05-09-05P03:32 RCVD

Special Exposure Cohort Petition

Submitted to

Office of Compensation Analysis and Support

On behalf of

Former employee of
National Bureau of Standards, Van Ness Street
Washington, D.C.

NIOSH Tracking

May 6, 2005

Office Of Compensation Analysis and Support
NIOSH
SEC Petition
4676 Columbia Parkway
MS-C-47
Cincinnati, OH 45226

05-09-05P03:32 RCVD

RE: SEC status for NIOSH #[redacted]

Dear Sir:

I would like to respectfully submit a petition for Special Exposure Cohort status for my [redacted] He was a [redacted] the [redacted] the National Bureau of Standards, Van Ness Street, Washington, D.C. from [redacted] until [redacted]

I am the official representative for [redacted] who on [redacted] filed a claim with the EEOICPA as a surviving spouse. Official documentation of my status as representative is included in her original claim.

There is one petitioner, [redacted]

My [redacted] has the only claim from the National Bureau of Standards. He was diagnosed with myelofibrosis, one of the specified cancers (see doc. A11, A12) and it appears that NIOSH will not be able to locate adequate information to complete dose reconstruction with sufficient accuracy. I believe this claim therefore, meets the qualifications to be considered for inclusion in the SEC.

After studying many documents provided through the FOIA and speaking with a former National Bureau of Standards colleague of [redacted], it is my understanding that during the years [redacted] worked at the National Bureau of Standards workers were exposed to radioactive materials on a daily basis, but no personal monitoring for either external or internal exposure was available (see doc. A1). My research shows that individual monitoring most likely began later than [redacted] If there were records of monitoring prior tc [redacted] hese records have been lost or destroyed. At this time, NIOSH has not been able to reconstruct the radiation doses in the Radioactivity Lab at NBS and it is my firm belief that radiation doses may have endangered the health of [redacted] am submitting copies of research articles co-authored by [redacted] (see docs. A13, A14, A15, A16, A17), newspaper articles showing him within feet of radium (see docs.A3, A4) and pictures taken of him working with Dr. A.V. Astin and Leon Curtiss (see doc. A18, A25). There are also pictures taken by him of these and other researchers and of projects and locations at the National Bureau of Standards (see docs. A5, A19, A20, A21, A22, A23, A24).

Documents provided through the FOIA, which I have documented and enclosed with this petition, reinforced some information I already had and provided much new information. During the time of [redacted] employment at NBS, the Radioactivity Lab was located in the East Building, Building #2 (see docs. A3, A42, A43, A48). Thorium, uranium and radium are all listed in inventories of the NBS from the early 1940s until 1946 (see docs. A49, A50, A51, A52, A53). Radioactive materials were not used in this building after 1952 (see docs. A7, A43). I am including the levels of radiation present in 1968 prior to decontamination. The levels, [redacted] and sixteen years after radioactive materials were no longer used, are shocking (see doc. A7, pages 6-9). Many rooms were so contaminated that floors, windows, doorway frames, doors, and in some rooms and hallways, three-inch thick concrete floors had to be removed. Four weeks were spent on attempting to decontaminate this building. After one hundred 55- gallon drums were filled with radioactive waste and removed, there were rooms remaining that had their doorways bricked over so no one could enter. It is not surprising that no long-term employees are alive today. Building #2 was approved for demolition in 1976. No new structures were built upon the site (see docs. A7 and A48).

In this petition I have included a statement from Dr. Rosalind B. Mendell who was also a physicist in the Radioactivity Lab for two years during the mid-1940s. At the time of my phone interview with ORAU, December 8, 2004, I was not aware of any living co-workers. She called me several weeks ago after doing a computer search for [redacted] She wanted to reestablish contact with her former colleague. Unfortunately, I had to tell her of his passing. Rosalind is anxious to help any way she can with [redacted] case. I sent copies of all the documents provided through the FOIA for her review. She has no doubt that his health was endangered by the work with radioactive materials he performed at the National Bureau of Standards as part of the Manhattan Project (see doc. A1). After reviewing the document listing the levels of radiation found in Building 2 prior to decontamination in 1968, document A7, Dr. Mendell stated, "When I read about the radiation in Building 2, the levels that were reported just about scared me to death. I am amazed that I am still here at 84 years of age after all that exposure (see doc. A10). In addition to uranium, thorium and plutonium, she thinks he may have also been exposed to neutrons. At the time she worked with [redacted], Dr. Mendell had an M.S. degree from Cornell University, time in research at Columbia University and a year at New York University. She is now a retired NYU Senior Research Scientist in experimental cosmic ray physics (see doc. A26) and is the author of many research articles. The titles of these papers I am attaching will show her to be a respected expert, both in the United States and internationally, in the field of radiation exposure.

