment and low cost.

The ALARA level for a particular operation is that level of collective effective dose below which the cost of any additional radiation protection measures would exceed the worth of the resulting reduction in health detriment. Further discussion of the meaning and application of ALARA is given in attachment II, and additional discussion of ALARA plus the modus operandi of the AECB in its compliance activities is given in attachment III.

The AECB encourages the application of the ALARA concept through its licensing and compliance activities, although it has not yet incorporated ALARA into the Atomic Energy Control Regulations. At the time of the last major revision of the Regulations (1974), it was decided not to include a statement of ALARA because it was not needed, since Ontario Hydro and other licensees were already following the ALARA principles. It was feared that inclusion of an ALARA statement in the 1974 revision would be subject to such wide variations in interpretation that the disadvantages of including the statement would outweigh the advantages. However, considerable clarification of the application of the ALARA concept has been made since 1974 and it now appears appropriate to incorporate a statement of ALARA into the regulations.

A useful variation of the ALARA concept is to specify a fixed numerical value for some operations. For example, experience has shown that nuclear power stations such as Pickering and Bruce can operate with radioactive effluents at less than 1% of the release limit derived from the dose limits, and so 1% has become a design and operating target for nuclear power stations. The 1% target can be considered as a sort of ALARA value, although a proper application of the ALARA principles might result in different targets for different stations, depending on the proximity and density of the surrounding populations.

The number of people exposed is significant because this, combined with their average dose, determines the collective dose (man-rem),

which is proportional to the collective detriment resulting from the given operation. The AECB has specified a collective dose limit for application to a limited population around nuclear power plants (10,000 man-rem per year to those receiving 5 mrem per year or more) but this limit has shortcomings and is under review. The ICRP does not recommend a collective dose limit because it appears that better control can be achieved by requiring that all sources of exposure be justified and that the doses from all justifiable sources be as low as reasonably achievable. Nevertheless, the ICRP does recommend that the total collective dose from all sources be kept under review in order to assure that it remains acceptably low.

The limits for release of radioactive substances to the environment are based on the concept of committed dose, which is the total dose received during the 50 years following release to the environment. If the committed dose due to releases in any given year is within the annual dose limits, then the maximum annual dose received after 50 years of accumulation in the environment will also be within the dose limits. Since most radioactive substances released from nuclear power plants have mean lives much less than 50 years, the present system for limiting releases accounts for any possible build-up of radioactivity in the environment.

The foregoing paragraphs apply to routine operation of power plants. Different criteria are appropriate when designing equipment for limiting the radiological consequences of accidents, and a reference dose value of 25 rems has commonly been used. This is not a permissible dose value, just as accidents are not permissible. Nevertheless, accidents might occur and design reference dose values are needed. The fact that reference dose values greater than the dose limits are specified is simply an acknowledgement of the fact that doses higher than the normal limit might be received in the event of an accident. The 25 rem value is rather arbitrary, being the dose level at which temporary changes in the blood become readily observable.

.../

There is no imminent danger from a 25 rem dose, but the expectation of long-term injury (cancer or genetic damage) is five times as high as at the 5 rem limit. Even higher reference dose values have been considered as design targets for limiting the radiation doses from some very improbable types of accident, but, again, these reference values cannot be considered as permissible doses, just as the improbable accidents in question cannot be considered as permissible accidents.

The AECB has tended to follow ICRP recommendations, and is currently considering how it might incorporate all or part of the latest recommendations into the Atomic Energy Control Regulations. The rest of the nuclear world subscribes more-or-less to the ICRP principles, as evidenced by the work of the International Atomic Energy Agency (IAEA), which is currently revising its Basic Safety Standards for Radiation Protection (as well as various other documents) in accord with ICRP publication 26. The revision is being undertaken by an advisory group composed of radiation protection experts from eleven countries (including Canada, represented by an AECB staff member) plus four international organizations (IAEA, World Health Organization, International Labour Office, and Nuclear Energy Agency). The IAEA solicited comments on the first draft of the revision from its member states and found no serious disagreement with the ICRP principles, although some countries expressed reservations about perceived difficulties in applying some of the concepts (optimization of radiation protection, for example). According to a paper presented at an IAEA Seminar on the Practical Implications of the ICRP Recommendations⁽²⁾, the U.S. Nuclear Regulatory Commission (NRC) has some serious reservations about adopting the new ICRP recommendations. The NRC apparently believes that the ICRP principles are sound but would be difficult to implement under the climate of nuclear controversy currently existing in the USA. For example, the new ICRP system of dose limitation implies higher dose limits for irradiation of some individual organs. In actual practice, however, the new system of dose limitation would generally be more restrictive than previous systems, because of the requirement to consider the total detriment from all irradiated tissues and because of the increased emphasis on ALARA. Another objection

is that the new ICRP system of dose limitation does not fully account for the risk of radiation exposure, since only fatal cancers, and genetic effects in only the first two generations, are considered. This shortcoming is acknowledged by the ICRP, at least with respect to members of the public, and additional guidance is forthcoming from the IAEA, UNSCEAR and the ICRP. This aspect will be considered carefully by the AECB in its current review of the Atomic Energy Control Regulations.

