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Subseries: General Science Files

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Folder Title:
Life Sciences: Radiation [1991-92]

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"LIFE SCIENCES (CORRESPONDENCE TRACKING)"

TYPE: ACTION DOCUMENT NUMBER: 9123435
ORIGINATOR: 02 STATUS I DIRECTORATE STATUS C

FROM: VIOLA, V.E.: INDIANA UNIVERSITY

TO: DR. D.A. BROMLEY

DATE OF
CORRESPONDENCE: 08/06/91

SUBJECT: CONCERN OVER THE RAADIATION LEVELS TO WHICH
PERSONNEL (AND EXPERIMENTS) ON THE SPACE STATION
WILL BE EXPOSED.

DIRECTORATE STAFF
ASSIGNED: LIFE SCIENCES ASSIGNED: Alicia K. Dustira

ACTION STAFF
REQUIRED: FOR DAB'S SIGNATURE ACTION: Bromley Signature

SENDER'S DUE DATE:
OSTP DUE DATE: 08/26/91 STAFF DUE DATE 08/26/91
DATE COMPLETED: DATE COMPLETED/DEPT:09/18/91

COPIES TO: D. Allan Bromley D.A. Henderson
PHYSICAL SCIENCES
Carl Bretscher

WHITE HOUSE TRACKING #: CONTACT PERSON:
PHONE: EXT:
REMARKS:

OSTP RECEIVED: 08/12/91
DEPT RECEIVED: 08/12/91

FILE: P-LIFE SCI-RADIATION*PS-SPACE

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

September 18, 1991

Dear ~~Dr.~~ ^{*vic*} Viola:

Thank you for your letter of August 6, 1991, outlining your concerns about the radiation levels to which personnel and experiments on the space station will be exposed. You should be reassured that the National Aeronautics and Space Administration has in fact given serious consideration to the radiation environment of the space station, as evidenced by the attached letter from Dr. Schimmerling that addresses each of your concerns in detail.

I appreciate your taking the time to bring these matters to my attention, and I would encourage you to contact Dr. Schimmerling at NASA if you have any further questions.

Sincerely,



D. Allan Bromley
Director

Enclosure

V. E. Viola
Distinguished Professor of Chemistry
Department of Chemistry
Indiana University
Bloomington, IN 47405

"Document Control"

TYPE: INFORMATION

DOCUMENT NUMBER: 9202968

ORIGINATOR: 02

STATUS C

DIRECTORATE STATUS

FROM: ZIEMER, Paul L.: U.S. DEPARTMENT OF ENERGY

TO: DR. D.A. BROMLEY

DATE OF
CORRESPONDENCE: 09/23/92

SUBJECT: HE IS FORWARDING A COPY OF THE DOE RADIOLOGICAL
CONTROL MANUAL.

DIRECTORATE STAFF
ASSIGNED: ASSIGNED:

ACTION STAFF
REQUIRED: ACTION:

SENDER'S DUE DATE:
OSTP DUE DATE: STAFF DUE DATE
DATE COMPLETED: DATE COMPLETED/DEPT:

COPIES TO: D. Allan Bromley
LIFE SCIENCES

WHITE HOUSE TRACKING #: CONTACT PERSON:
PHONE: EXT:
REMARKS: ENCLOSURES TO DR. BROMLEY.

OSTP RECEIVED: 10/01/92 DEPT RECEIVED:
FILE: P-LIFE SCIENCES-RADIATION

CENTRAL FILES:



Department of Energy
Washington, DC 20585

2968

SEP 23 1992

The Honorable D. Allan Bromley
Assistant to the President
for Science and Technology
Office of Science & Technology Policy
Old Executive Office Building, Room 360
Washington, D.C. 20500

Dear Dr. Bromley:

In continuation of Secretary Watkins' high priority for improving radiological protection in the Department of Energy (DOE), he issued the DOE Radiological Control (RadCon) Manual on June 17, 1992. It is my pleasure to forward a copy of the DOE RadCon Manual to you for your information and use.

The RadCon Manual was developed by the Office of Health Physics and Industrial Hygiene, under the direction of my Office of Environment, Safety and Health, and with assistance from a task force made up of representatives from various departmental elements as well as experts from the private sector. The Manual's provisions define the Department's philosophy and standards for radiological protection and challenge DOE and contractor facilities to go beyond minimum requirements to maximize worker safety and health related to radiological practices. The RadCon Manual serves as the keystone in DOE's initiative to establish excellence in radiological health and safety and reaffirms the Department's commitment to the protection of workers, the public and the environment.

The RadCon Manual adopts the latest national and international recommendations on radiation protection and control and is a prescriptive guide for DOE Line Managers who are responsible for radiological control programs. The comprehensive nature of the document encourages standardization of operations and procedures, establishes uniform and consistent training and provides the framework for expected practices in radiological control. The Manual will be updated or revised annually to reflect any changes needed based on its use and success in achieving improved radiological control.

For additional copies of the DOE RadCon Manual or discussions concerning the provisions of the document please contact Mr. Rick Jones, Director of the Office of Health Physics and Industrial Hygiene at (301) 903-6061.

Sincerely,

A handwritten signature in cursive script, reading "Paul L. Ziemer", is written above the typed name.

Paul L. Ziemer, Ph.D.
Assistant Secretary
Environment, Safety and Health

U.S. Department of Energy
Radiological Control
Manual



U.S. Department of Energy
Assistant Secretary for Environment,
Safety and Health

June 1992

TYPE: ACTION DOCUMENT NUMBER: 9202037
ORIGINATOR: 02 STATUS I DIRECTORATE STATUS C

FROM: NEY, W. Roger: NCRP

TO: DR. D.A. BROMLEY

DATE OF
CORRESPONDENCE: 05/26/92

SUBJECT: HE IS FORWARDING A COPY OF A DRAFT REPORT FOR DR.
BROMLEY'S REVIEW AND COMMENTS.

DIRECTORATE STAFF
ASSIGNED: LIFE SCIENCES ASSIGNED: William Raub

ACTION STAFF
REQUIRED: REVIEW FOR DAB ACTION: REVIEW FOR DAB

SENDER'S DUE DATE:
OSTP DUE DATE: 06/17/92 STAFF DUE DATE 06/17/92
DATE COMPLETED: DATE COMPLETED/DEPT: 06/19/92

COPIES TO: D. Allan Bromley

WHITE HOUSE TRACKING #: CONTACT PERSON:
PHONE: EXT:
REMARKS:

OSTP RECEIVED: 06/03/92 DEPT RECEIVED: 06/04/92
FILE: LIFE SCIENCES-RADIATION
CENTRAL FILES:



NCRP

2037-
National Council on Radiation Protection
and Measurements

7910 WOODMONT AVENUE, SUITE 800, BETHESDA, MARYLAND 20814-3095

AREA CODE (301) 657-2652

FAX (301) 907-8768

TOLL FREE 1-800-229-2652

CHARLES B. MEINHOLD, *President*

S. JAMES ADELSTEIN, M.D., *Vice President*

W. ROGER NEY, J.D., *Executive Director*

RECEIVED
32 JUN 3 AM 12
MAIL ROOM
May 26, 1992

Dr. D. Allen Bromley
Director
Office of Science and Technology
Policy
Old Executive Office Building
Room 360
Washington, D.C. 20500

Dear Dr. Bromley:

Pursuant to the liaison relationship between the Office of Science and Technology and the NCRP, I am pleased to enclose a copy of a draft report prepared by Scientific Committee 83, "Research Needs in Radiation Protection". We would appreciate receiving any comments or suggestions you might have regarding the draft report. I am sure you understand that the draft report is a privileged NCRP document which should not be disseminated, quoted, or cited.

I look forward to receiving your comments on the draft report.

Sincerely yours,

W. Roger Ney
W. Roger Ney
Executive Director

WRN/lja

enclosure: Draft report
Questionnaire

NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS
7910 Woodmont Avenue, Suite 800
Bethesda, Maryland 20814

Special Liaison
Review of Report Entitled

"Research Needs in Radiation Protection"

Instructions: After completing your review of the report, complete one copy of this form and return it to the secretariat at the address above before June 19, 1992.

I should like to offer the following comments on the report: (To simplify handling of your detailed and specific comments, please list them by page and line number e.g., p. 18, line 2..... p. 23, line 12.....) [A list of your comments on separate sheets may be appended if you wish.]

Signature _____

Date _____

NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS
7910 Woodmont Avenue, Suite 800
Bethesda, Maryland 20814

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Signature _____

Date _____

"Document Control for Division of Life Sciences"

TYPE: ACTION DOCUMENT NUMBER: 9202037
ORIGINATOR: 02 STATUS I DIRECTORATE STATUS I

FROM: NEY, W. Roger: NCRP

TO: DR. D.A. BROMLEY

DATE OF
CORRESPONDENCE: 05/26/92

SUBJECT: HE IS FORWARDING A COPY OF A DRAFT REPORT FOR DR.
BROMLEY'S REVIEW AND COMMENTS.

PKT -
Ney's due
date is
June 19 -

DIRECTORATE STAFF
ASSIGNED: LIFE SCIENCES ASSIGNED: William Raub

ACTION STAFF
REQUIRED: REVIEW FOR DAB ACTION: REVIEW FOR DAB

SENDER'S DUE DATE:
OSTP DUE DATE: 06/17/92 STAFF DUE DATE 06/17/92
DATE COMPLETED: DATE COMPLETED/DEPT:

COPIES TO: D. Allan Bromley

WHITE HOUSE TRACKING #: CONTACT PERSON:
REMARKS: PHONE: EXT:

OSTP RECEIVED: 06/03/92 DEPT RECEIVED: 06/04/92
FILE: LIFE SCIENCES-RADIATION
CENTRAL FILES:

6/5

Dr. Henderson:

Dr. Bromley sent the attached correspondence, from Roger Ney regarding radiation, for your comments. When the original correspondence was received, it was assigned to Dr. Raub.

Should Dr. Raub answer the incoming; or do you plan to answer the incoming correspondence?

dic

YES
//

correspondence for you to
Dr. Bromley sent the attached
Dr. Henderson:

6/5

"Document Control"

TYPE: ACTION

DOCUMENT NUMBER: 9202037

ORIGINATOR: 02

STATUS I

DIRECTORATE STATUS

FROM: NEY, W. Roger: NCRP

TO: DR. D.A. BROMLEY

DATE OF
CORRESPONDENCE: 05/26/92

SUBJECT: HE IS FORWARDING A COPY OF A DRAFT REPORT FOR DR.
BROMLEY'S REVIEW AND COMMENTS.

DIRECTORATE

STAFF

ASSIGNED: LIFE SCIENCES

ASSIGNED:

6/5

DO NOT communicate please DOB

ACTION

STAFF

REQUIRED: REVIEW FOR DAB

ACTION:

SENDER'S DUE DATE:

OSTP DUE DATE: 06/17/92

STAFF DUE DATE

DATE COMPLETED:

DATE COMPLETED/DEPT:

COPIES TO: D. Allan Bromley

WHITE HOUSE TRACKING #:

CONTACT PERSON:

REMARKS:

PHONE:

EXT:

OSTP RECEIVED: 06/03/92

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FILE: LIFE SCIENCES-RADIATION

CENTRAL FILES:

NCRP

*National Council on Radiation Protection
and Measurements*

7910 WOODMONT AVENUE, SUITE 800, BETHESDA, MARYLAND 20814-3095

AREA CODE (301) 657-2652

FAX (301) 907-8768

TOLL FREE 1-800-229-2652

CHARLES B. MEINHOLD, *President*

S. JAMES ADELSTEIN, M.D., *Vice President*

W. ROGER NEY, J.D., *Executive Director*

MAILED May 26, 1992

Dr. D. Allen Bromley
Director
Office of Science and Technology
Policy
Old Executive Office Building
Room 360
Washington, D.C. 20500

Dear Dr. Bromley:

Pursuant to the liaison relationship between the Office of Science and Technology and the NCRP, I am pleased to enclose a copy of a draft report prepared by Scientific Committee 83, "Research Needs in Radiation Protection". We would appreciate receiving any comments or suggestions you might have regarding the draft report. I am sure you understand that the draft report is a privileged NCRP document which should not be disseminated, quoted, or cited.

I look forward to receiving your comments on the draft report.

Sincerely yours,

W. Roger Ney
W. Roger Ney
Executive Director

WRN/lja

enclosure: Draft report
Questionnaire

NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS
7910 Woodmont Avenue, Suite 800
Bethesda, Maryland 20814

Special Liaison
Review of Report Entitled

"Research Needs in Radiation Protection"

Instructions: After completing your review of the report, complete one copy of this form and return it to the secretariat at the address above before **June 19, 1992**.

I should like to offer the following comments on the report: (To simplify handling of your detailed and specific comments, please list them by page and line number e.g., p. 18, line 2..... p. 23, line 12.....) [A list of your comments on separate sheets may be appended if you wish.]

Signature _____

Date _____

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7910 Woodmont Avenue, Suite 800
Bethesda, Maryland 20814

Special Liaison
Review of Report Entitled

"Research Needs in Radiation Protection"

Instructions: After completing your review of the report, complete one copy of this form and return it to the secretariat at the address above before June 19, 1992.

I should like to offer the following comments on the report: (To simplify handling of your detailed and specific comments, please list them by page and line number e.g., p. 18, line 2..... p. 23, line 12.....) [A list of your comments on separate sheets may be appended if you wish.]