Attached please find descriptions of work being done at the National Bureau of Standards (see docs. A40, A41, A42, A43, A44, A 45, A46, A47, A48), materials present at NBS (see docs. A49, A50, A51, A52, A53) and research papers [redacted] wrote while at the Bureau (see docs. A13, A14, A15, A16, A17). I have included proof of his employment at NBS from [redacted] (see doc A54) and a letter written to the selective service regarding [redacted] low draft number. It states, "[redacted] of this section, informs me that he holds a low number in the selective service lists and may receive a questionnaire at any time. [redacted] is engaged in research on problems in radioactivity concerned with national defense, of a confidential nature, which would be seriously delayed if he were called away for a year. This work involves studies of nuclear fission as a source of atomic energy and requires the use of highly specialized equipment, which he has developed and with which he alone is familiar. It would be difficult to replace him and it would require at least a year to train a man to attain the desired proficiency in the conduct of these investigations. It therefore appears that the national defense is best served by retaining him in his present work." The letter is unsigned but, is believed to have been written by Dr. Leon Curtiss (see doc. A55). These materials are included to document that work he did was with radioactive materials.

Dr. Mendell is an expert in the field of radioactivity and is qualified to provide testimony to the fact that as physicists working in the Radioactivity Lab, their exposure levels were not monitored and that the levels were extremely high. As evidence of her expertise in the area, attached are research articles where Dr. Mendell is either an author, her work is referenced or she is cited as an expert (see docs. A27, A28, A30, A32, A33, A34, A35, A37, A39). She can also tell you to what elements was exposed during her time of employment. Dr. Mendell has offered to be available to you by phone, mail or email for any questions you may have concerning exposure, events and materials was exposed to in the lab. Her email address is Rbmendell@aol.com, her home address is . If you would like her home phone number, please contact me and I will send it to you.

In addition to the documents included with this petition, please evaluate documents already in my claim file as they pertain to my request for SEC status.

Thank you for your time. I have the original newspaper articles, pictures and proof of employment. If you would like me to present them to the Seattle office I would be happy to do so. Please contact me if you have any questions or need more information or documentation. I look forward to hearing from you.

Respectfu

Representative for

NIOSH claim #

AMY ALBEE
COMM. EXP.
APRIL 30, 2005

Special Exposure Cohort Petition
under the Energy Employees Occupational
Illness Compensation Act

U.S. Department of Health and Human Services
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

OMB Number: 0920-0639 Expires: 05/31/2007

Special Exposure Cohort Petition — Form B

Use of this form and disclosure of Social Security Number are voluntary. Failure to use this form or disclose this number will not result in the denial of any right, benefit, or privilege to which you may be entitled.

General Instructions on Completing this Form *(complete instructions are available in a separate packet)*:

Except for signatures, please **PRINT** all information clearly and neatly on the form.

Please read each of Parts A — G in this form and complete the parts appropriate to you. If there is more than one petitioner, then each petitioner should complete those sections of parts A – C of the form that apply to them. Additional copies of the first two pages of this form are provided at the end of the form for this purpose. A maximum of three petitioners is allowed.

If you need more space to provide additional information, use the continuation page provided at the end of the form and attach the completed continuation page(s) to Form B.

If you have questions about the use of this form, please call the following NIOSH toll-free phone number and request to speak to someone in the Office of Compensation Analysis and Support about an SEC petition: **1-800-356-4674.**

If you are:	☐ A Labor Organization,	Start at D	on Page 3
	☐ An Energy Employee (current or former),	Start at C	on Page 2
	☐ A Survivor (of a former Energy Employee),	Start at B	on Page 2
	☐ A Representative (of a current or former Energy Employee),	Start at A	on Page 1

A Representative Information — Complete Section A if you are authorized by an Employee or Survivor(s) to petition on behalf of a class.

A.1 **Are you a contact person for an organization?** ☐ Yes (Go to A.2) ☒ No (Go to A.3)

A.2 **Organization Information:**

Name of Organization

Position of Contact Person

A.3 **Name of Petition Representative:**

Mr./[✓ Mrs.]/Ms./First Name Middle Initial Last Name

A.4 **Address:**

Street Apt # P.O. Box

City State Zip Code

A.5 **Telephone Number:** (

A.6 **Email Address:**

A.7 ☒ Check the box at left to indicate you have attached to the back of this form written authorization to petition by the survivor(s) or employee(s) indicated in Parts B or C of this form. An authorization form for this purpose is provided.