An Advisory Committee on Radiation Protection was established by the AECB earlier this year. The terms of reference of the committee and a list of its members are attached (Attachments IV and V). The committee has appointed a sub-group to review the various epidemiological studies that are published from time to time in the scientific literature. One of the high priority tasks of the new committee is to review the biological aspects of the new ICRP recommendations and to consider how these recommendations might be incorporated into the Atomic Energy Control Regulations. The AECB is not bound to adopt the new ICRP recommendations, however, there does not appear to be any better system of dose limitation available.

References

1. Sources and Effects of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation, 1977 report to the General Assembly, with annexes. (Annex G, para 83, 84).
2. Practical Implications to the United States Nuclear Regulatory Commission of the ICRP Recommendations (1977). Robert E. Alexander and Walter S. Cool (Office of Standards Development, Nuclear Regulatory Commission, Washington, D.C., 20555), presented at the Topical Seminar on the Practical Implications of the ICRP Recommendations (1977) and the Revised IAEA Basic Standards for Radiation Protection, Vienna, March 5-9, 1979.

I

W-10 BUSH



The International
Commission on
Radiological Protection

INTRODUCTION

The International Commission on Radiological Protection (ICRP) has been functioning since 1928 when it was established, under the name of the International X-ray and Radium Protection Committee, by the Second International Congress of Radiology. It assumed the present name and organisational form in 1950 in order to cover more effectively the rapidly expanding field of radiation protection. As one of the commissions established by the International Congress of Radiology, ICRP has continued its close relationship with succeeding Congresses of Radiology, and it has also been looked to as the appropriate body to give general guidance on the more widespread use of radiation sources caused by the rapid developments in the field of nuclear energy. The Commission continues to maintain its traditional contact with medical radiology and the medical profession generally, and it also recognises its responsibility to other professional groups and its obligation to provide guidance within the field of radiation protection as a whole. The policy adopted by the Commission in preparing its recommendations is to consider the fundamental principles upon which appropriate radiation protection measures can be based while leaving to the various national protection bodies the responsibility of formulating the specific advice, codes of practice, or regulations that are best suited to the needs of their individual countries.

MEMBERSHIP AND CURRENT WORK

The Commission's rules require that its members be elected every four years. The membership of the Commission and of its committees for 1977-1981 is as follows:

Main Commission

B. Lindell <i>physicist</i> (Chairman)	S. Takahashi <i>M.D., radiodiagnostician</i>
D. J. Beninson <i>M.D., chemist</i> (Vice-Chairman)	A. C. Upton <i>M.D., pathologist</i>
H. J. Dunster <i>physicist</i>	J. Vennart <i>physicist</i>
W. Jacobi <i>physicist</i>	K. Z. Morgan (Member emeritus)
H. Jammet <i>M.D., radiotherapist</i>	F. E. Pochin (Member emeritus)
J. Liniecki <i>M.D.</i>	L. S. Taylor (Member emeritus)
C. B. Meinhold <i>physicist</i>	
A. A. Moiseev <i>physical engineer</i>	
K. A. Rowley <i>M.D., radiodiagnostician</i>	
W. K. Sinclair <i>physicist</i>	F. D. Sowby <i>M.D.</i> (Scientific Secretary)

Committees

At its meeting in November 1977 the Commission decided to modify its former system of committees, and to plan its work for 1977-1981 with the following committee structure:

Committee 1 on Radiation Effects

Committee 1 will assess the risk and severity of stochastic effects and the induction rates of the non-stochastic effects of irradiation. It will consider the modifying influence of exposure parameters such as dose rate, fractionation of dose, RBE, spatial distribution of dose and any synergistic effects of chemical and physical factors.

~~D. J. Schinckel~~

~~A. G. Searle~~ (Chairman)

S. Abrahamson
G. W. Barendsen
V. P. Bond
J. M. Brown
J. Lafuma

H. Mutsudaira

B. Modan
R. H. Mole
P. Ohedal
A. G. Searle
G. Silini

Committee 2 on Secondary Limits

The basic function of Committee 2 is to develop values of secondary limits, based on the Commission's recommended dose-equivalent limits. For the immediate future the committee will be fully concerned with the preparation of secondary limits for internal irradiation; because of this, matters to do with the derivation of secondary limits for external irradiation will, for the time being, be considered by Committee 3.

J. Vennart (Chairman)

W. J. Bair
G. W. Dolphin
L. E. Feinendegen
M. R. Ford
A. Kaul
C. W. Mays

J. C. Nenot

B. Nosslin
P. V. Ramzaev
C. R. Richmond
R. C. Thompson
N. Veall

Committee 3 on Protection in Medicine

The Commission considers that its relationship to the International Congress of Radiology and its traditional contacts with the medical profession warrant the establishment of a committee specifically concerned with radiation protection in medicine. Matters requiring particular attention by the committee include protection of the patient in radiodiagnosis and radiotherapy and protection in nuclear medicine. Committee 3 will temporarily be concerned with the development of secondary standards for external radiation.