Signature _____

Date _____

Research Needs In Radiation Protection

Recommendations of the
NATIONAL COUNCIL ON RADIATION
PROTECTION AND MEASUREMENTS

DRAFT
*Not to be quoted, cited,
referenced or duplicated*

| N | C | R | P |

Research Needs In Radiation Protection

NCRP DRAFT
*Not to be quoted, cited,
referenced or duplicated*

Recommendations of the
**NATIONAL COUNCIL ON RADIATION
PROTECTION AND MEASUREMENTS**

| N | C | R | P |

Draft Report SC-83
May, 1992

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Draft Report SC-83
May, 1992

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May, 1992

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1. Introduction

Scientific Committee 83 was established to identify areas of additional research needed to improve the bases for recommendations on radiation protection. The work of the Committee was expected to address ionizing radiation only. The areas of research determined to be those where increased information would be most useful can be organized under the following categories:

- (1) Biologic studies including host factors and modifiers.
- (2) Dose determination including models, measurement markers and exposure analysis.
- (3) Risk assessment.
- (4) Prevention and intervention including public understanding and public policy.

The Report also responds to a request by the President of the NCRP asking the Council to identify "critical questions in research including laboratory and epidemiologic research related to radiation protection and requiring resolution at this time."

1 The responses overwhelmingly identified the estimation of
2 low-dose and low-LET radiation risks as the most important issue,
3 but other aspects of the problem were also singled out. On the
4 basis of the Council's responses and its own reflections, the
5 Committee recognizes that there are five central questions facing
6 the radiation protection research community:

7 (1) What are the risks associated with low dose exposure
8 (below 100 mSv), particularly, what is the shape of the
9 low dose response curve for carcinogenicity,
10 inheritable disorders and developmental abnormalities,
11 taking into account dose rate, ionization density, age
12 at exposure, and individual susceptibility?

13 (2) How can we better define the spatial and temporal
14 distribution of dose as the basis for improving the
15 accuracy and precision of the dose term for dose-
16 response relationships at both the macroscopic and
17 microscopic levels?

18 (3) To what extent do new advances in molecular genetics
19 and structural biochemistry permit us to expand our
20 basic knowledge of radiation and to examine and
21 understand the cell's response to low doses (circa 100

1 mSv), thereby shedding light on the steps leading to
2 the production of cancer and other mutational damage.
3 From this knowledge can we derive an insight into dose-
4 response relationships at a level not attainable by
5 animal or human epidemiologic studies?

6 (4) Given that we live in a world that has radiation in the
7 environment, the work place, the clinic and outer
8 space, what preventive measures can be taken to reduce
9 exposure or the potential for exposure, and, when
10 exposure or potential exposure has taken place, what
11 intervening measures can be taken to minimize harm?
12 What should we do about radiation combined with
13 chemicals and other potential environmental toxins?

14 (5) Given the complexity of radiation effects and
15 protection, what can we do to promote public
16 understanding and to ensure rational and informed
17 judgements on policies related to the practice of
18 radiation hygiene?

19 It was against this background that the Committee conducted
20 its meetings. It created a Report designed as a series of
21 categorical needs, each backed by a statement of significance and

1 rationale. These needs and the accompanying narrative were
2 reviewed by a board of consultants who also critiqued the final
3 Report. There is no notion on the Committee's part that the list
4 of recommendations is complete or even definitive, but each of
5 the 60-odd recommendations is considered important. Like all
6 research agendas it is subject to revision as data accrue and as
7 new developments bring further issues to the forefront. It
8 should be revised every three to five years.

2. Cellular and Molecular Biology

Basic radiobiologic research at the mechanistic level will help illuminate the potential hazards of acute and chronic low-dose rate exposure of humans to ionizing radiation and may suggest methods of intervention following such exposures. New molecular biologic and biochemical approaches are likely to enhance our understanding of cellular and tissue responses to ionizing radiation by contributing increased sensitivity to subtle responses following low dose exposures. Such approaches may provide a biologic basis for individual and species variations in the risks of radiation carcinogenesis and for certain deterministic effects of radiation exposure.

2.1 Uncertainties

Efforts are needed to reduce uncertainties in the assessment of risks for defined biologic endpoints which are evident at short times following exposure. Particular attention should be paid to the risks of low dose, low-dose rate exposures, high-LET exposures, and combined exposure to radiation and other environmental agents.

Advances in molecular biology and biochemistry have presented unprecedented opportunities to increase our understanding of cellular, tissue, and organismal responses to low doses of ionizing radiations. Certain techniques, such as the polymerase chain reaction (Saiki et al., 1988) and in situ hybridization (Pinkel et al., 1986), permit the analysis of subtle alterations in the genetic constitution and functional integrity of individual cells within a complex milieu. Using these new approaches, an increased sensitivity to biological effects of low dose and low-dose rate radiation exposure should be achievable.

2.2 Acute Molecular Changes Produced by Ionizing Radiation Exposure of Cells

Studies are needed to improve the methods for the quantitation and distribution of DNA strand breaks, chromatin breaks, and base alterations at low doses. Biophysical models have established that the distribution of energy from sparsely and densely ionizing radiations differ and that these differences may be crucial to the increased effectiveness of densely ionizing radiations for a variety of biologic endpoints. These models require rigorous testing for the particular cases of low dose and low-dose rate exposures.

1 2.2.1 Mutational Risk as a Function of Dose Rate in
2 Human-Derived Cell Systems

3 The influence of dose rate on the induction of mutations in
4 somatic cells and on the induction of cancer remains an open
5 question that needs to be addressed. In addition, the biologic
6 basis for the reported increased effectiveness of low-dose rate
7 exposure to densely ionizing radiation for the induction of
8 neoplastic transformation in vitro, tumorigenesis at selected
9 sites in vivo, and somatic mutation, has not been adequately
10 assessed. Studies should be designed to determine whether these
11 observations may be verified in other cell and tissue types of
12 human or primate origin.

13 2.2.2 Cellular and Molecular Changes Following Combined
14 Exposures to Radiation, Drugs and Chemicals

15 Humans are environmentally exposed to mixtures of chemicals,
16 drugs, and, in some cases, to radiation. Our understanding of
17 the risks of combined exposure to radiation and other
18 environmental agents is poor and suggests a compelling area for
19 investigation. It is important to determine if the biologic
20 responses from these combined exposures can be predicted.
21 Radiation protection standards have been set for single exposures

1 with little information on potential interactions between damage
2 induced by one agent and that produced by additional agents. It
3 is not possible to conduct epidemiologic or experimental animal
4 studies that will address all potential interactions among the
5 wide variety of agents as a function of exposure sequences and
6 dose patterns. However, short-term cellular and molecular
7 techniques will permit evaluation over a wide range of exposure
8 conditions. With such approaches, mechanisms of interaction can
9 be defined. This level of understanding can help in
10 extrapolation from individual chemicals or types of radiation to
11 combined exposures, and in addition will assist in the design of
12 a limited number of experiments at higher levels of biologic
13 organization.

14 **2.2.3 Molecular Markers for Cells at Risk for Carcinogenesis in**
15 **the Respiratory Tract**

16 The only radionuclide exposure for which lung cancers have
17 been observed in humans is exposure to radon and its progeny in
18 uranium miners. However, radiation protection practices require
19 recommendations and standards covering a broad range of
20 radionuclides that emit alpha and beta particles or photons which
21 may be inhaled and deposited in different exposure-dose and dose-
22 response relationships than those occurring after exposure to

1 radon and its progeny. A crucial step in the refinement of risk
2 estimates for cancer of the respiratory tract is the precise
3 identification of the number and type(s) of cells at risk for
4 carcinogenesis. Information on the number and distribution of
5 these cells in suitable animal models, together with
6 determinations of RBE for various radionuclide exposures, will be
7 essential in order to permit appropriate extrapolations from
8 radon-associated human lung cancer data for prediction of the
9 risks of other inhaled radionuclide exposures.

10 **2.3 Genetic Variability and Risk of Radiation-Induced Cancer**

11 There is a wide range of susceptibility to radiation insult
12 in human populations. It is important to determine the genetic
13 basis for this variability in carcinogenic potential among
14 individuals. Standards that take this range into consideration
15 may need to be developed to limit radiation exposures of
16 sensitive subpopulations. The ability to identify host factors
17 that are indicative of radiation sensitivity (or resistance) is
18 important both for radiation protection and for an understanding
19 of the radiation dependent pathways in carcinogenesis.

20 Certain individuals have genetic disorders that are
21 associated with deficiencies in DNA repair or tolerance

1 processes. Relatively little is known about cancer induction by
2 radiation among individuals with these disorders (e.g., ataxia
3 telangiectasia, Bloom's syndrome, Fanconi's anemia, xeroderma
4 pigmentosum, Cockayne's syndrome, etc.). Even less is known
5 about the possibility of an increased risk of radiogenic cancer
6 in individuals who are heterozygous carriers of these and other
7 recessive inherited disorders (e.g., constitutional
8 heterozygosity for one of several tumor suppressor genes). The
9 numbers of persons in this latter grouping may be far more
10 numerous than those with overt disease.

11 Emphasis should be placed on the identification of
12 additional genetic traits which are indicators of increased
13 susceptibility to cancer. As these genes are identified, it will
14 be important to determine whether low dose radiation exposure
15 increases the likelihood that alterations associated with
16 initiation or progression of carcinogenesis will occur in these
17 loci. An attempt should be made to clarify these issues using in
18 vitro methods and tissue explants.

19 2.4 Unique Molecular Risk Markers

20 At present there are few molecular risk markers of radiation
21 exposure. It would be particularly useful to reexamine those

1 subjects enrolled in existing epidemiologic studies to determine
2 whether persistent markers of exposure may be identified. Such
3 an approach would aid in post-exposure dose reconstructions. In
4 addition, new radiation-dependent genetic alterations may be
5 discovered. If such radiation-induced alterations are found,
6 they might serve as early warning signals for past exposure and
7 future development of particular radiogenic cancers.

8 2.5 Biochemical Pathways

9 It is important to illuminate the biochemical steps of
10 initial and delayed cellular and tissue responses to radiation
11 with a view toward (1) the design of avenues for intervention to
12 limit cancer induction and developmental defects and (2) the
13 design of useful experiments at higher levels of organization.

14 An understanding of biochemical pathways involved in
15 cellular responses to ionizing radiation will assist in the
16 development of strategies to counteract the effects of these
17 exposures. It is possible that the constellation of cellular
18 responses to low dose, low-dose rate exposure and to acute
19 exposure are quite different. While emphasis should be placed on
20 the responses to very low dose exposures with a view toward
21 intervening in the process of radiation-induced carcinogenesis,

1 some attention should also be given to responses to higher doses
2 such as might occur under accident conditions. These
3 investigations may provide additional insight into the design of
4 therapeutic strategies.

5 **2.5.1 Induction of DNA Repair Enzymes (and Other Proteins)**

6 Little information is available on the particular proteins
7 involved in the acute radiation response and what their functions
8 may be. In addition, little is known about the involvement of
9 specific proteins in programmed cell death. Identification of
10 the proteins implicated in such responses might lead to the
11 development of therapeutic strategies to limit radiation necrosis
12 following acute exposures.

13 Studies are also required to identify the DNA repair enzymes
14 involved in the cellular response to ionizing radiation exposure.
15 Mutant cell lines with known DNA repair deficiencies, coupled
16 with their repair-competent parental lines, should aid in the
17 identification of specific enzymes involved in repair or bypass
18 of radiation damage.

19 Low doses of low-LET radiation have been shown to decrease
20 the responsiveness of blood lymphocytes and some fibroblasts to

1 acute high doses of radiation (Wolff et al., 1988). These low
2 doses cause the release of unique proteins. It was postulated
3 that these proteins may be involved in the repair of DNA damage.
4 It is important to determine if the induced proteins are repair
5 enzymes and if they can be induced in the epithelial cells since
6 these cells are so critical in carcinogenesis. These
7 observations need then to be expanded into animals.

8 If low-level radiation exposures also decrease the
9 responsiveness of epithelial cells to the induction of cancer,
10 this may suggest that low doses may not produce cancer as a
11 linear function of dose. The use of linear extrapolation models
12 to define radiation dose-response relationships at low dose may
13 not be applicable.

14 **2.5.2 Expression of Genes Associated with Cancer Loss,**
15 **Activation and Induction**

16 Extensive characterization of molecular genetic alterations
17 commonly associated with the development of particular neoplasms
18 is underway for a variety of human tumors. Studies are needed to
19 describe the risk of radiation-induced alteration of genetic
20 markers which have already been associated with the development
21 of human cancers. Such studies should focus on the use of human

1 biopsy materials where possible and define the role of LET, dose
2 and dose rate on mutational loss, activation and expression of
3 genes associated with cancer induction. Certain in vitro/in vivo
4 model systems, e.g., mouse mammary gland, rat tracheal epithelial
5 system, may provide useful information on the modulation of
6 cellular responses by host factors.

7 **2.5.3 Radiation-Induced Genetic Alterations as a Function of**
8 **Time in Cells That Retain Proliferative Capacity**

9 The time course for the development of permanent genetic
10 alterations in somatic cells following radiation exposure is a
11 subject for investigation. Research from several laboratories
12 has suggested that there are several phases to the development of
13 heritable changes at the DNA level — a rapid component that is a
14 function of the ionization of the DNA and its aqueous
15 environment, a second phase comprised of damage produced or
16 resolved in the first cell division cycle, and a more protracted
17 phase of lesion modification or development which may result in
18 cell death, mutation, or genomic instability. Further studies
19 are required to define the importance and mechanisms of the
20 delayed expression of radiation damage.

1 **2.5.4 Persistence of Radiation-Induced Genetic Alterations**

2 The persistence of radiation-induced genetic alterations in
3 vivo has not been widely examined. Experimental approaches
4 should be developed to determine whether there may be selection
5 for or against the various types of alterations produced. Model
6 systems for such studies might include peripheral blood
7 lymphocytes, stratified epithelia, and germ cells.