If you are representing a Survivor go to Part B. If you are representing an Employee go to Part C.

Name or Social Security Number of First Petitioner: _

February 1, 2005

To Whom It May Concern:

I give permission for my daughter, to act as my representative in any areas of my EEOICPA claim. This includes petitioning for SEC status.
Sincerely,

Special Exposure Cohort Petition
under the Energy Employees Occupational
Illness Compensation Act

U.S. Department of Health and Human Services
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

Special Exposure Cohort Petition — Form B

OMB Number: 0920-0639 Expires: 05/31/2007
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B Survivor Information — Complete Section B if you are a Survivor or representing a Survivor.

B.1 **Name of Survivor:**

Mr./[✓ Mrs.]/Ms. First Name h Middle Initial Last Name

B.2 **Social Security Number of Survivor:**

B.3 **Address of Survivor:**

Street Apt # P.O. Box

City State Zip Code

B.4 **Telephone Number of Survivor:**

B.5 **Email Address of Survivor:**

B.6 **Relationship to Employee:** ☒ Spouse ☐ Son/Daughter ☐ Parent ☐ Grandparent ☐ Grandchild

Go to Part C

C Employee Information — Complete Section C UNLESS you are a labor organization.

C.1 **Name of Employee:**

[✓ Mr.]/Mrs./Ms. First Name Middle Initial Last Name

C.2 **Former Name of Employee** (e.g., maiden name/legal name change/other):

Mr./Mrs./Ms. First Name Middle Initial Last Name

C.3 **Social Security Number of Employee:**

C.4 **Address of Employee** (if living):

Street Apt # P.O. Box

City State Zip Code

C.5 **Telephone Number of Employee:** ( ) N/A

C.6 **Email Address of Employee:** N/A

C.7 **Employment Information Related to Petition:**

C.7a Employee Number (if known):

C.7b Dates of Employment: Start End

C.7c Employer Name:

C.7d Work Site Location: National Bureau of Standards Radioactivity Lab, Van Ness Street, Washington, D.C. Bldg #2, East Bldg.

C.7e Supervisor's Name:

Go to Part E

Name or Social Security Number of First Petitioner:

D Labor Organization Information — Complete Section D ONLY if you are a labor organization.

D.1 **Labor Organization Information:**

Name of Organization ______________________

Position of Contact Person ______________________

N/A

D.2 **Name of Petition Representative:** ______________________

D.3 **Address of Petition Representative:**

Street ______________________ Apt # ______ P.O. Box ______

City ______________ State ______________ Zip Code ______

D.4 **Telephone Number of Petition Representative:** (____) ____-______

D.5 **Email Address of Petition Representative:** ______________________

D.6 **Period during which labor organization represented employees covered by this petition** (please attach documentation): Start ________ End ________

D.7 **Identity of other labor organizations that may represent or have represented this class of employees** (if known):

____

Go to Part E

Name or Social Security Number of First Petitioner: ______________________

Special Exposure Cohort Petition
under the Energy Employees Occupational
Illness Compensation Act

U.S. Department of Health and Human Services
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

Special Exposure Cohort Petition — Form B

OMB Number: 0920-0639 Expires: 05/31/2007

E Proposed Definition of Employee Class Covered by Petition — Complete Section E.

E.1 **Name of DOE or AWE Facility:** National Bureau of Standards
Van Ness St., Washington, D.C.

E.2 **Locations at the Facility relevant to this petition:**
Radioactivity Lab, East Building (Building #2)

E.3 **List job titles and/or job duties of employees included in the class. In addition, you can list by name any individuals other than petitioners identified on this form who you believe should be included in this class:**
Physicist

E.4 **Employment Dates relevant to this petition:**

Start ______ End ______
Start ______ End ______
Start ______ End ______

E.5 **Is the petition based on one or more unmonitored, unrecorded, or inadequately monitored or recorded exposure incidents?:** ☒ Yes ☐ No

If yes, provide the date(s) of the incident(s) and a complete description (attach additional pages as necessary):

See doc. A-1 from Dr. Rosalind Mendell

Go to Part F

Name or Social Security Number of First Petitioner: ______

F Basis for Proposing that Records and Information are Inadequate for Individual Dose — Complete Section F.

Complete **at least one** of the following entries in this section by checking the appropriate box and providing the required information related to the selection. You are not required to complete more than one entry.

F.1 ☒ I/We have attached either documents or statements provided by affidavit that indicate that radiation exposures and radiation doses potentially incurred by members of the proposed class, that relate to this petition, were not monitored, either through personal monitoring or through area monitoring.

(Attach documents and/or affidavits to the back of the petition form.)