C. B. Meinhold (Chairman)

D. K. Bewley
J. H. E. Carmichael
R. O. Gorson
V. I. Ivanov
J. Jenkowski
A. M. Kellerer
S. Koga

C. Lagergren

L.-E. Larsson
P. Pellerin
A. K. Poznanski
E. L. Saenger
R. H. Thomas
J. Villforth

Committee 4 on the application of the Commission's recommendations

Committee 4 will continue its role of providing advice on the Commission's system of dose limitation, and on protection of the worker and the public. The committee will also serve as a major point of contact with international organisations concerned with radiation protection.

H. Jammet (Chairman)
R. M. Alexakhin
R. M. Fry
A. J. Gonzalez
O. Ilari
E. Kunz
D. Méchali

D. W. Moeller
F. Morley
H. Muth
J.-O. Snihs
R. Wilson
B. C. Winkler
Y. Yoshizawa

FINANCIAL SUPPORT

Meetings of the Commission and all its committees are held approximately every two years, and the Commission itself meets about once a year. In addition, committees and task groups meet on their own to discuss and prepare their reports. The Commission has been able to support the travel costs of some of the individuals attending these meetings, thanks to grants of money generously made to it by the World Health Organization, the International Atomic Energy Agency, the United Nations Environment Programme, the International Society of Radiology, the International Radiation Protection Association, the Nuclear Energy Agency, the European Economic Community and national sources in Canada, Japan and the United Kingdom. Nevertheless, the contribution that the Commission can make to travel expenses is severely limited and during recent years between one-half and two-thirds of the total travel costs have been borne by the institutions of the ICRP members. The Commission is greatly indebted to this support, without which it would not be possible to carry out its work.

RELATIONSHIPS WITH OTHER BODIES

The Commission has an official relationship with the World Health Organization and the International Atomic Energy Agency. Close working relationships are also maintained with the United Nations Scientific Committee on the Effects of Atomic Radiation, the International Labour Office, the United Nations Environment Programme, the Nuclear Energy Agency and the European Economic Community. The Commission is represented by observers at a number of meetings organised by these bodies; all of the above bodies are invited to send representatives to the Commission's meetings with its committees.

RULES GOVERNING THE SELECTION AND WORK OF THE COMMISSION

The following are the Commission's rules, as approved by the International Executive Committee of the International Congress of Radiology.

1.(a) The International Commission on Radiological Protection (ICRP) shall be composed of a Chairman and not more than twelve other members. The selection of the members shall be made by the ICRP from nominations submitted to it by the National Delegations to the International Congress of Radiology and by the ICRP itself. The selections shall be subject to approval by the International Executive Committee (IEC) of the Congress. Members of the ICRP shall be 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 to nationality.

(b) The membership of the ICRP shall be approved during each International Congress, for service until the end of the succeeding Congress, or until new members are appointed. Not less than three but not more than five members shall be changed at any one congress. In the intervening period vacancies may be filled by the ICRP.

(c) In the event of a member of the ICRP being unable to attend the ICRP meetings, a substitute may be selected by the ICRP as a temporary replacement. Such a substitute shall not have voting privileges unless specifically authorised by the ICRP.

(d) The ICRP shall be permitted to invite individuals to attend its meetings to give special technical advice. Such persons shall not have voting privileges, but their opinions may be recorded in the minutes.

2. The Chairman shall be elected by the ICRP from among its members to serve until the end of the succeeding Congress, or until his successor is elected. The choice shall not be limited to the country in which it is proposed to hold the succeeding Congress. The Chairman shall be responsible for reporting the proceedings and recommendations of the ICRP at the next Congress.

3. The ICRP shall elect from among its members a Vice-Chairman who will serve in the capacity of Chairman in the event that the Chairman is unable to perform his duties.

4. Minutes of meetings and records of the ICRP shall be made by a Scientific Secretary selected by the Chairman of the ICRP, subject to the approval of its members. The Scientific Secretary need not be a member of the ICRP. The records of the ICRP shall be passed on to the succeeding Scientific Secretary.

5. The Chairman, in consultation with the Vice-Chairman and the Scientific Secretary, shall prepare a programme to be submitted to the Commission for discussion at its meetings. Proposals to be considered shall be submitted to the Chairman for circulation to all members of the ICRP and other specially qualified individuals at least two months before any meeting of the ICRP.

6. Decisions of the ICRP shall be made by a majority vote of the members. A minority opinion may be appended to the minutes of a meeting if so desired by any member upon his submission of the same in writing to the Scientific Secretary.

7. The ICRP may establish such committees as it deems necessary to perform its functions.

Bo Lindell, (Chairman)

F. D. Sowby, (Scientific Secretary)

International Commission on Radiological Protection,
Clifton Avenue, Sutton, Surrey, England SM2 5PU.

May 1978

PUBLICATIONS

PRINCIPLES OF ENVIRONMENTAL MONITORING RELATED TO THE HANDLING OF RADIOACTIVE MATERIALS. A report prepared by a Task Group of ICRP Committee 4. ICRP Publication 7, Pergamon Press, Oxford (1966).

REPORT OF COMMITTEE 4 ON EVALUATION OF RADIATION DOSES TO BODY TISSUES FROM INTERNAL CONTAMINATION DUE TO OCCUPATIONAL EXPOSURE. ICRP Publication 10, Pergamon Press, Oxford (1968).