8 **2.5.5 Definition of Mechanisms of Subacute**

9 (Deterministic) Radiation-Induced Pathologies

10 Acute radiation syndromes were described when few molecular
11 techniques were available to understand the mechanisms involved
12 in their induction. The new molecular technologies may provide a
13 means to establish exposure standards for selected tissue sites
14 and exposure situations with regard to the development of
15 nonstochastic radiation responses. Tissues where these sequelae
16 bear particular notice include the lung, where damage associated
17 with high doses of internally deposited radionuclides or external
18 exposures may elicit an inflammatory response, a fibrogenic
19 response, and a local immune response. Each of these changes can
20 impact cell proliferation, differentiation and gene expression.

1 Other organs of interest include the central nervous system and
2 the lens of the eye.

3 **2.5.6 Biologic Bases for Species Differences in Radiation**
4 **Response**

5 To maximize the use of dose-response data obtained in non-
6 human biologic systems for radiation protection applications,
7 additional research should be devoted to establishing stronger
8 links among studies conducted in different species of animals,
9 and among studies at the tissue, cellular and molecular levels.
10 One recent example of an area in which information on species
11 variation in response may have some bearing on the differences in
12 rates of cancer induction is that of preferential repair of
13 actively transcribed DNA, wherein the ability to repair
14 nontranscribed DNA has been shown to vary widely between human
15 and rodent cells exposed to certain environmental agents (Bohr et
16 al., 1985; Madhandi et al., 1986; Mellon et al., 1986; 1987). It
17 is necessary to understand and account for differences in dose-
18 response relationships for a variety of radiation-induced
19 endpoints in order to minimize errors in extrapolation of risk
20 among species.

1 **2.5.7 Studies in Animal Systems to Test Biologically**
2 **Based Models of Carcinogenesis and Intervention in**
3 **Radiation Carcinogenesis**

4 A limited number of animal studies may be required to assign
5 weighting factors to given biologic parameters in a multistage
6 model of radiation carcinogenesis. Emphasis should be placed on
7 studies that cannot be carried out in vitro, such as the role of
8 tissue organization on progression of initiated cells. A few
9 additional studies may focus on the design of strategies to
10 intervene in the process of carcinogenesis in animals that have
11 been exposed to radiation.

12 **2.6 In vitro Studies**

13 It is important to develop new resources for the in-vitro
14 study of radiation-induced cancer in humans. These should
15 include methods for detection of genetic alterations in
16 transformed cells, methods for determination of candidate
17 markers, and perfection of biologic dosimeters.

18 The identification of heritable genetic alterations
19 important to the development of neoplasia may be underestimated
20 by the assay systems currently used to detect these changes

1 (e.g., NIH3T3, C3H/10T1/2, rat 2 cells, nude mouse assays). New
2 techniques such as the polymerase chain reaction, fluorescence in
3 situ hybridization, and the use of transgenic animals may enhance
4 the likelihood of detecting all of the important alterations.
5 Emphasis should be placed on the use of human biopsy materials in
6 concert with these or other novel approaches.

7 To date, the study of radiation effects at the cellular and
8 subcellular level has been limited to a narrow group of model
9 systems, many of which have an unknown relevance to the
10 assessment of the risks of carcinogenesis. Emphasis should be
11 placed on studies using human epithelial tissues, neurons, and
12 endothelial cells.

13 Studies on epithelial cells and organoid cultures of
14 epithelial tissue are important for the determination of the
15 risks of radiation-induced neoplasia as well as for the
16 identification of more subtle changes in the epithelia and
17 associated stromal tissues which may alter the risk of neoplasia.
18 The response of endothelial cells to radiation exposure is likely
19 to involve a plethora of reactions in a wide variety of exposed
20 tissues.

1 In addition to carcinogenic risk, the effect of radiation
2 exposure on the functional integrity of nondividing cells such as
3 neurons is important to consider. Damage can accumulate as a
4 function of age and, in the particular case of astronauts,
5 functional damage may increase rapidly on extended space
6 missions.

7 Few measurements have been taken on the cellular and
8 molecular changes that are present during the early stages of
9 carcinogenesis. Many useful molecular probes have been developed
10 for human cells and tissues to define changes as cells move from
11 normal to neoplastic. These alterations in gene expression,
12 activation of genes, and gene loss provide mechanistic probes to
13 help define the carcinogenic process. The expression of specific
14 mRNAs and proteins which may have important functions in the
15 cellular response to radiation should be examined, e.g., growth
16 factors and growth factor receptors. Markers for cell-surface
17 antigens also are well developed in humans. Cellular changes
18 also need to be defined such as alterations in cell
19 proliferation, chromosome translocations and karyotypic
20 alterations.

21 If such probes can be applied in animal models, such as dogs
22 or subhuman primates, where individual animals and tissues can be

1 followed over time during the carcinogenic process additional
2 understanding can be developed. The process can be followed from
3 the initial insult from well-defined radiation dose, through the
4 early changes in the cells and on to the ultimate development of
5 cancer. Combining molecular techniques with whole animal models
6 will link the molecular, cellular and animal data derived both in
7 vitro and in vivo to human risks and will help define mechanisms
8 involved in carcinogenesis. Better understanding of the biologic
9 processes will help to validate mathematical models of
10 carcinogenesis which can in turn feed information into possible
11 new experimental directions.

12 2.7 Biologic Markers of Radiation Exposure

13 Chromosome aberrations in human blood lymphocytes have
14 provided a good biologic dosimeter for acute, whole-body
15 radiation exposure when the cells are sampled shortly after the
16 exposure (Bender et al., 1989). However, there are limitations
17 on the usefulness of this system. First, at low total doses it
18 is very expensive to sample and score an adequate population of
19 cells to estimate dose. Second, the distribution and number of
20 aberrations change following partial body exposure or when there
21 is a long time between exposure and evaluation of the aberration
22 frequency. Both of these problems limit the usefulness of

1 chromosome aberrations as a biologic dosimeter. New techniques
2 of either staining repeated sequences at the telomere or
3 centromere region or chromosome painting which uses molecular
4 probes to paint a whole chromosome make it possible to score
5 chromosome translocations more rapidly and accurately. Certain
6 of these aberrations are stable and not markedly influenced by
7 time after exposure. Their usefulness as dosimeters should be
8 explored further.

9 Additional techniques to estimate exposure and dose are
10 being developed by measuring the induction of mutations in blood
11 lymphocytes at the (HPRT) and HLA gene loci and in red blood
12 cells at the glycophorin A and beta globin gene loci. If
13 properly validated, these procedures may be useful in screening
14 large human populations to estimate dose in those individuals
15 thought to be at risk for radiation exposure.

16 2.8 Estimates of Genetic Effects

17 A new integration of Japanese atomic bomb data suggests a
18 mutation doubling dose of about two sievert, with one sievert as
19 the lower bound, which is higher than estimates in the past (Neel
20 et al., 1990). Additional data are needed to confirm or disprove
21 this.

1 There are several views on the best ways to proceed in
2 developing sensitive and appropriate indices of mutation rate.
3 One view is that new developments are needed with respect to
4 protein markers: new technical means of looking for small
5 changes in large numbers of proteins and better means for
6 detecting "null" mutations in such proteins. Another is that
7 genetic effects are best tested at the DNA level. There is
8 general agreement that the best opportunity for such studies is
9 in Hiroshima and Nagasaki. Work is underway there to establish
10 cell lines for DNA studies based upon exposed and unexposed
11 parents and their offspring. The problem associated with further
12 DNA studies are the rarity and heterogeneity of the radiation
13 induced DNA alterations. Better DNA methods are required to deal
14 with these problems before there will be a reasonable hope of
15 learning much more from the established cell lines.

16 2.8.1 Genetic Alterations in Germ Cells

17 It is important to better define genetic alterations in germ
18 cells. New techniques to detect changes in sperm are being
19 developed using in situ DNA hybridization. Additional mutation
20 tests in transgenic animals are being developed. These new
21 methods will help the understanding of the impact of

1 multifactorial genetic diseases on morbidity, mortality and
2 radiation risk.

3 **2.8.2 Genetic Risk as a Function of Dose Rate and Ionization**
4 **Density**

5 The influence of dose rate on the induction of mutations in
6 germ cells, especially for high-LET radiation on the induction of
7 transmitted mutations, remains an open question. Studies with
8 internally deposited plutonium demonstrated that the RBE for
9 transmitted mutations was low (Russell, 1978). However, evidence
10 indicated that the severity of the genetic damage produced by
11 alpha particles may be qualitatively more serious than that
12 induced by gamma rays (NCRP, 1989). Because of the sensitivity
13 of mouse oocytes to cell killing (Dobson and Cooper, 1974)
14 assumptions based on mouse data on risks to offspring of persons
15 irradiated with densely ionizing radiations at low-dose rates
16 over long periods of time have been called into question (Dobson
17 et al., 1978). Data are scarce on the influence of dose rate and
18 LET on mutation rates in germ cells in higher primates and
19 humans.

1 **2.8.3 Heritable Genetic Risks in Females of Species Other Than**
2 the Mouse

3 Data from the female mouse have been shown to have limited
4 application for prediction of genetic damage to human females.
5 Mouse oocytes are uniquely sensitive to radiation-induced cell
6 killing (Dobson and Cooper, 1974). They may not reflect the
7 mutational spectra that would be induced in human oocytes. Thus
8 the dose rate effect observed in the mouse may not be applicable
9 to other animals, especially humans. There is a need for
10 additional female animal systems to study dose-response
11 relationships for induction of both dominant and recessive
12 mutations. The observed unique sensitivity of oocytes to cell
13 killing in experimental animals when exposed in utero needs to be
14 further characterized to determine if such effects are present in
15 human oocytes exposed in utero.

16 **2.8.4 Radiation-Induced Genetic Alterations in Reproductive**
17 Tissues

18 Little is known about the persistence of radiation-induced
19 genetic alterations in germinal tissues in vivo. Experimental
20 approaches should be developed to determine whether there may be
21 selection for or against the various types of alterations

produced and if these have greater or less impact depending on the type of alteration.

2.8.5 Radiation in the Induction of Aneuploidy

Errors in chromosome segregation, resulting in aneuploidy, produce genetic diseases many of which are related to mental retardation and congenital malformations. Evidence to date that a relationship exists between radiation exposure and the induction of aneuploidy has been marginal, resulting in high doubling doses and low risk estimates for radiation-induced aneuploidy (NAS/NRC, 1990). Recent estimates of the magnitude of genetic disease from radiation-induced aneuploidy have been made (Abrahamson et al., 1990) based on new mouse (Griffin and Tease, 1988) and human data (Martin et al., 1986). The data base for these estimates is weak, and additional information and analysis are required for these to be made with the needed degree of accuracy.

2.8.6 Multifactorial Genetic Diseases

Estimates of the magnitude of the risk for multifactorial genetic diseases in the population have increased markedly during the past few years (NAS/NRC, 1990). Depending on the assumptions

1 made for dose-response relationships for induction of these
2 diseases, and the amount of time required after exposure for the
3 diseases to reach genetic equilibrium, multifactorial diseases
4 can make a major impact on genetic risk estimates. The BEIR V
5 Committee (NAS/NRC, 1990) suggested that "while the risks could
6 be negligible, they could also be as large or larger than all
7 other" genetic effects of radiation combined. New experimental
8 methods are required to determine potential dose-response
9 relationships for radiation-induced multifactorial genetic
10 diseases. Some suggestions have been made for animal model
11 systems that use direct methods (Selby, 1990) to estimate risks
12 for genetic disorders of complex etiology (Russell, 1990).
13 Research is also necessary to develop animal models that will
14 define the time required after radiation exposure for
15 multifactorial diseases to reach genetic equilibrium. Such
16 research is difficult because of the length of time for the
17 expression of many of these diseases, but essential because of
18 the large potential impact multifactorial diseases could have on
19 genetic risk.

2.9 In utero Exposure

2.9.1 Cancer and Developmental Risks

The influence of radiation in utero needs to be further defined in terms of both potential risk for induction of cancer in the offspring and for developmental changes.

After high dose and dose rate exposures from the atomic bomb there were no increases in the cancer rate in the F₁ population. However, increasing numbers of reports are being released to indicate that the risk from irradiation in utero or prenatally at low doses and dose rates can cause marked risks for cancer induction in experimental animals (Antal et al., 1991; Benjamin et al., 1991; Watanabe et al., 1991). These studies have been conducted on a range of species with a series of different cancer endpoints. Additional research is needed to determine if these observations are applicable to humans and if the results can be translated into meaningful changes in human risk. Such information can be derived with additional mechanistic studies which combine in vivo exposure of whole animals with in vitro studies at the cellular and molecular levels. This approach makes it possible to follow changes with time and radiation dose

1 and type. When this information becomes available, between
2 species extrapolations can be better made.

3 2.9.2 Mental Retardation Risks

4 Mental retardation was induced in human populations exposed
5 in utero to the atomic bomb. This is one of the most sensitive
6 endpoints for high dose and high-dose rate in utero radiation-
7 induced damage.

8 This observation can be further evaluated in experimental
9 animal models to define the site and extent of the damage.
10 Careful study of the toxic effects of radiation and other
11 teratogenic agents is needed to unravel the neurobiology of these
12 phenomena. The incorporation of molecular biology and
13 neurotoxicologic concepts, approaches and techniques into studies
14 of brain development provides opportunities for understanding the
15 processes and defining the mechanisms involved in these effects.
16 With this understanding, decisions concerning the shape of dose-
17 response relationships and the possibility of a threshold can be
18 made. The mechanisms of action of these effects can be addressed
19 in many cases in animals.

1 **2.9.3 Premature Senility**

2 Studies are needed to establish dose-response relationships
3 and to extrapolate from animal data to humans. The question of a
4 linear dose-response relationship for induction of premature
5 senility and age related changes in IQ is not resolved. An issue
6 which has not been addressed substantially until now is whether
7 radiation exposure may accelerate normal central nervous system
8 aging and mental deterioration. In the Japanese atomic bomb
9 study, a plan to establish a baseline of intelligence and/or
10 other measure of mental acuity, followed by periodic retesting in
11 order to examine age-related changes, could be implemented.