Describe as completely as possible, to the extent it might be unclear, how the attached documentation and/or affidavit(s) indicate that potential radiation exposures were not monitored.

In the attached statement from Dr. Rosalind B. Mendell, a well-respected authority on radioactivity and a former colleague of in the Radioactivity Lab at the National Bureau of Standards, Van Ness Street, Washington; D.C, she states that, "In those days, there were no badges to monitor our exposure to radiation; and samples were brought into the laboratory without information as to the nature of the materials delivered." and I shared the same laboratory on Van Ness Street in the National Bureau of Standards (see continuation page)

F.2 ☐ I/ We have attached either documents or statements provided by affidavit that indicate that radiation monitoring records for members of the proposed class have been lost, falsified, or destroyed; or that there is no information regarding monitoring, source, source term, or process from the site where the employees worked.

(Attach documents and/or affidavits to the back of the petition form.)

Describe as completely as possible, to the extent it might be unclear, how the attached documentation and/or affidavit(s) indicate that radiation monitoring records for members of the proposed class have been lost, altered illegally, or destroyed.

Part F is continued on the following page

Special Exposure Cohort Petition
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U.S. Department of Health and Human Services
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

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Special Exposure Cohort Petition — Form B

Appendix — Continuation Page

Continuation Page — Photocopy and complete as necessary.

F.1 (con't) during World War II." "I was hired by Leon Curtis of the NBS to work on the alpha particle spectroscopy of "W Metal." Such was the degree of secrecy (classification) of the Manhattan Project in our area. I was not kept informed about the nature of my research. I knew that I was working on a project involving artificially induced fission of uranium." Dr. Mendell describes in detail what she calls "one incident of frightening proportions." A five foot high glass case containing "rather large pieces of shiny metal" was wheeled into their laboratory. "At some point during the day, began to fill his experimental geiger counter with gas generated in his glass apparatus. The lab was rather large and experiment was at the other end of the laboratory from the glass case. When , turned on his electronics, he was shocked to find no geiger counts from the natural background radiation... he began making tests, nothing worked". The glass case was rolled from the room..." counter began to count furiously once the case was out of the laboratory, with the door closed. The radiation coming from the glass case had swamped the geiger counter across the laboratory and was causing maximum geiger counts even when removed from the laboratory. I do not know how many other cases we had of exposure to unusual doses of radiation from apparatus rolled into the lab, but this one was enough to cling to my memory for 60 years." Dr. Mendell describes a radium spill in the "Radium Room" where worked & fears of cleaning it up because of the potential for causing problems with future fertility." (see doc. A2, pages 11-14) was sterile until 3 yrs after leaving NBS, Dr. Mendell suffered s after working at NBS. She also describes handling radioactive materials from Oak Ridge (see document A2)

"*Scientists Find Device to Protect Radium Workers From Death - Remote Laboratory Is Used for Research Activities With Valuable Metal*" The newspaper article describes an "imaginary visit to the bureau's radium testing laboratories... you enter room 317... at the East building..." (see doc A-3, A-5). The large picture shown under the title of this article identifies my father, 'sitting in (see continuation page)

Attach to Form B if necessary.

Name or Social Security Number of First Petitioner: ______________________

Special Exposure Cohort Petition
under the Energy Employees Occupational
Illness Compensation Act

U.S. Department of Health and Human Services
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

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Special Exposure Cohort Petition — Form B

Appendix — Continuation Page

Continuation Page — Photocopy and complete as necessary.

E.1 (con't.) perfect safety, 5 feet from the radium, manipulates a stylus, the only machine of its kind in the world, which has just been developed by Bureau of Standards scientists after years of research (see document A-2)." This picture shows No monitoring badges are seen.

is shown using "a recently developed radium detector at the Bureau of Standards. The device already has proved its efficiency in locating the tiny hollow needles used in applying radium. The needles frequently become lost and heretofore a long and tedious search has been necessary to find them (see document A-4)." This is another newspaper article with a picture of without any monitoring badge.

"From the early 1920s till 1952, the Radioactivity Laboratory was located in the East Building (Building #2." "Since 1952 these rooms were used as non-radioactive laboratories and offices." "They found that the attic had a large number of spots which indicated a contamination to the extent of 100,000 - 1,000,000 counts/minute." "It was recalled that the attic in the East Building had been used as a laboratory and for storage areas (see document A-5) This is a Memorandum, United States Government To Mr. Robert S. Walleigh, A.Dir. Admin From: Abraham Schwebel, Chief, Health Physics Section dated March 22, 1962. No reference is made in this document to any samples taken prior to this time. After reviewing this document, Dr. Mendell said she's amazed that she is still alive. "And I do recall that when I read about the radiation in Building 2, the levels that were reported just about scared me to death. I am amazed that I am still here at 84 years of age after all that exposure...(see doc A-[illegible] 19-16)"... in those days there were no badges to monitor our exposure to radiation (see document A-1)."