THE ASSESSMENT OF INTERNAL CONTAMINATION RESULTING FROM RECURRENT OR PROLONGED UPTAKES. A report of ICRP Committee 4. ICRP Publication 10A, Pergamon Press, Oxford (1971).

A REVIEW OF THE RADIOSENSITIVITY OF THE TISSUES IN BONE. A report prepared by a Task Group for ICRP Committees 1 and 2. ICRP Publication 11, Pergamon Press, Oxford (1968).

GENERAL PRINCIPLES OF MONITORING FOR RADIATION PROTECTION OF WORKERS. A report prepared by a Task Group of ICRP Committee 4. ICRP Publication 12, Pergamon Press, Oxford (1969).

RADIATION PROTECTION IN SCHOOLS FOR PUPILS UP TO THE AGE OF 18 YEARS. A report by Committee 3 of ICRP. ICRP Publication 13, Pergamon Press, Oxford (1970).

RADIOSENSITIVITY AND SPATIAL DISTRIBUTION OF DOSE. Reports prepared by two Task Groups of ICRP Committee 1. ICRP Publication 14, Pergamon Press, Oxford (1969).

PROTECTION AGAINST IONIZING RADIATION FROM EXTERNAL SOURCES: A report of ICRP Committee 3 ICRP Publications 15 and 21, Pergamon Press, Oxford (1976).

PROTECTION OF THE PATIENT IN X-RAY DIAGNOSIS. A report prepared by a Task Group of ICRP Committee 3. ICRP Publication 16, Pergamon Press, Oxford (1970).

PROTECTION OF THE PATIENT IN RADIONUCLIDE INVESTIGATIONS. A report prepared for ICRP and adopted by the Commission in September 1969. ICRP Publication 17, Pergamon Press, Oxford (1971).

THE RBE FOR HIGH-LET RADIATIONS WITH RESPECT TO MUTAGENESIS. A report prepared by a Task Group of ICRP Committee 1. ICRP Publication 18, Pergamon Press, Oxford (1972).

THE METABOLISM OF COMPOUNDS OF PLUTONIUM AND OTHER ACTINIDES. A report prepared by a Task Group of ICRP Committee 2. ICRP Publication 19, Pergamon Press, Oxford (1972).

ALKALINE EARTH METABOLISM IN ADULT MAN. A report prepared by a Task Group of ICRP Committee 2. ICRP Publication 20, Pergamon Press, Oxford (1973).

IMPLICATIONS OF COMMISSION RECOMMENDATIONS THAT DOSES BE KEPT AS LOW AS READILY ACHIEVABLE. A report of ICRP Committee 4. ICRP Publication 22, Pergamon Press, Oxford (1973).

REPORT OF THE TASK GROUP ON REFERENCE MAN. A report prepared by a Task Group of Committee 2 of ICRP. ICRP Publication 23, Pergamon Press, Oxford (1975).

RADIATION PROTECTION IN URANIUM AND OTHER MINES. A report of ICRP Committee 4. ICRP Publication 24, Pergamon Press, Oxford (1977). (Annals of the ICRP vol 1, no. 1).

THE HANDLING, STORAGE, USE AND DISPOSAL OF UNSEALED RADIONUCLIDES IN HOSPITALS AND MEDICAL RESEARCH ESTABLISHMENTS: A report of a Task Group of ICRP Committees 3 and 4. ICRP Publication 25, Pergamon Press, Oxford (1977). (Annals of the ICRP Vol. 1, No. 2).

RECOMMENDATIONS OF THE INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION. (Adopted January 17, 1977). ICRP Publication 26, Pergamon Press, Oxford (1977). (Annals of the ICRP vol. 1, no. 3).

PROBLEMS INVOLVED IN DEVELOPING AN INDEX OF HARM: A report prepared by a Task Group of the International Commission on Radiological Protection. ICRP Publication 27. Pergamon Press, Oxford (1977). (Annals of the ICRP Vol. 1 No. 4).

PUBLICATIONS IN PREPARATION:

PRINCIPLES CONCERNING EMERGENCY AND ACCIDENTAL EXPOSURES

**LIMITS FOR INTAKES OF RADIONUCLIDES BY WORKERS
PLANNED AND UNPLANNED RELEASES OF RADIOACTIVE MATERIALS**

BIOLOGICAL EFFECTS OF INHALED RADIONUCLIDES

The reports and recommendations of the ICRP are now available in the form of a new review journal, **Annals of the ICRP**. Subscribers to the journal will be assured of receiving each new report as soon as it appears, thus ensuring that they are kept abreast of the latest developments in the important field, and can build up a complete set of ICRP reports and recommendations.

Single issues of the journal will be available separately for those individuals and organizations who do not require a complete set of all ICRP publications, but would like to have their own copy of a particular report covering their own field of interest. Please order through your bookseller, subscription agent, or, in case of difficulty, direct from the publisher at your nearest Pergamon Press office.

Pergamon Press Ltd.

Headington Hill Hall, Oxford, OX3 0BW, England

Pergamon Press Inc.

Maxwell House, Fairview Park, Elmsford, New York 10523, USA

Pergamon of Canada Ltd.

75 The East Mall, Toronto, Ontario M8Z 5W3, Canada

Pergamon Press (Aust.) Pty. Ltd.