3. Dose Determination: Models, Measurements, Markers and Exposure Analysis

3.1 Introduction

To understand and to quantify the risks related to radiation exposure and then to establish appropriate control measures, the radiation dose must be determined. For many experimental and epidemiologic studies a precise definition of absorbed dose is needed at both the macroscopic and microscopic levels. At the present time, calculational models do not take into consideration physiologic differences among individuals and are only beginning to adjust for physical differences related to age and sex. Further research and development are required to account more precisely for human metabolism and physical dose distributions related to radioactive materials taken internally.

Radiation transport calculations for dose reconstruction of both internal and external radiation sources use analytical models as well as Monte Carlo simulations. These methods appear to work well at energies above a few tens of kilovolts. However, increased sophistication is needed in modeling particle tracks at

1 the scale of macromolecules and at energies less than one
2 kilovolt.

3 Verification of these calculational models necessitates
4 development of experimental techniques and instrumentation. New
5 dosimeters, especially a biological system using specific markers
6 that can identify the occurrence of a radiation exposure as well
7 as measure its magnitude, would be a significant advance in
8 dosimetry. Some specific markers associated with genetic
9 mutations have been determined. These have potential for
10 establishing radiation exposure, if not as quantitative
11 dosimeters (Mendelsohn, 1990).

12 Exposure to particular sources of radiation demands special
13 attention in dose determination. At this time, exposure of the
14 public to naturally-occurring decay products of radon gas,
15 potential exposure of the public to radioactive material present
16 in the environment near contaminated disposal sites, and
17 potential exposure of spacecraft crew members to high atomic
18 number/high energy (HZE) cosmic radiation are three most
19 important areas in need of research.

20 Research requirements in the area of dose determination are
21 detailed in this Section. These requirements are directed at

1 methods for better definition of dose and its spatial and
2 temporal distribution at the macroscopic and microscopic levels.

3 3.2 Biologic and Physiologic Models

4 3.2.1 Modification of Current Metabolic Models for Internally 5 Deposited Radionuclides to Account for Variations in Age, 6 Health Status and Anatomy

7 Radiation protection for internally deposited radionuclides
8 requires an in-depth understanding of the relationship between
9 exposure by various routes, including inhalation, ingestion and
10 wounds, and dose to critical tissues and cells, and the resulting
11 biological effects. Both the exposure-to-dose and the dose-to-
12 response relationships are influenced by a broad range of
13 biologic and physiologic factors. Research needs that must be
14 addressed include the development of metabolic models that
15 account for age and health-related variations.

16 As more attention is given to past and present general
17 population exposures to radionuclides in the environment, there
18 is an increasing need for metabolic models that reflect more
19 accurately the differences which may occur among individuals.

1 For instance, very young children may have patterns of
2 radionuclide intake and uptake considerably different from
3 adults. Individuals with diseases of the lungs, gastrointestinal
4 tract and kidneys may exhibit rates of absorption and excretion
5 different from individuals who are not diseased. These factors
6 should be incorporated into the models used to calculate
7 population doses to ensure adequate radiation protection for
8 these subpopulations. The biologic and physiologic data
9 describing the uptake, transfer and elimination of radionuclides
10 and specific chemical compounds containing radionuclides need to
11 be established. This is particularly important for medical
12 diagnostic applications where patients may be of various ages and
13 disease states (NCRP, 1985a; 1985b).

14 **3.2.2 Relationship of Bioassay Results (Excretory Measurements)**
15 **to the Variables in Biokinetic Models**

16 There is a need to relate accurately biokinetic models and
17 bioassay information in order to assess potential exposure and
18 control intake for workers. The uncertainties associated with
19 assessment of intake, deposition and excretion should be better
20 defined.

Bioassay protocols are vital components of radiation protection programs for situations where internal exposure to radionuclides is possible. Results from bioassay determinations are used to detect the occurrence of possible exposures and to estimate the doses that will be received by various body organs and tissues. Many of the mathematical models currently available for estimating intake, deposition, excretion and subsequent organ doses from bioassay results are simplified, general purpose models, devised primarily for health protection planning. More research should be devoted to element-specific bioassay models and the physical, chemical and biologic factors that influence them.

3.2.3 Determination of the Impact of Nonuniform Deposition and Retention of Radionuclides on Effective Dose and Consequent Risk

Internally, radionuclides may be deposited nonuniformly in various regions of target organs. There is a need to understand the relationship between the nonuniform deposition of radioactivity and the resultant nonuniform dose distribution to critical cells and cellular components and the ultimate risk. With penetrating low-LET radiation, the dose quantity can be averaged over an organ or organ system, whereas with low-energy

1 electrons and alpha particles, microscopic distribution of the
2 energy absorption may be more appropriate for assessing the true
3 risk.

4 It is well known that such nonuniformity of radionuclide
5 deposition occurs in various organs from occupational, medical
6 and environmental exposures. Each of these exposures has its own
7 characteristics related to the energy deposited in critical cells
8 and structures. Research is needed to determine when average
9 dose calculations provide adequate information and protection and
10 when more detailed dosimetric relationships or calculations are
11 necessary to ensure that the required level of radiation
12 protection is achieved.

13 The current concept of effective dose is based on a
14 summation of weighted risk to various body organs from acute
15 external irradiation. The relationship between these risks and
16 the risks due to irradiation from internally deposited
17 radionuclides, which may have widely differing temporal and
18 spatial dose distributions, must be understood. Uncertainties in
19 the specification of the appropriate dose quantity and its
20 relationship to measured quantities and ultimate risk to the
21 individual must be made smaller.

1 There is a need to define more accurately the dose quantity
2 that is most appropriate to the assessment of the risk to an
3 individual from external radiation exposure, and its dependence
4 upon age, sex and the rate at which the dose is accumulated.
5 Effective dose, which measures the dose to the total body based
6 on weighting partial body exposures in some prescribed way, has
7 been recommended as the appropriate dose quantity. There is some
8 question whether specific organ doses or doses to specific
9 tissues are not more appropriate for highly nonuniform or partial
10 body exposure, exposure to low-energy radiations, and exposure to
11 radiation by charged particles. The temporal effect of prolonged
12 low-dose rate exposure must also be more fully characterized.

13 The health risk weighting factors for various organs
14 currently applied in the concept and calculation of effective
15 dose are derived primarily from brief, acute exposures of the
16 Japanese population to an external radiation source, primarily of
17 gamma rays. However, they are used to weight the risk of
18 individual organs when exposed to chronic irradiation by x rays,
19 gamma rays, neutrons, HZE and other charged particles. Such a
20 procedure does not specifically address the changes in risk
21 weighting factors that may occur under these circumstances due to
22 varying degrees of dose prolongation. Additional biologic
23 response data are needed to define and apply a dose quantity

related to ultimate risk and to reduce the uncertainties in this relationship.

3.3 Physical Dosimetry Models and Radiation Transport

3.3.1 Development of Improved Calculational Models for Determining the Distribution of Energy Deposition from Internal Emitters

The present models used for determining doses to organs from internally deposited radionuclides do not take into account the variation among individuals in age and anatomy, the complex geometry of internal structures and the heterogeneity of tissues. Because of this, the uncertainty in the dose calculated from these models for any specific individual is large. This is caused in part by the lack of biologic and physiologic data, but also by the lack of physical models that incorporate age- and sex-dependent variations and tissue heterogeneity. Present calculations assume homogeneous organ composition and do not take into account heterogeneities that will affect the distribution of energy deposition. The complex geometry of the bronchial airways must be better modeled to determine accurately the radiation dose from inhaled radionuclides, in particular radon

1 decay products. Knowledge of the radiation dose to the bone
2 marrow is particularly important in radionuclide therapy and some
3 occupational and environmental exposures. The dose to bone
4 marrow progenitor cells from beta particles and low-energy
5 electrons must be accurately assessed (NCRP, 1985a; 1985b).

6 Dose estimates to date depend on a single computer model.
7 Completely independent computer algorithms should be developed to
8 verify the single algorithm that has been used for almost all
9 calculations of dose from internal emitters. The algorithms must
10 be improved to increase the range of particle energies considered
11 (NCRP, 1989).

12 **3.3.2 Development of Improved Calculational Models for Relating**
13 **Exposure to External Radiation Fields and the Dose**
14 **Quantity**

15 The present models used for determining doses to organs from
16 external radiation fields are only beginning to take into account
17 the variation among individuals in age and anatomy, the complex
18 geometry of internal structures and the heterogeneity of tissues.
19 Because of this, there is still a large uncertainty in the dose
20 calculated from these models for any specific individual.

1 Calculational models have been developed by the
2 International Commission on Radiation Units and Measurements
3 (ICRU, 1985; 1988) to relate specifically defined, measured
4 radiation quantities to the effective dose. However, the
5 measured quantities include energy-dependent quality factors for
6 neutron radiation and in general they overestimate the effective
7 dose by a large amount for both photon and neutron radiation.
8 External exposure to high-energy particles is not addressed.

9 There is a need for further development of calculational
10 algorithms that relate the fundamental field quantity of energy
11 fluence to absorbed dose and dose equivalent, especially for
12 neutrons and HZE particles (including secondary neutrons
13 resulting from their interactions). These models must include
14 methods to account for age- and sex-dependence, tissue
15 heterogeneities and complex internal geometries. In medical
16 diagnostic applications there is a need for accurate dosimetry
17 relating organ dose to patient size, information about bone
18 marrow distribution related to age and organ doses from computed
19 tomography.

1 **3.3.3 Relationship of the Microscopic and Submicroscopic**
2 **Distribution of Energy Absorbed to the Risk of Radiation**
3 **Injury**

4 There is a need to understand the relationship between
5 microscopic and submicroscopic energy distribution from
6 radionuclides in the body and the dose quantity most
7 appropriately related to risk. This relationship may be most
8 applicable to low-energy electrons and alpha particles from
9 internally deposited radionuclides. It has been demonstrated in
10 a limited number of studies that the microscopic distribution of
11 energy deposition is more descriptive of risk than is the average
12 energy deposition. In particular, these investigations have
13 involved the incorporation into DNA of the low-energy beta
14 emitter ^3H and the Auger electron emitter ^{125}I . Other studies have
15 shown that the distribution of an alpha particle emitter in the
16 testis (and thus the distribution of energy deposition) can
17 affect the ultimate risk. However, the specification of the
18 appropriate dose quantity related to risk remains uncertain. In
19 some cases, particularly low-LET radiation, an average organ dose
20 may be appropriate. With high-LET particles, or very low-energy
21 electrons, risk may be more closely related to the microscopic or
22 submicroscopic energy deposition.

1 **3.3.4 Improvement of the Data Base of Environmental Parameters**
2 **for Use in Dose Assessment Models**

3 Improvement in environmental dose assessment models depends
4 on having an accurate data base of environmental factors that
5 affect the transport and resultant effects of long-lived
6 radioactive material. United States agencies have significantly
7 reduced support for research on the fate and effect of long-lived
8 radionuclides in the environment. Without continued support for
9 the acquisition of information about the basic physical, chemical
10 and biologic processes that occur when these radionuclides reach
11 the environment, improved modeling capabilities and attempts to
12 reduce the uncertainties in these models will be nullified by the
13 use of outdated transport parameters. One example is technetium.
14 This radionuclide has a six percent fission yield, an extremely
15 low affinity for soil and sediment particles and an extremely
16 high degree of bioavailability, and thus is a unique component of
17 the nuclear fuel cycle. Significant quantities of technetium are
18 present in soil and ground water at sites where fuel is
19 reprocessed. However, unlike most of the radionuclides
20 associated with reprocessed fuel, technetium has been identified
21 as presenting more of a risk as a chemical toxicant than as a
22 radiological hazard. It interacts as a sulfur analog in
23 metabolic and chemical processes. This can lead to the metabolic

1 dysfunction and death of the involved organism. Evidence
2 indicates that this interaction is most pronounced with the
3 complex proteins used in electron transport: thus in plants,
4 photosynthesis and protein metabolism are affected. While there
5 is a wealth of information for the soil/plant system, its
6 implications for the subsequent food pathways have been neglected
7 and require attention.

8 Carbon is ubiquitous, and of all elements has been the most
9 researched; substantial pool and flux information is available,
10 especially on a global basis. However, there are several
11 radiologically important unknowns concerning the fate of gaseous
12 radiocarbon close to release points. These include the rates of
13 equilibration with soil carbonate minerals, the flux rates for
14 photosynthetically fixed radiocarbon to accumulated refractory
15 carbon (including soluble fulvates and humates), and the flux
16 rates for soil-borne radiocarbonates to plant roots. Each of
17 these processes can influence the transport of radiocarbon to
18 humans. Acquisition of these necessary data would reduce the
19 present uncertainty. Additionally, there are questions about the
20 observation that deposited radionuclides such as ^{90}Sr , ^{137}Cs , ^{129}I
21 and ^{14}C are depleted from the available biosphere more rapidly
22 than can be accounted for by physical decay alone.

3.4 Experimental Techniques, Measurements and Instrumentation

3.4.1 Development of Dosimetric Techniques for the Experimental Verification of Complex Calculational Models

There is a need to develop measurement techniques to verify the mathematical models used in the calculation of energy deposition distributions and dose in situations that cannot be measured, especially relating to internal radiation emitters. (NCRP, 1985a). It is also important to substantiate the models for exposure to external radiation that take into account age and sex differences, tissue heterogeneities and complex internal structures. Similarly the models used to relate measured field quantities to absorbed dose or dose equivalent must be validated by some measurement technique. These requirements could result in the development of new radiation measurement and dosimetric devices (including biological dosimeters) and phantoms.

3.4.2 Development of Accurate and Sensitive Methods for Monitoring Intake

Accuracy and sensitivity of monitoring must be improved to assure good radiation safety practice and compliance with current recommendations for Annual Limits on Intake (ALI).

1 The concept of a 50 y committed dose that is currently the
2 basis for many radiation protection standards for control of
3 internal exposure to radionuclides makes it necessary to detect
4 and to quantify very low annual intakes from in vivo or in vitro
5 bioassay samples, or from air samples collected in the work area.
6 Although each of these approaches has strengths and weaknesses,
7 all have been impacted by the need to detect and to quantify
8 radionuclides at levels that are much lower than previously
9 required. Additional research should be directed to the
10 development of more sensitive detection and analysis
11 methodologies to facilitate these monitoring programs. Also,
12 improved approaches for distinguishing the exposure of interest
13 from background exposures must be evolved.

14 **3.4.3 Development of a More Exact Method for Monitoring Uranium**
15 Uptake

16 There is a particular need to develop a more exact method
17 for determining the exposure of individuals to uranium because
18 the present method is not optimized for regulating chronic
19 exposures. The exposure limit for soluble forms of uranium is
20 based on controlling a peak concentration value for uranium in
21 the kidney to $3\mu\text{g g}^{-1}$ of tissue. Although this approach appears
22 to have provided an overall adequate level of protection to

uranium workers, it may not be the best way to control prolonged or repeated brief occupational exposures. Chronic exposures might produce dose-response relationships that are different from those related to acute exposures. In turn, this might lead to different health protection approaches for soluble forms of low-specific-activity uranium compounds.

3.4.4 Development of a Generic Guidance Document for Environmental Monitoring of Radionuclides and Chemicals

Environmental monitoring is crucial to the assessment of the potential radiation dose resulting from the release of radioactive material to the environment. Guidance is required so that this procedure is performed in a consistent manner that is useful for accurate dose assessment.

Over the last four decades a number of strategies have been developed for monitoring the environment following radioactive releases. These testing efforts should be extended to include hazardous chemicals. There is thus a requirement for a guidance document detailing the constitution of an effective, cost-efficient environmental monitoring program. Such a guidance document would assist facilities in the development of more

defensible monitoring programs, particularly when coupled with a risk assessment methodology.

3.4.5 Development of Instrumentation to Relate Radiation Field Quantities to Relevant Dose Quantities

There is a need for instrumentation that can accurately measure radiation field quantities so that the measurements can be related to radiation dose or dose equivalent for purposes of radiation protection. To assess the risk to persons exposed to radiation from external sources, measurement devices are placed on the individual. The response of these devices must then be related to a radiation dose received by the individual or a radiation dose to specific organs of the individual. Although for x-ray and gamma-ray radiation the current indication is that the response of these devices does not underestimate the effective dose to the individual, there is considerable uncertainty in the actual relationship between the instrument response and the dose, or dose equivalent to the individual. These uncertainties must be reduced. In particular, for neutron radiation and for high-energy, high Z (HZE) charged particle radiation, better instrumentation is required for measuring dose quantities at levels necessary for good radiation protection. Typical neutron measurement devices are still very insensitive in

the range of energies and intensities that are important for many exposures to neutron sources (ICRU, 1988; NCRP, 1989).

3.5 Exposures to Specific Sources

3.5.1 Development of Accurate Models of the Dose to Bronchial Tissues from Radon Progeny in Relation to Airborne Radon Concentration

There is a need for more accurate modeling of radiation dose to bronchial tissue from radon progeny and for more accurate methods of relating radon exposure of the general public to the exposure data from studies of underground miners. Additional research is necessary to determine which exposure and response factors for the general population exposure to indoor radon differ from those that apply to uranium miners, and how these differences might affect the extrapolated health risk per unit of exposure to radon and its progeny.

The relationship between airborne radon and the dose to bronchial tissues from radon decay products involves many physical and biologic factors, some of which are age- and sex-dependent, and some of which are dependent on the health status of the individual. In addition to better models, as discussed in

1 Section 3.2, a greater understanding of the physical relationship
2 between airborne radon and the radiation dose to bronchial tissue
3 (e.g., radiation equilibrium, particle size, attachment to
4 aerosols) must be achieved.

5 **3.5.2 Development of Screening Models for Environmental**
6 **Contaminants**

7 There is a need to improve and further develop screening
8 models that will identify the significant environmental
9 contaminants and assess their contribution to the dose the public
10 receives. Uncertainty analysis must be applied to these models
11 and site-specific testing must be instituted. Many of the tools
12 that are used to produce quantitative risk assessments rely
13 heavily upon the use of computer models, the results of which are
14 subject to large uncertainty. To address this problem it is
15 recommended that intentionally biased screening calculations be
16 developed to eliminate contaminants, and possibly sites, whose
17 contribution to the population radiation dose and risk is clearly
18 trivial. At the same time, these models must clearly identify
19 those contaminants and sites that could pose a significant risk.
20 This methodology should not only allow the decision-maker to set
21 consistent national priorities but also provide priorities for
22 site-specific remediation. Once additional data on the most

1 important contaminants become available, more realistic models
2 can be employed. It is essential that these models include
3 uncertainty analyses to provide confidence limits on dose and
4 risk predictions, and to delineate the exposure pathways and
5 model parameters that contribute most to the uncertainty. These
6 results will then identify site-specific research essential for
7 testing and improving the reliability of the models and
8 parameters used for risk assessment.

4. Risk Assessment

This Section will provide an overview of a number of areas encompassed by risk assessment and will attempt to highlight particular requirements for more research. The key concerns relate to knowledge about carcinogenesis and, to a lesser extent, genetic effects pertaining to dose-response relationships, the magnitude of effects at low doses, and the effects of fractionation or protraction of exposure. The need for further research is motivated by several considerations: few data may be available or they may be of questionable quality, the uncertainties as they affect risk may be large, and the exposures may be ubiquitous so that the public health implications are major.

4.1 Animal Studies and Their Relationship to Human Studies

There are problems in defining the shape of the dose-response relationship for induction of cancer by radiation, especially at low total doses. An adequate sample size of "exposed individuals" can be identified using the epidemiological approach, but the magnitude of the dose and potential for interaction with other environmental carcinogens cannot be

1 controlled. In experimental animal studies, dose can be defined
2 and exposure to other agents regulated to some extent, but many
3 experimental animals are needed to detect a significant effect.
4 In most past studies animal numbers have not been adequate. The
5 exceptions to this were studies at Oak Ridge National Laboratory
6 in which large numbers of mice were used. In mouse studies, many
7 different strains are available and each strain has its own
8 unique distribution of disease types, making it difficult to
9 extrapolate mouse data to humans. In larger animals, such as
10 dogs or nonhuman primates, the expense of life-span experiments
11 is prohibitive. Consideration of a large radiation experiment
12 using the rat may be important for standard-setting. The problem
13 of adequate animal numbers and the ability to extrapolate the
14 tumor data to humans may be minimized by using rats. Radiation-
15 induced tumor type and tumor frequency in rats seem to be similar
16 to those estimated for humans.

17 4.1.1 Species Dose Response Differences at the Tissue, Cellular
18 and Molecular Levels to Species Differences in Response

19 To maximize the use of dose-response data obtained in
20 nonhuman biologic systems for radiation protection applications,
21 additional research should be devoted to establishing stronger
22 links among studies conducted in humans, in different species of

1 laboratory animals, and at the tissue, cellular and molecular
2 levels.

3 It is well known that different dose-response relationships
4 for internally deposited radionuclides can occur among various
5 species including humans. Recognizing that much of our current
6 knowledge in this area has been, and is being, derived from
7 studies in nonhuman systems, in the extrapolation process we must
8 understand and account for these dissimilarities, which can arise
9 as a result of both species dosimetric differences and variations
10 in the types and degrees of biologic response. New techniques at
11 the tissue, cellular and molecular levels are facilitating a
12 deeper understanding of the bases for species differences that
13 should enhance our ability to combine dose-response data from
14 diverse sources to obtain better health risk estimates for people
15 exposed to internally deposited radionuclides.

16 **4.1.2 Integration of Animal and Human Data to Provide**
17 **the Best Estimates of Dose-Response, RBE and DREF**

18 The principal issues of radiobiology (e.g., dose-response
19 curves, RBE, DREF) deserve a thorough analysis based on all
20 available data. There is a need to develop reliable methods, or
21 improve existing ones, to factor in the body of knowledge derived

1 from mammalian radiobiology and carcinogenesis and to apply it to
2 human cancer and genetic risk estimation. Currently there are a
3 few attempts at this (Storer et al., 1988), which have
4 encompassed only a fraction of the available data sets. Parallel
5 analyses of available animal data need to be undertaken with the
6 same degree of sophistication and thoroughness as recent analyses
7 of the human data (e.g., NAS/NRC, 1988; 1990). This may require
8 the development of new methodological approaches, both in
9 modeling and integrating the animal data and in extrapolating
10 from animal to human risks. It would be of interest to model
11 with the animal data factors similar to those modeled in the
12 epidemiologic data, e.g., absolute versus relative risks, to
13 determine if there are congruities.

14 **4.1.3 Studies in Animal Systems to Validate Mathematical**
15 **Models of Carcinogenesis**

16 One goal in modeling animal data is to make the transition
17 from phenomenological ("curve fitting") models to those that are
18 biologically realistic. Models suggest the multistage nature of
19 carcinogenesis and the interactions between different elements in
20 the biologic system required for cells to progress to the stage
21 where they become cancerous. Few measurements that could provide
22 data to elaborate or validate models have been taken on the

1 cellular and molecular changes during the early stages of
2 carcinogenesis. Some data useful in model validation are
3 modifications of cell proliferation, karyotypic alterations, and
4 activation or inactivation of oncogenes and other growth-
5 regulating factors. Data on the effect of inflammation or
6 immunologic changes on cell types, proliferation, and
7 differentiation observed during early stages of carcinogenesis
8 will also provide useful input into carcinogenesis models.

9 4.1.4 Determination of the Influence of Parental Exposure on
10 Leukemia Risk in Offspring

11 A recent report (Gardner et al., 1990) has suggested that
12 children of fathers who worked in a nuclear reprocessing plant
13 have an increased risk for the development of leukemia if the
14 fathers received more than ten millisievert in the six months
15 before conception of the children and/or more than 100 mSv in
16 preceding years. An attempted replication of this study at
17 another nuclear facility has failed to confirm these findings
18 (Urquhart et al., 1991). Other studies of leukemia and paternal
19 preconception irradiation have shown mixed results (Graham et
20 al., 1966; Hicks et al., 1984; Shu et al., 1988; Buckley et al.,
21 1989; Yoshimoto, 1990; McKinney et al., 1991). The very limited
22 findings from animal research with regard to this issue are also

1 equivocal (Nomura, 1982; Batra and Sridharan, 1964; Kohn et al.,
2 1965; Vorobstova, 1989). Additional human and animal studies are
3 needed to clarify the presence, nature and magnitude of possible
4 risks from preconception irradiation.

5 4.2 Human Epidemiologic Studies

6 This Section will provide an overview of the areas of
7 research encompassed by radiation epidemiology and will attempt
8 to highlight those in which there is a need for more work. The
9 research needs are motivated by several considerations: few data
10 may be available or they may be of questionable quality, the
11 uncertainties as they affect risk may be large, and the exposures
12 may be ubiquitous so that the public health implications are
13 major.

14 In all areas of research in radiation epidemiology it is
15 important to consider carefully the value of potential (or
16 completed) studies. Several elements enter into this
17 consideration; if one or more is lacking, the study is of limited
18 value even though the topic may be of high interest. Can the
19 pertinent individual exposures or doses be adequately
20 characterized, and do they have a sufficient range so as to be
21 informative? Will the combination of dose, number of persons and

1 length of observation be sufficient so that effects can likely be
2 seen, i.e., does the study have adequate statistical power? Is
3 there enough ancillary information available to check on or
4 control for important covariates of risk? Do the study design
5 and the data collection methods avoid potential biases in subject
6 selection or information acquisition, and are the measures
7 employed sufficiently reliable? Have the primary hypotheses and
8 analyses been specified in advance, so that a "fishing
9 expedition" is avoided in the data analysis phase? For completed
10 studies, have they been interpreted in a balanced fashion and in
11 the light of all other available data?

12 4.2.1 Improvement of the Estimates of the Risks from Exposure to
13 Low Dose and Fractionated or Protracted Irradiation

14 Much of the concern about the effects of ionizing radiation
15 pertains to situations where the total exposures are low or where
16 they have been accrued over a period of weeks or years. There is
17 a large range of uncertainty about the relative amount of risk
18 (per unit dose) from such exposures when compared with acute,
19 high-dose radiation. There is a large range of uncertainty about
20 low dose and dose rate effectiveness factors (DDREFs), so
21 information on them is of critical importance.

1 Two types of information potentially converge to provide a
2 basis for estimating DDREFs. (1) Insofar as the shape of dose-
3 response curves for various health endpoints can become better
4 defined from epidemiologic (and also animal) studies, especially
5 in the low-to-moderate-dose range, they provide information on
6 the expected risks at low doses. For example, if the dose-
7 response is linear-quadratic, a solid estimate of the linear
8 component of the curve is essential. (2) Studies in which the
9 radiation exposure was fractionated or protracted contrasted with
10 those in which similar doses were received acutely may yield
11 information for estimating the DDREFs, providing the cumulative
12 doses are sufficiently high to be informative. Careful parallel
13 analyses of low-dose rate studies will provide the best
14 opportunity for such comparisons. For example, a recent analysis
15 of three occupational radiation studies found that the risks for
16 leukemia and for total cancers were lower than those predicted by
17 linear extrapolation from the Japanese atomic-bomb data, although
18 the differences did not attain statistical significance (Gilbert
19 et al., 1989).

1 4.2.2 Development of Additional Information on the Temporal
2 Expression of Radiation-Induced Cancer

3 The time-response behavior of radiation carcinogenesis has
4 both practical and theoretical implications, and at present our
5 knowledge is very incomplete. Assumptions about this factor have
6 a substantial impact on lifetime risk projections.