19a, Boundary Street, Rushcutters Bay, N.S.W. 2011, Australia

Pergamon Press SARL

24 rue des Ecoles, 75240 Paris, Cedex 05, France

Pergamon Press GmbH

6242 Kronberg-Taunus, Pferdstrasse 1, Federal Republic of Germany

The Meaning of ALARA

ALARA: As low as reasonably achievable, economic and social factors being taken into account.

ALARA is discussed under the following headings:

- 1. Reason for ALARA.
- 2. ALARA: optimization of radiation protection by differential cost-benefit analysis.
- 3. Constraint of ALARA by individual dose limits.
- 4. Supplementing ALARA with good practice.
- 5. Supplementing ALARA with environmental and political considerations.
- 6. Health detriment of a man-rem, and its value (\$/man-rem).
 - 6.1 \$/man-rem for partial or non-uniform irradiation; effective dose.
 - 6.2 Value of an MPC-hour and of a Working-Level-hour.
- 7. Optimization of radiation protection and cost-benefit analyses in practice.
- 8. ALARA and non-stochastic hazards (radiological and other).

1. Reason for ALARA

Any exposure to ionizing radiation in potentially harmful, with the expectation of harm being directly proportional to the effective dose equivalent*. Since the harm cannot be prevented completely, it should be kept

as low as reasonably achievable.

* effective dose equivalent (in rems or sieverts)

$$= \sum_T w_T H_T, \text{ where}$$

w_T is a weighting factor which represents the proportion of the total stochastic risk (risk of cancer and genetic effects) contributed by tissue T when the whole body is irradiated uniformly (w_T values are given in section 6.1), and H_T is the dose equivalent in tissue T.

Dose equivalent (in rems or sieverts) = absorbed dose (in rads or grays) x Q, where

Q is the quality factor, which accounts for the different effectiveness of different types of ionizing radiation in causing injury.

2. ALARA: Optimization of Radiation Protection by Differential Cost-Benefit Analysis

In order to determine the lowest level of exposure that is reasonably achievable, a differential cost-benefit analysis is required, the objective of which is to obtain the best combination of good protection and low cost. In other words, radiation protection should be optimized, such that any expenditure for reducing a dose is commensurate with the resulting benefit.

To optimize the radiation protection for a given operation, the incremental costs involved in reducing the collective effective dose from a given level to a range of lower levels are compared with the incremental health benefits that result from the respective reductions in collective dose. The ALARA value is that level of collective effective dose below which the cost of any additional

radiation protection measures would exceed the worth of the resulting reduction in health detriment.

The value of the health detriment associated with unit dose reduction is discussed below, in section 6. Dose reductions below the ALARA level, although not economically justifiable, are sometimes justifiable on other grounds, as discussed below, in sections 3 to 5.

3. Constraint of ALARA by Individual Dose Limits

The objective of ALARA is to achieve an optimum balance between low collective detriment and low cost, but this optimum would in some cases be achievable only at the expense of unacceptably high individual doses. It is therefore necessary to constrain the optimization process by applying individual dose limits. Individual dose limits should generally be respected, regardless of cost, and, once this guarantee of individual protection is obtained, radiation protection should be optimized so as to minimize the collective effective dose in accord with the ALARA concept.

4. Supplementing ALARA with Good Practice

Good, commonly-accepted, industrial hygiene practices should be followed, even if a differential cost-benefit analysis demonstrates that certain good practices are not economically justifiable. If practices such as good ventilation, good housekeeping and use of protective clothing are generally accepted in other industries using similar industrial practices, then they should be used where applicable in the nuclear industry as well, regardless of quantitative cost/benefit considerations.

5. Supplementing ALARA with Environmental and Political Considerations.

Other conditions that could be superimposed on the quantitative ALARA considerations are that environmental quality be maintained and that the views of the public be considered. Both these factors are rather nebulous, and any reduction of dose below the ALARA level for environmental or political reasons requires qualitative, subjective or arbitrary judgements. Any such judgements should be kept separate from the quantitative ALARA considerations so that the health detriment component of the ALARA value remains recognizable.

6. Health Detriment of a Man-Rem, and its Value (\$/man-rem)

In order to determine if a certain improvement in radiation protection would be worthwhile, the cost of the improvement should be compared with the benefit that results due to the reduction in collective dose (as explained in section 2 above). The benefit resulting from a reduction in dose takes the form of a reduction in the mathematical expectation of harmful health effects, and the value of such a reduction in harm to health can be derived from considerations such as the amount of money that society spends to improve public safety, or the amounts of compensation or insurance awards. For example, the USEPA has concluded from such considerations that it would be reasonable to spend between 1/4 and 1/2 million dollars on effluent controls in order to avert a serious health effect. By combining such dollar values with risk per rem (or risk per man-rem) values, one obtains a \$/man-rem value. For example, assuming a risk factor of 2×10^{-4} serious health effects per man-rem, the USEPA criterion for effluent controls is equivalent to \$50 to \$100 per man-rem averted.