7 In recent years the risk assessment community has shifted
8 from using the absolute risk model for projecting lifetime
9 radiation risks to using the relative risk model, which tends to
10 fit the existing data better. For many cancer sites, however,
11 the constant (over time since irradiation) relative risk model
12 predicts much higher risks for the remaining, as yet not
13 observed, lifetime than does the absolute risk model. Several
14 recent analyses of epidemiologic radiation data have suggested
15 that a constant relative risk model may overestimate risk at
16 longer follow-up times (and older ages), but the results are
17 uncertain.

18 For the major specific cancer sites there is a pressing need
19 to analyze all available irradiated cohorts in parallel in order
20 to better establish the temporal pattern of risk. There is also
21 a need to pursue additional years of follow-up for various

1 irradiated cohorts to better estimate the temporal pattern of
2 risk and the risk coefficients. Discontinuance of follow-up of
3 any of the several dozen major groups that have been studied is
4 shortsighted, because the scientific information from a cohort
5 increases substantially with longer follow-up time.

6 Irradiated groups exposed early in life and now reaching
7 ages of 40 plus have had a substantial impact upon the recent
8 revisions in risk estimates, so further follow-up of these groups
9 is particularly important to determine whether the high relative
10 risks continue unabated or decline at older ages. Continued
11 follow-up of those in the Japanese atomic-bomb study irradiated
12 in-utero, and possibly other studies, will also be valuable.

13 **4.2.3 Development of Better Methods for Transporting Risk**
14 **Estimates Across Populations**

15 The scientific guidelines for transferring risk estimates
16 developed in one population to another with different
17 characteristics are not well developed. This is particularly
18 important in radiation epidemiology, because risk coefficients
19 developed largely on the strength of the Japanese atomic-bomb
20 data have been transferred to American and European populations
21 where different cancer rates (e.g., stomach cancer) and age-

dependencies (e.g., breast cancer) prevail. Methodological work is needed to develop additional statistical methods or to evaluate the circumstances in which existing alternative methods are preferable.

It is also of importance that expert groups developing risk estimates consider more comprehensively the full range of data sets available from various populations in deriving and evaluating risk estimates. This will help assure compatibility in the transfer of risk estimates.

4.2.4 Development of a National Dose Registry of Radiation Workers

A comprehensive registry of individual occupational radiation doses would be very valuable both for worker protection and for epidemiological purposes. The present ad hoc system of documenting previous worker radiation exposures is inefficient, expensive and incomplete. Especially with the new, more stringent guidelines concerning allowable cumulative radiation doses, new employees will not want the high "assigned" doses that are mandated when past doses cannot be documented; having a national dose registry would largely obviate such assigned doses and also greatly facilitate epidemiologic studies of radiation

workers. Developing accurate rosters of workers and their doses is currently a very expensive proposition; a registry would largely automate such a task.

4.3 Risk Assessment of Exposure to Internal Radionuclides and Heavy, Energetic Particles

4.3.1 Life-Span Studies of Dose-Response Relationships for Internally Deposited Radionuclides in Laboratory Animals

Major life-span studies of dose-response relationships for internally deposited radionuclides in laboratory animals, especially those in a long-lived species, should be followed to completion with a degree of intense scrutiny and analysis comparable to that accorded the human studies which are, of necessity, more limited in scope.

Because of the small number of radionuclides and routes of exposure available for study in human populations, much of our knowledge of dose and dose-response relationships for many radionuclides, and the factors that can modify these relationships, come from laboratory studies nearing completion. Detailed analysis and modeling of the results will provide a stronger basis for radiation protection recommendations for

internally deposited radionuclides and for the conduct of future studies directed at underlying mechanisms of radiation-induced cancer.

4.3.2 Studies of Human Populations Exposed to Internally Deposited Radionuclides Both Medically (^{232}Th , ^{224}Ra , ^{131}I) and Occupationally (^{226}Ra , ^{222}Rn and its Progeny)

It is of major importance that studies of human populations that have had known exposures to internally deposited radionuclides - such as medically administered ^{232}Th (Thorotrast), ^{224}Ra , or ^{131}I , or occupational exposure to ^{226}Ra (dial painters and chemists) or Rn and its progeny - be continued to ensure completeness of follow-up, especially for the individuals exposed at low-to-moderate levels where there is the most uncertainty about the magnitude of risks.

Because these exposures resulted primarily from past practices, the populations represent a unique, current opportunity for study that cannot be repeated in the future. Therefore, it is critical that these studies be followed to completion to ensure that maximum scientific benefits are derived from the available subjects.

1 **4.3.3 Improvement of the Estimates of the Risk from Occupational**
2 **Radon Exposure**

3 Radon is a very important issue from both health and
4 economic viewpoints. When expressed on the basis of the total
5 average effective dose equivalent received by the US population,
6 exposure to radon and its progeny is the largest contributor.
7 The BEIR IV Committee (NAS/NRC, 1988) made a number of
8 recommendations regarding radon research with which this Report
9 agrees. Briefly, they are:

10 (1) Continue studying existing cohorts of radon-exposed
11 miners for their lifetimes and obtain additional
12 information on their smoking habits where possible.

13 (2) Analyze the miner studies carefully for the temporal
14 expression of lung-cancer risk.

15 (3) Obtain additional information from both animal and
16 epidemiologic studies on the interaction between radon
17 daughters and cigarette smoking with regard to lung
18 cancer induction.

1 (4) Evaluate variations between occupational and
2 residential (or environmental) settings in the
3 translation coefficient from exposure to lung dose, in
4 order to provide a comparative basis for describing the
5 risk associated with residential exposures.

6 (5) Address the issue of comparative risk (relative to
7 occupational exposures) in studies of residential radon
8 exposures. Such studies should be designed with
9 sufficient statistical power to evaluate both the null
10 hypothesis and the comparative risks.

11 Several more correlated comments and recommendations can be
12 added. Studies of additional miner populations would be valuable
13 if they have well-characterized exposures, sufficient person-year
14 sievert for adequate statistical power, and good smoking
15 histories. Many of the present studies are weak in one or more
16 of these attributes.

17 Although the BEIR IV Committee (NAS/NRC, 1988) made
18 significant advances in risk estimation by assessing risk from
19 several studies and by delineating the factors that may modify
20 risk (e.g., age at exposure, age at risk, time since exposure,
21 smoking history), there is a need to conduct analyses of

1 additional miner data sets to increase the precision and ensure
2 the generality of the risk estimates and their modifiers. It
3 would also be useful to conduct uncertainty analyses vis a vis
4 the magnitude of error in radon exposure estimates, smoking
5 estimates, etc.

6 Several special questions need to be addressed: the cells
7 at risk for lung cancer from radon progeny, the impact of the
8 radon progeny equilibrium factor upon dose to the lung, and risk
9 following childhood exposures. (The Chinese tin-miner study may
10 provide valuable information on juvenile exposures.)

11 Exposure to radon and its progeny is the largest contributor
12 to the total average effective dose received by the US
13 population. Our knowledge of dose-response relationships — upon
14 which current health risk assessments for indoor population
15 exposures to radon and its progeny are based — is derived
16 primarily from the health risk data derived from populations of
17 uranium miners.

18 Thus, it is important to determine the degree of difference
19 between the exposure and response factors for general population
20 exposures to indoor radon and those for miners and how much these
21 differences might alter extrapolated health risks. Similarities

1 and differences between mine, home, school and work place
2 exposures need to be evaluated as to the temporal and spatial
3 patterns by which the radiation dose is received, since these
4 factors may alter the biologic effects and dose-response
5 relationships.

6 A number of studies of residential radon and lung cancer are
7 ongoing. These studies are expensive and difficult and many
8 suffer from various weaknesses (e.g., limited exposure
9 assessments). When more are undertaken, the populations should
10 be chosen selectively. Important selection criteria are: a
11 potential for good historical exposure assessment and an adequate
12 population fraction at higher exposure levels, adequate smoking
13 histories and limited population mobility (in order to permit the
14 assessment of radon exposure levels in residences over the entire
15 lifetime). When the several residential studies currently
16 underway have been completed, it is essential to conduct parallel
17 analyses to obtain the most accurate assessment of risk. The
18 comparative findings also will help identify important gaps in
19 our knowledge or unresolved questions. New studies can then be
20 targeted to reduce these uncertainties.

1 **4.3.4 Improvement of the Estimates of Risk From ^{131}I**

2 An unresolved issue of importance to the radiation
3 protection community is the magnitude of thyroid cancer risk from
4 ^{131}I . More human data are needed, especially among those exposed
5 to ^{131}I as children, since (1) the thyroid cancer risk estimates
6 from external radiation studies are based mainly on childhood
7 exposures, and (2) the limited age data suggest that children's
8 thyroid glands have greater radiation sensitivity than adult
9 glands. The present animal and adult human data from ^{131}I
10 exposures are sparse. Children exposed to fallout from the
11 Chernobyl accident represent an especially important population
12 to study for thyroid neoplasia. This population is large, and
13 the thyroid doses range up to 15 Gy.

14 **4.3.5 Determination of the Biologic Effects of Radiation in**
15 **Space**

16 The biologic effects of heavy, highly energetic particles
17 are much less studied than those of light particles (e.g.,
18 electrons, protons) and photons. Of particular interest are
19 probabilistic endpoints such as carcinogenesis and deterministic
20 ones such as central nervous system damage. The relative
21 biologic effectiveness of these particles for cancer production

1 in animals and mutagenesis in cell systems must be determined,
2 and whether the underlying mechanisms are the same as those for
3 light particles resolved. In the case of central nervous system
4 damage, the production of microlesions (i.e., a central core of
5 cells killed by the direct effects of high Z particles and a
6 surrounding shell of cells damaged by secondary radiation) needs
7 to be reexamined and whether such lesions could critically damage
8 a vital center in the brain investigated. Lastly, the
9 interaction of radiation with microgravity effects needs to be
10 analyzed.

11 4.3.6 Determination of the RBE of Neutrons in Humans

12 The question of the RBE of neutrons is of some practical
13 concern because of occupational neutron exposures. Since no good
14 occupationally exposed cohorts have been identified, the best
15 study group is probably persons given neutron radiation therapy.

16 4.4 Improvement of Epidemiology Methods and Applications

17 A number of suggestions can be listed synoptically, some of
18 which have been touched on in other sections as well.

(1) Pooled analyses have the potential to provide more insights into radiation effects and more precise estimates of risk. They will aid in developing a closer understanding of the relationship between radiation effects and the complex phenomena that modify the risk. The increased precision of the pooled data sets will permit the examination of various important parameters in more detail and with more confidence in the generality of the results. Parameters that might be examined include (but are not limited to) the shape of the dose-response curve; the slope of the linear component to the curve; the temporal pattern of risk, possibly as modified by age; variations in risk associated with dose-fractionation or dose-protraction; modification of risk by sex, age, lifestyle factors, etc.

(2) More attention should be given to the best way(s) to transport generalized risk estimates from one population to another. What is the effect of different background rates or of temporal changes in background rates (see Section 4.2)?

(3) Some attention should be given to statistical issues involved in the temporal and dose relationships for protracted exposure, e.g., long-lived internal emitters.

(4) Further techniques should be developed that allow appropriate adjustment for dose measurement error or other uncertainties associated with the data. These then need to be translated into flexible and generally available software for dealing with uncertainties in estimates of exposure and covariates.

(5) New statistical methodologies need to be explored in relation to radiation risk estimation. For example, Bayesian methods appear promising for dealing with dose measurement error. Moreover, mathematical models that attempt to describe the biologic processes of cancer (e.g., Moolgavkar Knudson model), rather than just perform curve-fitting, may provide new insights into radiation-induced cancer risks.

(6) It is important that the most sensitive and informative statistical procedures available be applied to all studies; not to analyze the data well is extremely

1 wasteful since data collection is so expensive, while
2 good quality analyses add relatively little cost.

3 **4.5 Elaboration of Risks by Studying Host Susceptibility Factors**

4 Determining host factors that identify especially sensitive
5 subpopulations is very important for radiation protection and is
6 also likely to provide insights for understanding radiation
7 carcinogenesis. Relatively little is known about cancer
8 induction by radiation among those with special genetic disorders
9 (e.g., ataxia telangiectasia, Bloom's syndrome, Fanconi's anemia,
10 xeroderma pigmentosum, nevoid basal cell carcinoma syndrome).
11 Even less is known about whether there may be increased
12 radiogenic cancer risk among those who are heterozygous carriers
13 for recessively inherited disorders, who are orders of magnitude
14 more numerous than those with overt disorders. This is therefore
15 an issue of some importance, but biomarkers must be developed for
16 detecting cancer (or other disease) susceptibility before
17 meaningful studies of carriers can be conducted.

1 **4.5.1 Development of Models that Provide Individualized**
2 **Molecular Risk Assessment for Cell Survival and**
3 **Carcinogenesis**

4 Extensive efforts have been made to develop predictive
5 models for cell survival following radiation exposure. These
6 models have rarely included experimentally derived biochemical
7 parameters (i.e., rate constants for the function of repair
8 enzymes). As such biochemical information becomes available, it
9 should be utilized in the development of biologically-based
10 radiation-response models. This is perhaps most important in the
11 development of models of radiation-induced carcinogenesis, where
12 the physical aspect of the radiation exposure is certainly the
13 best understood variable in the outcome. In the carcinogenic
14 process, the intervening stages between the deposition of energy
15 in the affected cell and the endpoint of tumor development are
16 dependent on a series of biochemical events each with an
17 associated likelihood of occurrence. Efforts to develop models
18 of carcinogenesis and mutation should aim to determine which of
19 the experimentally observed biochemical changes are crucial to
20 the outcome in question.