A wide range of \$/man-rem values have been proposed by various authors, based on considerations such as the foregoing. The USNRC has used an interim value of \$1000 per man-rem, and the ICRP has quoted (in its publication No. 22) a range of \$10 to \$250 per man-rem (in 1966 to 1972 dollars). The wide range of values reflects the subjective nature of the estimates, and suggests that it might not be prudent for a regulatory body to specify a single, fixed value. Some authors have suggested that the value of a man-rem saved should increase as the magnitude of individual dose increases, with higher values being appropriate as dose limits are approached.

The above values refer to the worth of the health detriment avoided due to a reduction in dose, and should not be confused with values of a man-rem calculated for other purposes, such as the much higher (several \$1000/man-rem) values based on the cost of replacing a skilled worker who exceeds a dose limit.

6.1 \$/man-rem for Partial or Non-Uniform Irradiation; Effective Dose.

The \$/man-rem values given above are based on uniform irradiation of the whole body; if only part of the body is irradiated, the health consequences per rem are less than for a whole-body dose of 1 rem. The relative magnitude of the health consequences of irradiating single organs or tissues is given by the weighting factors recommended in ICRP publication 26: 1.00 for the whole body, 0.25 for the gonads, 0.15 for the breast, 0.12 for the lungs and for the marrow, 0.03 for the thyroid and for the bone surfaces, and 0.06 for each (up to five) of the other organs or tissues that receive a significant dose. If an expenditure of \$100 is considered reasonable for reducing a whole-body dose by 1 rem, then the

corresponding values for reducing the dose to single organs or tissues by 1 rem would be \$25 for the gonads, \$15 for the breasts, \$12 for the lungs or marrow, \$3 for the thyroid or bone surfaces, and \$6 for other organs or tissues (up to a maximum of five).

For dealing with combined exposures of more than one organ, or with combinations of whole-body exposures and individual organ exposures, the ICRP has developed the effective dose concept. Multiplying the dose equivalent to each organ or tissue by the appropriate weighting factor yields a weighted dose equivalent for each organ, and the sum of these weighted values is the effective dose equivalent (or simply the effective dose). For example, if the whole body dose is 1 rem and the lung dose is 15 rems (the current AECB limit), the effective dose is 1 (for the whole body) + 15×0.12 (for the lungs) = $1 + 1.8 = 2.8$ rems. In other words, 1 rem to the whole body plus 15 rems to the lungs has the same biological significance as 2.8 rems to the whole body.

If only part of an organ or tissue is irradiated, the dose should be averaged over the entire mass when calculating the effective dose. For example, if only half of the bone marrow is irradiated and receives 1 rem, then the dose equivalent averaged over the entire marrow is 0.5 rem, and the weighted dose equivalent is $0.5 \times 0.12 = 0.06$ rem.

The biological significance of irradiating the skin can be estimated by using a weighting factor of 0.01; however, the risk from skin irradiation is primarily non-stochastic (see section 8), and there-

fore the weighted skin dose should not be included in the calculation of effective dose. If an expenditure of \$100 is justifiable for reducing a whole-body dose (or an effective dose) by 1 rem, then the corresponding justifiable expense to save 1 rem of skin dose would be \$1. If only 10% of the skin is irradiated, an expenditure of 10¢ is all that could be justified in order to reduce the exposure by 1 rem.

6.2 Value of an MPC-hour and of a Working-Level-Hour

Knowing the relationship between MPC-hours and committed dose, the \$/man-rem concept can be translated into \$/MPC-hour (or \$/man-MPC-hour). For example, an exposure of 1 MPC-hour results in a committed dose of 2.5 mrem for substances which irradiate the whole body, and so, a value of \$100 per man-rem saved would be equivalent to \$0.25 per MPC-hour saved (or \$2/day for preventing an eight-hour exposure to 1 MPC).

Ideally, the above value (25¢/MPC-h) should apply to any radioactive substance (as it will when the new ICRP concept of effective dose has been fully implemented) but when \$100/man-rem is translated in terms of the ICRP-2 MPC values, the \$/MPC-h values are less than 25¢ for substances that irradiate single organs. For example, one MPC-hour of exposure to a substance that irradiates primarily the lungs would result in a committed dose of 7.5 mrems, which is an effective dose of only 0.9 mrem (0.12×7.5), and so \$100/man-rem is equivalent to only 9¢ per MPC-hour for lung irradiators. The corresponding value for substances that irradiate only the thyroid gland would be only 4½¢ per MPC-hour.

For exposure to radon daughters, the value corresponding to \$100/man-rem would be about 74¢ per WL-hour, assuming the risk from 4 WLM (plus associated gamma radiation and ore dust) is equivalent to the risk from 5 rem of whole-body exposure. As for exposure to other radioactive substances, complete elimination of the radiological detriment resulting from 8 hours of work at the maximum permissible average concentration (0.34 WL) would warrant an expenditure of \$2.

7. Optimization of Radiation Protection and Cost-Benefit Analyses In Practice

Significant reductions in dose can often be achieved in practice at virtually zero cost, simply by developing and following good operating procedures. In such cases, no formal analysis nor \$/man-rem value is needed. Conversely, it is sometimes apparent without a formal analysis that a possible improvement would cost thousands of dollars but result in only trivial dose reduction. In both cases, an order of magnitude value of \$/man-rem could help to determine whether or not a proposed improvement in radiation protection was cost-effective, but a precise \$/man-rem value is not needed.

In other cases, however, especially at the design stage, detailed cost-benefit analyses should be made. The cost-effectiveness of a given design proposal would often be easy to demonstrate over a wide range of values, (such as \$10 to \$1000 per man-rem), but in some cases a single value would be helpful to the designer. As suggested in section 6, however, it might be premature for the AECB to specify a precise value. Further development of cost-benefit analysis procedures is currently being

developed by both the IAEA and the ICRP, and it would seem prudent not to pre-empt them in this area.

8. ALARA and Non-Stochastic Hazards (Radiological and Other)

Non-stochastic hazards are those for which the severity of the effect is proportional to the dose or exposure, and for which a threshold exists (for example, irradiation of the skin or eyes, or exposure to H₂S). If the exposure to such a noxious agent is less than the lowest threshold value, then no quantifiable benefit would result from a further reduction and consequently no quantitative balance could be made against the costs of reducing the exposure. It follows that any regulatory effort to reduce exposure in such cases should be rationalized on some grounds other than ALARA (such as the good-practice criterion mentioned in section 4, above).

WRB/el

1979 May 29.

SEMINAR ON RADIATION PROTECTION IN CANADA

April 26, 27, 1979, Toronto

- Session I: Radiation Protection Regulations

Theme : Responsibility for Radiation Protection

A : ROLE OF THE ATOMIC ENERGY CONTROL BOARD

by W. R. Bush, Manager, Radiation Protection Division, AECB.

SUMMARY

The primary responsibility for protecting workers and the public from excessive exposure to ionizing radiation belongs at the source of potential exposure; i.e., at the workplace, but it is subject to regulatory control by the AECB, as provided for by the Atomic Energy Control Act of 1946.

Few specific radiation protection provisions other than a schedule of dose limits are included in the Atomic Energy Control Regulations and the AECB's guidelines for regulating radiation protection have been largely unwritten. The lack of regulatory detail has allowed a beneficial degree of operational flexibility which has been conducive to the development of good radiation protection policies and practices by the AECB's licensees. Nevertheless, radiation protection regulations are likely to become more complex, and detailed regulatory guides are now needed, for three reasons:

1. A new system of dose limitation has been recommended by the ICRP, which is more rational but also more complex than previous systems. If the AECB decides to incorporate the essence of the new system in its regulations, the regulations are bound to become more complex than at present.

2. Greater regulatory attention is being given to the front end of the fuel cycle (uranium mining, milling, refining and fuel fabrication), and additional regulatory guidance is needed in these areas.

3. Questions, comments and demands from public-spirited groups, labour unions, politicians, journalists and concerned citizens indicate an increasing need to publicize the criteria and methods used by the AECB in regulating the nuclear industry so as to minimize the radiation exposure of workers and the public.

A major gap in the regulations is the absence of an as-low-as-reasonably-achievable (ALARA) statement, although the AECB does encourage ALARA through its licensing and compliance activities. It now seems desirable to incorporate the ALARA principle into the regulations, and one possible way of doing this would be to provide by regulation for the setting of authorized dose and release limits for specific operations that would be more restrictive than the basic dose limits and derived limits.

The derivation of authorized limits should be based on differential cost-benefit analyses; in other words, the limits should be based on radiation protection practices that have been optimized so as to obtain the best protection at the lowest cost, in accord with the ALARA principles of the ICRP. The quantitative cost-benefit balance should be supplemented by the application of good industrial hygiene practices, and in some cases by subjective, qualitative judgements involving non-quantifiable factors such as environmental quality.

The significance of exceeding an authorized limit is

more administrative than biological, the main significance being simply that the licensee has failed to respect his commitment to observe the authorized limits. It would therefore seem appropriate to apply an administrative sanction such as requiring a report to the AECB if an authorized limit is exceeded, instead of a biologically-based sanction such as removal from further exposure. The removal sanction should perhaps be reserved for exposure in excess of a basic dose limit.

The application of authorized limits would not likely result in any reduction in doses received in most cases, because ALARA is already being widely practiced even though it is not included in the regulations. On the other hand, a clearly formulated ALARA policy could help counter the pressures occasionally put on the AECB to reduce its limits without regard to either the resulting costs or the resulting benefits.

Some of the regulatory questions provoked by ICRP publication 26 are discussed, such as:

- Should the AECB adopt the new recommendations, which imply less-restrictive limits for some organs? (In fact, the proper application of the ICRP's new system of dose limitation would generally be more restrictive than the old critical-organ approach because it accounts for the total risk.)
- Should the AECB supplement the dose limits for individual workers with a lower limit for application to the average dose to all the workers in a given occupation?
- Should the radiological risk of uranium mining be set by comparison with the standard of safety in the safer

industries, or should the comparison be made with mining in general, which is not one of the safer industries?

- Should the annual limit for members of the public be supplemented with a limit on the annual exposure averaged over a lifetime? Should the limits be applied to individuals, or to the average member of a critical group?
- Should dose indices be used for determining compliance with the regulatory limits (instead of using the more conventional but obsolescent surface dose measurements)?