1 **4.5.2** Characterization of Radiation Risks in Relation to Host
2 Susceptibility Factors and Age of Exposure

3 The development and function of the immune system may be
4 altered by radiation exposure. Differences in immune competence
5 have been defined among individuals with genetic disease. Other
6 subclinical differences exist in some fractions of the
7 population. The role these subclinical differences play in
8 individual sensitivity for development of radiation-induced
9 cancer needs to be defined. There is evidence that in utero
10 irradiation may alter the development of the immune system. It
11 is important to determine if this alteration can affect the
12 frequency of radiation-induced cancer.

13 The degree to which age at exposure to ionizing radiation
14 modifies the risk for various cancer sites is not well
15 understood. The BEIR V Committee found age-at-exposure effects
16 for leukemia, breast cancer, digestive cancer and "other
17 cancers". It would be useful to evaluate age-at-exposure effects
18 among the number of tumor sites which were not specifically
19 analyzed. It is also an interesting radiobiological question as
20 to how there is suppression of tumor expression for many years
21 following exposure and why it occurs for a longer period of time

(for some cancer types at least) when radiation is received at a younger age.

A special case of age at exposure pertains to prenatal irradiation. In addition to developing estimates of cancer risk from in utero irradiation, two new concerns over prenatal irradiation have recently surfaced which require further study: intelligence deficits associated with irradiation during weeks 8 to 15 of gestation (see Section 2.6), and the possible association between leukemia and preconception irradiation which was suggested by a recent study of residence near Sellafield (see Section 4.1.5).

It is important to evaluate the utility of studying a given population for host susceptibility factors or interactions among factors. A situation in which the radiation dose, and hence the magnitude of effect, is low is not likely to be useful for delineating factors that modify the radiation effect. Resources should be invested only in studies that have reasonable prospects of yielding meaningful results.

4.6 Interactions of Radiation and Other Toxicants

Humans are exposed to mixtures of chemicals, drugs and radiation. It is important to determine if the biologic responses from these combined exposures can be predicted. Radiation protection standards have been set for single exposure with little information on potential interactions between damages induced by multiple agents. Because there are many potential types of chemical exposure in the environment and wide ranges of radiation exposure sequences and dose patterns, it is not possible to conduct studies that will address all potential interactions. However, short-term cellular and molecular techniques allow evaluation of a wide range of different exposure conditions. Chemicals and types of radiation exposure with potential for antagonistic or synergistic interactions can be identified for further investigation. With cellular and molecular approaches, mechanisms of interaction can also be defined. This level of understanding can help in extrapolation from individual chemicals or types of radiation to combined exposures.

Few interactions of radiation and other agents have been identified in human studies to date, perhaps because large populations with substantial exposure to both radiation and some

1 other toxicant are uncommon. Some epidemiologic information is
2 available concerning the joint effects of smoking and radiation
3 exposure upon lung cancer risk, ultraviolet and ionizing
4 radiations upon skin cancer risk, and cancer chemotherapy and
5 radiation exposure upon various second-cancer risks. All these
6 interactions have been rather crudely defined and more
7 information is needed. Other agents which are likely candidates
8 for epidemiologic study based on laboratory studies or other
9 considerations include asbestos, ELF electromagnetic fields and
10 heat.

5. Prevention, Intervention and Perception

5.1 Prevention

Prevention starts with an understanding of who is at risk from a genetic point of view and of the factors that amplify this risk.

5.1.1 Utilization of Molecular and Cellular Techniques to Identify Individuals Who May Have an Increased Risk for Radiation-Induced Cancer

Certain individuals are hemizygous for tumor suppressor genes. Thus, single deletions of the remaining active gene can result in cancer development. Tumor suppressor genes have been identified that are associated with the induction of retinoblastoma, lung, colon and bone cancer. Additional research is required to establish the presence of other tumor suppressor genes that may be associated with other types of cancers and genetic diseases. Molecular techniques can be developed to determine sensitive human subpopulations. Standards could then be set to limit radiation exposure of sensitive sub-populations.

1 5.1.2 Characterization of Radiation Risks in Relation to Host-
2 Susceptibility Factors and Age of Exposure

3 The development and function of the immune system may be
4 altered by radiation exposure. Differences in immune competence
5 have been defined among individuals with genetic disease. Other
6 subclinical differences exist in some fraction of the population.
7 The role these subclinical differences play in individual
8 sensitivity for development of radiation-induced cancer needs to
9 be defined. There is evidence that in utero irradiation may
10 alter the development of the immune system. It is important to
11 determine if this alteration can affect the frequency of
12 radiation-induced cancer.

13 The degree to which age-at-exposure to ionizing radiation
14 modifies the risk for various cancer sites is not well
15 understood. The BEIR V Committee (NAS/NRC, 1990) found age-at-
16 exposure effects for leukemia, breast cancer, digestive cancer
17 and "other cancers." It would be valuable to evaluate age-at-
18 exposure effects among the number of tumor sites which were not
19 specifically analyzed.

20 A special case of age-at-exposure pertains to prenatal
21 irradiation. In addition to developing estimates of cancer risk

1 from in utero irradiation, two new concerns over prenatal
2 irradiation have recently surfaced which require further study:
3 intelligence deficits associated with irradiation during weeks 8
4 to 15 of gestation (see Section 2.6), and the possible
5 association between leukemia and preconception irradiation which
6 was suggested by a recent study of residence near Sellafield
7 (Gardner et al., 1990; Graham et al., 1966; Shiono et al., 1980).

8 It is important to evaluate the utility of studying a given
9 population for host susceptibility factors or interactions among
10 factors. A study in which the radiation dose, and hence the
11 magnitude of effect, is low is not likely to be useful for
12 studying factors that modify the radiation effect. Resources
13 should be invested only in studies that have reasonable prospect
14 of yielding meaningful results.

15 5.1.3 Relationship of Patient Dose to Radiologic Image Quality 16 and Diagnostic Outcomes

17 Poor quality radiologic examinations result in little, or
18 no, benefit to the patient while exposing the patient to a
19 potentially significant radiation dose and its attendant risk.
20 The technical and diagnostic accuracy of imaging in radiology is
21 an area that could benefit from research evaluating the efficacy

1 of the imaging procedure and examining potential actions to
2 reduce the collective dose to the general population.

3 **5.1.4 Assessment of the Impact of New Technologies and Changing**
4 **Demographics on Risks from Medical Radiation Sources**

5 Three factors may contribute to increases in annual and
6 lifetime per capita doses to the population; in some cases, these
7 doses can be translated into a higher risk of induced
8 malignancies. The factors are: (1) the salvaging of very-low-
9 birth-weight infants on whom multiple diagnostic and therapeutic
10 procedures are performed, primarily after birth but in some cases
11 in utero; (2) the increased use of computed tomography and
12 interventional radiology techniques for diagnosis and/or therapy
13 with associated increases in gonadal and marrow doses; and (3)
14 the increasing life expectancy of the population many of whom
15 will now live beyond the age at which induced malignancies might
16 have been previously thought to occur. On the basis of risk
17 estimates made in 1985 and exposure values from 1977, previous
18 work indicated that less than one percent of all breast cancers
19 and one percent of all cases of leukemia resulted from diagnostic
20 radiology and that the highest incidence for these occurred at
21 ages 76 and 69, respectively (Evans et al., 1986).

1 In terms of research, efforts should be made to estimate the
2 magnitude of radiation exposure from diagnostic and therapeutic
3 sources and to use these with updated risks in order to determine
4 the magnitude of induced cancers under present conditions.

5 **5.1.6 Acquisition of Additional Data on Transmission,**
6 **Scattering and Fragmentation That Will Help in the**
7 **Development of Better Shielding**

8 The need for research in radiation shielding arises
9 primarily from an anticipated reduction in radiation doses
10 permitted under revised protection guidelines. Substantial work
11 will be required to verify existing calculational models, develop
12 new models and evaluate various existing, and potentially new,
13 construction models. This information will be important in
14 optimizing the design of facilities (medical, industrial,
15 aircraft) to provide suitable shielding for radiation protection
16 while maintaining cost and space requirements as low as possible.

17 It has been pointed out that the error in tenth value layer
18 for leakage radiation from a ten million electron volt electron
19 accelerator may be as much as 50 percent (Tochline and LaRiviere,
20 1979). This could lead to substantial overshielding and an cost
21 overrun of \$10,000 or more depending on the facility. Including

1 a safety factor of ten in shielding design to account for unknown
2 uncertainties could have similar results.

3 Although much of the necessary information has been
4 determined for materials and energies used in diagnostic
5 radiology (although not yet published), there is a need for
6 better attenuation information for x rays in concrete in the
7 range 50 keV to 25 MeV. This information is required for the
8 different concrete mixes using various aggregates.

9 Because of the potential reduction in allowable radiation
10 exposures based on current risk estimates, new techniques must be
11 developed for evaluating more accurately the transport of
12 radiation through and around shielding. Currently, estimates of
13 radiation transport through ducts and entrance mazes to radiation
14 facilities are based on a few measurements and use empirical
15 models that are relatively inaccurate and generally lead to
16 overdesign of protective barriers. More measurements of neutron
17 and photon scattering and transport are needed as well as more
18 accurate calculational models in order to design optimal
19 facilities.

20 Galactic cosmic rays are the major radiation source found in
21 space outside of the magnetosphere. These are composed

1 principally of protons (87 percent) and helium ions (12 percent).
2 A small but significant component are heavy ions, high in energy,
3 and of these, iron is the most important.

4 Shielding has little effect on the penetration of these
5 energetic, heavy ions into the spacecraft, but the shielding may
6 cause fragmentation of the particles with the production of
7 secondary particles. These secondary particles will be an
8 important source of radiation for missions deep in space. In
9 order to better estimate the doses likely to be received by those
10 exposed during these flights, we require more information about
11 the fragmentation of iron and other heavy particles as they pass
12 through the spacecraft and about the spectra of the resulting
13 secondary particles.

14 In addition to radiations not normally encountered on earth,
15 space exploration may involve the use of materials which are not
16 normally used in construction on earth. Materials available for
17 use in spacecraft and in potential construction on other planets
18 may be substantially different from those that have been
19 previously evaluated for radiation shielding.

1 Also, the problems of shielding high energy, high Z
2 particles are different from those encountered in shielding
3 radiations normally found on earth.

4 5.2 Interventions

5 Interventions cover several areas and this Section is partly
6 based on material already discussed in Section 3 on Dose
7 Determination. The development of interventional strategies can
8 be based on experience with previous radiologic accidents.

9 5.2.1 Development of Information on Counter-Measures Taken 10 Following Large Radiologic Accidents and Their 11 Effectiveness

12 The information slowly being released by the Soviet
13 authorities from their experiences at Chelyabinsk and Chernobyl
14 indicates how important post accident countermeasures are in
15 mitigating health and environmental problems, and how little we
16 know about the efficacy of some of them. While considerable
17 research was conducted in the USA on countermeasures in the case
18 of nuclear war, this research was never validated. The events in
19 the USSR, and in those European countries subjected to Chernobyl
20 fallout, provide an opportunity to examine our data and proposals

1 and to compare them with the USSR and European information. The
2 areas of importance are those related to the urban environment,
3 such as indoor reduction of inhalation and external dose,
4 particle size deposition rates inside and on building surfaces,
5 and decontamination techniques for buildings, roads, gardens and
6 parks. Considerable data are also available on variations in
7 deposition on various agricultural crops, translocation,
8 resuspension and rainsplash, rates of transfer to animal
9 products, and their subsequent elimination. An additional area
10 for study is the agricultural practices that were employed by the
11 USSR and other nations to reduce the accumulation of long-lived
12 radionuclides in agricultural products. Correlation of these
13 data should lead to the development of a generic plan for
14 implementing countermeasures and clean-up activities following a
15 nuclear accident, one which would take into account the
16 technical, social and economic factors.

17 **5.2.2 Development of Informational Materials for Public Use**
18 **After a Radiation Accident**

19 Experiences at Three Mile Island and Chernobyl have
20 indicated the need for better educational materials for the
21 public following a radiation accident. This material should
22 cover several items, including the nature of the accident (see

1 Section 5.2 on approaches to describing the risks associated with
2 the accident), safe living practices (e.g., eating, drinking,
3 traveling), the availability of social support and counseling
4 mechanisms. The optimum source of this information (e.g., a
5 member of the radiation community or a lay person) and the
6 factors that will maintain the confidence of the public in the
7 source of this information should be determined.

8 5.3 Perception and Public Policy

9 To date there has been no sustained, systematic effort to
10 develop a thorough understanding of public perceptions of
11 radiation risks or adequate methods for communicating about these
12 risks. From the technical perspective, much effort and many
13 resources have been spent to discover and assess risks. Only a
14 minute fraction of the effort has been devoted to obtaining
15 knowledge needed for managing those risks in the public domain.
16 The time seems ripe to begin to address this imbalance (Slovic,
17 1990, personal communication).

1 **5.3.1 Development of Common Expression of Risk for All**
2 **Carcinogens**

3 Assessments that quantify health and environmental risks are
4 essential to ensure remedial actions are cost effective and to
5 compare and evaluate alternatives. Past assessments have been
6 limited solely to examining regulatory compliance regarding
7 permissible dose, exposure and concentration. Risk evaluation is
8 the only meaningful way to compare potential exposures to
9 chemicals and radionuclides. Unfortunately, risk conversion
10 factors for radionuclides and chemicals are neither derived nor
11 interpreted in a consistent manner.

12 When the bases for chemical carcinogen risk factors and
13 radionuclide risk factors are examined, it is evident that they
14 do not have common points for comparison nor are they based on
15 similar exposure time periods. Risk factors for chemical
16 carcinogens are usually derived from laboratory studies in the
17 absence of human data and represent the upper 95 percent
18 extrapolation for the occurrence of excess cancer incidents,
19 assuming a lifetime exposure. This lifetime exposure is usually
20 taken to be 70 y. Risk factors for radionuclides are derived
21 from best-estimate extrapolations from extensive human data, but
22 represent only the incidence of fatal cancer. Furthermore, the

1 current system of dose limitation for radionuclides is based upon
2 maximum annual rather than lifetime risk. To be meaningful, risk
3 factors need to be developed that reflect common endpoints. It
4 is recommended that this endpoint be a weighted lifetime risk of
5 developing cancer with fatal cancers receiving a higher weight
6 than nonfatal cancers.