The AECB must remain sensitive to public perceptions of radiation and should try to reflect the general interests of society in its regulatory process, but it should not let itself be intimidated by unsupported demands for ever-decreasing dose limits. If the AECB does become convinced that the basic limits recommended by the ICRP should be reduced for biopolitical or bio-social reasons, these social or political safety factors should remain identifiable and not confused with the basic limits. The basic dose limits should be preserved in order to provide an internationally recognized reference point against which the biological significance of radiation exposures can be judged objectively.

ADVISORY COMMITTEE ON RADIOLOGICAL PROTECTION

Terms of Reference

Purpose: To advise the Board on matters relating to health protection concerning ionizing radiation.

Scope: The Committee will be expected to advise on any health aspect of exposure to ionizing radiation related to the activities of the Board, including such matters as:

- interpretation and application of the recommendations of the International Commission on Radiological Protection and other international bodies concerned with radiation protection, including review of proposed regulations;
- interpretation of new information on biological effects of ionizing radiation that could have a bearing on radiation protection standards;
- research and development related to radiological health and protection;
- broad or generic radiation protection issues associated with the licensing activities of the Board.

Function: Normally the Committee will advise on matters referred to it by the Board but may, on its own initiative, offer advice on any matter pertaining to radiological protection aspects of the Board's activities.

The Committee shall meet at such times as deemed necessary but at least once per year.

The Board will supply secretarial and support services for the Committee, but no member of the staff shall be a member of the Committee.

The Committee will report to the President of the Board.

Membership: Membership shall be no less than 10 and no more than 15.

Members will be appointed by the Board for 2 year terms and may be re-appointed (except initially members will be appointed for 2 or 3 year terms in approximately equal proportion). The Chairman shall be named by the Board.

The primary qualification for membership shall be expertise (recognizable by appropriate peer groups) in subjects relevant to the Committee's purpose, such as:

biological effects of radiation; work of ICRP, UNSCEAR and other international bodies; nuclear medicine; public and occupational health related to ionizing radiation; practical aspects of radiation protection associated with the use of radioactive prescribed substances and the operation of nuclear facilities.

Within this basic requirement membership should reflect the nature and geographical distribution of nuclear activities as much as possible.

79/1/8

ADVISORY COMMITTEE ON / COMITÉ CONSULTATIF DE
RADIOLOGICAL PROTECTION / PROTECTION RADIOLOGIQUE

Membership List / Liste des Membres
(Provisional) (Provisoire)

Chairman/Président

Dr. G.C. Lutler
Biological Science Laboratories
National Research Council
Laboratoire des Sciences Biologique
Conseil National des Recherches
Ottawa, Ontario
R1A 016
Tel. (613)-995-6600

Vice-Chairman / Vice President

Dr. C.G. Stewart
Chalk River Nuclear Laboratories
Atomic Energy of Canada Research
Company
Chalk River, Ontario
R6J 1J0
Tel. (613)-687-5561

Members / Membres

Dr. R.H. Bédicq, Ph. D.
Centre Hospitalier de l'Université
de Montréal
Hôpital Notre-Dame
1500, rue Sherbrooke est
Montréal, Québec
H2L 4R8
Tél. (514)-876-7270

Dr. D. Hollywood
Cottage Hospital
St. Lawrence, Newfoundland
A0L 2V0
Tel. (709)-873-2220

Dr. P. Lachance
Département de santé communautaire
Centre hospitalier de l'Université
Laval
2705, boulevard Laurier
Québec, Québec
G1V 4G2
Tél. (418)-656-7883 (Université)
-656-6085 (Hôpital)

Dr. E.G. Létourneau
Radiation Protection Bureau
Health and Welfare Canada
Brookfield Road
Bureau de la Radioprotection
Santé et Bien-Être Social
Chemin Brookfield
Confederation Heights
Ottawa, Ontario
K1A 1C1
Tel. (613)-998-3624

Dr. A. Marko
Chalk River Nuclear Laboratory
Atomic Energy of Canada Research
Company
Chalk River, Ontario
R6J 1J0
Tel. (613)-687-5561

Dr. J. Muller
Special Studies and Services Branch
Ministry of Labour (Ontario)
400 University Avenue
Toronto, Ontario
M7A 1T7
Tel. (416)-965-6375

Mr. K. Keiner
Oil, Chemical and Atomic Workers
International Union
10603, 100th Avenue
Edmonton, Alberta
T5C 0B2
Tel. (403)-422-7932

Dr. J.B. Sutherland
Nuclear Medicine
Health Sciences Centre
700 William Avenue
Winnipeg, Manitoba
R3E 0Z3

Dr. L.L. Skarsgaard
B.C. Cancer Research Centre
661 West 10th Avenue
Vancouver, British Columbia
V5Z 1L3
Tel. (604)-873-8461

Mr. A. Wilson
Health and Safety Department
Ontario Hydro
700 University Avenue
Toronto, Ontario
M5G 1X6
Tel. (416)-592-2491

Secretary / Secrétaire

Dr. D.M. Hiblett
c/o Atomic Energy Control Board
P.O. Box 1046
Ottawa, Ontario
K1P 5S5
Tel. (613)-995-3181

Science Adviser (Coordinator) / Conseiller Scientifique (Coordonnateur)

F.C. Boyd
Atomic Energy Control Board
P.O. Box 1046
Ottawa, Ontario
K1P 5S5
Tel. (613)-593-7561