7 **5.3.2 Development of a Better Understanding of the Public's**
8 **Perception of Risk and Improved Methods**
9 **of Presenting Information on Exposure and Risk**

10 A large body of literature indicates that individuals do not
11 easily understand small risks, cannot differentiate between small
12 risks of different magnitudes, make systematic errors in
13 estimating smaller versus larger risks, and make choices on the
14 basis of risk information depending upon the analytic
15 presentation of the information. Some of this was summarized in
16 NCRP Proceedings No. 1, Perceptions of Risk (NCRP, 1980); other
17 material is presented in the publications of Bell et al. (1988);
18 Starr (1969) and others. Further basic work in cognitive
19 psychology will enhance improved understanding by the public of
20 risk assessment. In the context of radiation protection several
21 specific research applications should be encouraged. These are:

(1) Assessment of factors that contribute to the public's misunderstanding of either the magnitude or impact of radiation exposure.

(2) Development of better ways to express exposures, particularly in relation to natural background or to accepted exposures from other sources (environmental, occupational health, etc.).

(3) Development of improved methods for describing risks. These should deal not only with presentation of absolute risks per se but also with presentation of incremental risks. The former should emphasize approaches to minimizing bias in choices made as a result of the information on risks. The latter should emphasize differences in presentation for incremental increases (e.g., as a result of the new dosimetric results) and decreases (e.g., as a result of improved protection devices). Need for the latter derives from known differences in choices made by individuals depending upon whether the choices are framed as gains or losses.

(4) Development of better methods to teach probabilistic concepts to students. The evolution of improved methods to describe risks (see Section 5.3) may depend upon gradually increasing the ability of students at all levels to understand probabilistic concepts, ranging from an understanding of a simple probabilistic event to an understanding of more complicated situations (conditional events, conjunctive or disjunctive situations, etc.). Although students are sometimes exposed to these concepts at the high school level and more frequently at the college level, current approaches fail to give them an intuitive understanding of probabilistic events.

5.3.3 Assessment of Societal Values with Respect to Radiation and Other Risks

Public policies related to risks of any sort depend upon the extent to which a society values gains achieved from risk reduction and supports the costs necessary to achieve these gains. Preliminary information is increasingly available from medicine on the extent to which society is willing to devote resources for particular purposes. Some of this information comes from explicit cost-effectiveness (or less frequently cost-

1 benefit) calculations on the use of particular screening,
2 diagnostic or therapeutic interventions. Some is obtained from
3 extrapolation of these same techniques to decisions regarding the
4 provision of health services; recent activities in the State of
5 Oregon illustrate this. Research on assessing these values and
6 associated willingness-to-pay estimates should be performed for
7 risk reductions related to medical and environmental radiation
8 sources. Willingness-to-pay estimates should be made with
9 explicit consideration of the effect of such expenditures on
10 other public goods.

11 **5.3.4 Development of Levels of Acceptability for Various Types**
12 **of Risk**

13 Presently there is an inconsistent interpretation of risk
14 limits. For example, the boundaries of acceptable and
15 unacceptable risks need to be defined. For any given situation,
16 there will be a level of risks that can be considered clearly
17 acceptable just as there are levels of risks that can be seen as
18 clearly unacceptable. These two levels are not identical. We
19 need to recognize those risks considered trivial, warranting no
20 further investigation. On the other hand, risks above the
21 clearly unacceptable level must be avoided regardless of the cost
22 of remedial action. Risks occurring between the two extremes

1 should be reduced as far as it is economically, socially, and
2 politically practical to do so. This point of view is consistent
3 with the general philosophy underlying radiation protection
4 practices and should be applied in the case of mixed wastes.

5 The problem exists because regulations for one group of
6 carcinogens have been derived from clearly unacceptable risk
7 levels and regulations for others have been derived from clearly
8 acceptable risk levels, with both being used as guides for the
9 cleanup of contaminated sites. This inconsistency leads to a
10 large discrepancy in risk levels requiring current environmental
11 action for sites involving both chemicals and radionuclides.
12 Thus, when the environment is contaminated with both
13 radionuclides and chemical carcinogens, some actions may reduce
14 the threat from one type of contamination without reducing that
15 from the other. This disparity needs to be corrected.

6. Resource Requirements

The prosecution of the research set out in this agenda will require appropriate resources. These can be defined in terms of people, facilities and data bases.

First, the continued flow of young investigators trained in modern biology, epidemiology, medical and health physics, and environmental sciences into this field is essential. In particular the support of positions at universities, research institutes, teaching hospitals, and national laboratories is required to provide a cadre capable of addressing the research agenda laid out in this Report and maintaining a response to this national and world-wide need.

Second, special facilities are required for the pursuit of this research: long-term tissue banking units; special animal quarters with radiation sources, shielding, facilities for the handling of radionuclides as well as caging for life-term maintenance; irradiation sources including low dose and low-dose rate photon fields, particle accelerators and sources of neutrons with proper energies.

1 Third, certain collections of animal and human epidemiologic
2 data must be developed and maintained. These include the
3 completion and recording of animal life-span studies for
4 internally deposited radionuclides (see Section 4.3.1); the
5 completion of human studies involving medical (^{232}Th , ^{224}Ra , ^{131}I)
6 and occupational (^{226}Ra , ^{222}Rn and progeny) radionuclides deposited
7 internally (see Section 4.3.2); a registry of radiation workers
8 starting with those working in the nuclear industries (see
9 Section 4.2.4) but ultimately extending to medical professionals
10 in radiology and nuclear medicine; a pilot collection system for
11 patients from medical sources; and a compendium of data obtained
12 from large radiation accidents such as Chernobyl.

13 It is difficult to see how this research agenda will be
14 pursued absent the infrastructure described above. Certainly, if
15 no one wakes in the morning to think about the research issues of
16 radiation protection, there will be no research strategy designed
17 or proposals formulated. Nor can the research proceed without
18 the specialized capital investments that will be required. More
19 than that, the opportunity cost of not completing and storing the
20 data bases now in existence and being gathered is enormous and
21 the possibility of recreating them nonexistent or prohibitively
22 expensive. It is in the interest of those agencies, public and
23 private, that hold themselves responsible for radiation

1 protection to work collaboratively to see that they are completed
2 and preserved.

3 Lastly, a continuing source of funding for the year-to-year
4 support of this research will be needed. It is the Council's
5 hope that the specifics provided by this Report will provide a
6 rational basis for research allocations in this field.

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May, 1992

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THE WHITE HOUSE
WASHINGTON

June 22, 1992

Dear Dr. Ney:

Thank you for the opportunity to comment on the draft report entitled "Research Needs in Radiation Protection". Scientific Committee 83 has produced an excellent menu of needs and opportunities with respect to strengthening the relevant science base. The final report should be of considerable value to both individual scientists and sponsoring agencies as they strive to invest their intellectual and financial resources in the most productive way.

I applaud the emphasis on cellular and molecular indicia of radiation damage and biological response. The rapidly expanding concepts and techniques of biotechnology offer unprecedented leads for assessing the consequences of radiation - especially low-dose, infrequent exposures - in such fundamental terms as whether, how, and to what extent DNA is altered and cells' genetically determined DNA-repair processes respond to the challenge. I can think of no body of new knowledge that would do more to reduce the sometimes intractable uncertainty that traditionally has hampered the quest the put radiation protection on a scientifically sound footing.

Sincerely yours,



D. Allan Bromley
The Assistant to the President
for
Science and Technology

W. Roger Ney, J.D.
Executive Director
National Council on Radiation
Protection and Measurements
7910 Woodmont Avenue
Suite 800
Bethesda, MD 20814-3095

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TYPE: ACTION DOCUMENT NUMBER: 9200844
ORIGINATOR: 02 STATUS I DIRECTORATE STATUS C

FROM: KELLER, Ward M.: AMERICAN SOCIETY OF RADIOLOGIC TECHNOLOGISTS

TO: DR. D.A. BROMLEY



DATE OF
CORRESPONDENCE: 03/09/92

SUBJECT: HE REQUESTS DR. BROMLEY'S COOPERATION AND ACTION AS
CALLED FOR IN THE RESOLUTION ADOPTED BY THEIR HOUSE
OF DELEGATES REGARDING EXPOSURE LIMITS.

DIRECTORATE STAFF
ASSIGNED: LIFE SCIENCES ASSIGNED: William Raub

ACTION STAFF
REQUIRED: DIRECT REPLY ACTION: DIRECT REPLY

SENDER'S DUE DATE:
OSTP DUE DATE: 03/31/92 STAFF DUE DATE 03/31/92
DATE COMPLETED: DATE COMPLETED/DEPT: 04/07/92

COPIES TO: D. Allan Bromley

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ASSIGNED: LIFE SCIENCES ASSIGNED: William Raub

ACTION STAFF
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ACTION STAFF
REQUIRED: DIRECT REPLY ACTION:

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...the national professional organization representing radiography, radiation therapy technology, nuclear medicine technology and sonography

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THE AMERICAN SOCIETY OF RADIOLOGIC TECHNOLOGISTS

92 MAR 17 AM 11:31

15000 Central Avenue SE, Albuquerque, New Mexico 87123-3909; (505) 298-4500; Fax # (505) 298-5063

OSTP
MAIL ROOM

March 9, 1992

Dr. D. Allan Bromley
Assistant to the President for
Science and Technology
Office of Science and Technical Policies
Old Executive Office Building, RM. 360
Washington, D.C. 20500

Dear Dr. Bromley,

The House of Delegates of the American Society of Radiologic Technologists is the governing and legislative body for the organization. As such, the House of Delegates adopted Resolution 91-4.07, titled "Lowering of Occupational Exposure Limits."

The "Be It Resolved" section of the resolution is to urge the Federal Government to adopt and enforce the recommendations as set forth in Report #91, "Recommendations on Limits for Exposure to Ionizing Radiation," as recommended by the National Council on Radiation Protection and Measurements.

We request your cooperation and action as called for by this resolution.

Thank you.

Sincerely,

Ward M. Keller
Chief Executive Officer

WMK:jls

cc: Dr. Alvin L. Young, Chairman
Committee on Interagency Radiation Research
and Policy Coordination
1019 19th Street NW, Suite 700
Washington, D.C. 20036



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FACSIMILE COVER SHEET

DATE: 4/3/92

TO: Bill Raub

LOCATION: OSTP

FAX: (202) 395-1571 VERIFY: Yes No

FROM: Bill Mills TIME:

SUBJECT: Limits on Exposure to Ionizing Radiation

MESSAGE: Bill, suggested minor changes. CIRRPC Executive Committee

has not yet considered the way that review will be handled.

If you have questions about the changes call Merlene, I will be out of
town until 4/13/92.

Transmittal consists of 2 pages, including coversheet. If there are any problems with the transmission, please contact *Merlene Burnham* at (202) 653-8206. Thank you.

March , 1992

I am responding to your letter of March 9 regarding limits on exposure to ionizing radiation. I have been apprised that Report #91 of the National Council on Radiation Protection and Measurements now is under revision and that, as part of that process, consideration is being given to whether occupational exposure limits should be lowered and, if so, to what level. Moreover, I understand that this issue will be addressed in the months ahead on a Government-wide basis through the Committee on Interagency Radiation Research and Policy Coordination. Be assured that my staff and I will stay in close touch with these developments and will be prepared to facilitate them in any way we can.

Sincerely yours,

as may be appropriate.

DAB

Ward M. Keller
Chief Executive Officer
The American Society of
Radiologic Technologists
15000 Central Avenue SE
Albuquerque, NM 87123-3909

DRAFT

March , 1992

Dear Mr. Keller:

I am responding to your letter of March 9 regarding limits on exposure to ionizing radiation. I have been apprised that Report #91 of the National Council on Radiation Protection and Measurements now is under revision and that, as part of that process, consideration is being given to whether occupational exposure limits should be lowered and, if so, to what level. Moreover, I understand that this issue will be addressed in the months ahead on a Government-wide basis through the Committee on Interagency Radiation Research and Policy Coordination. Be assured that my staff and I will stay in close touch with these developments and will be prepared to facilitate them in any way we can.

Sincerely yours,

DAB

Ward M. Keller
Chief Executive Officer
The American Society of
Radiologic Technologists
15000 Central Avenue SE
Albuquerque, NM 87123-3909

*Sent to Mills, OR AU
for comment
3/19*

3/19

Bill Mills ORAU

Report #91 of WCRP

73 members on Council

#91 being revised

will take a while

5 REM ~~→~~ 2 REM ?

A. Cuv $\hookrightarrow$ generally acceptable

AA ARA

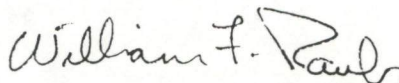
EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

April 7, 1992

Dear Mr. Keller:

I am responding to your letter of March 9 to Dr. D. Allan Bromley regarding limits on exposure to ionizing radiation. I have been apprised that Report #91 of the National Council on Radiation Protection and Measurements now is under revision and that, as part of that process, consideration is being given to whether occupational exposure limits should be lowered and, if so, to what level. Moreover, I understand that this issue will be addressed in the months just ahead on a Government-wide basis and considered by the Committee on Interagency Radiation Research and Policy Coordination as may be appropriate. Be assured that my colleagues and I will stay in touch with these developments so as to facilitate them as best we can.

Sincerely yours,



William F. Raub, Ph.D.
Special Assistant for Health Affairs

bcc: D. Allan Bromley
William Mills, ORAU

Ward M. Keller
Chief Executive Officer
The American Society of
Radiologic Technologists
15000 Central Avenue, S.E.
Albuquerque, NM 87123-3909