Attach to Form B if necessary.

Name or Social Security Number of First Petitioner:

F.3 ☐ I/We have attached a report from a health physicist or other individual with expertise in radiation dose reconstruction documenting the limitations of existing DOE or AWE records on radiation exposures at the facility, as relevant to the petition. The report specifies the basis for believing these documented limitations might prevent the completion of dose reconstructions for members of the class under 42 CFR Part 82 and related NIOSH technical implementation guidelines.

(Attach report to the back of the petition form.)

F.4 ☐ I/We have attached a scientific or technical report, issued by a government agency of the Executive Branch of Government or the General Accounting Office, the Nuclear Regulatory Commission, or the Defense Nuclear Facilities Safety Board, or published in a peer-reviewed journal, that identifies dosimetry and related information that are unavailable (due to either a lack of monitoring or the destruction or loss of records) for estimating the radiation doses of employees covered by the petition.

(Attach report to the back of the petition form.)

Go to Part G

G Signature of Person(s) Submitting this Petition — Complete Section G.

All Petitioners should sign and date the petition. A maximum of three persons may sign the petition.

Signature Date

Signature Date

Signature Date

Notice: Any person who knowingly makes any false statement, misrepresentation, concealment of fact or any other act of fraud to obtain compensation as provided under EEOICPA or who knowingly accepts compensation to which that person is not entitled is subject to civil or administrative remedies as well as felony criminal prosecution and may, under appropriate criminal provisions, be punished by a fine or imprisonment or both. I affirm that the information provided on this form is accurate and true.

Send this form to:

SEC Petition
Office of Compensation Analysis and Support
NIOSH
4676 Columbia Parkway, MS-C-47
Cincinnati, OH 45226

If there are additional petitioners, they must complete the Appendix Forms for additional petitioners. The Appendix forms are located at the end of this document.

Name or Social Security Number of First Petitioner:

Public Burden Statement

Public reporting burden for this collection of information is estimated to average 300 minutes per response, including time for reviewing instructions, gathering the information needed, and completing the form. If you have any comments regarding the burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, send them to CDC Reports Clearance Officer, 1600 Clifton Road, MS-E-11, Atlanta GA, 30333; ATTN:PRA 0920-XXXX. Do not send the completed petition form to this address. Completed petitions are to be submitted to NIOSH at the address provided in these instructions. Persons are not required to respond to the information collected on this form unless it displays a currently valid OMB number.

Privacy Act Advisement

In accordance with the Privacy Act of 1974, as amended (5 U.S.C. § 552a), you are hereby notified of the following:

The Energy Employees Occupational Illness Compensation Program Act (42 U.S.C. §§ 7384-7385) (EEOICPA) authorizes the President to designate additional classes of employees to be included in the Special Exposure Cohort (SEC). EEOICPA authorizes HHS to implement its responsibilities with the assistance of the National Institute for Occupational Safety (NIOSH), an Institute of the Centers for Disease Control and Prevention. Information obtained by NIOSH in connection with petitions for including additional classes of employees in the SEC will be used to evaluate the petition and report findings to the Advisory Board on Radiation and Worker Health and HHS.

Records containing identifiable information become part of an existing NIOSH system of records under the Privacy Act, 09-20-147 "Occupational Health Epidemiological Studies and EEOICPA Program Records. HHS/CDC/NIOSH." These records are treated in a confidential manner, unless otherwise compelled by law. Disclosures that NIOSH may need to make for the processing of your petition or other purposes are listed below.

NIOSH may need to disclose personal identifying information to: (a) the Department of Energy, other federal agencies, other government or private entities and to private sector employers to permit these entities to retrieve records required by NIOSH; (b) identified witnesses as designated by NIOSH so that these individuals can provide information to assist with the evaluation of SEC petitions; (c) contractors assisting NIOSH; (d) collaborating researchers, under certain limited circumstances to conduct further investigations; (e) Federal, state and local agencies for law enforcement purposes; and (f) a Member of Congress or a Congressional staff member in response to a verified inquiry.

This notice applies to all forms and informational requests that you may receive from NIOSH in connection with the evaluation of an SEC petition.

Use of the NIOSH petition forms (A and B) is voluntary but your provision of information required by these forms is mandatory for the consideration of a petition, as specified under 42 CFR Part 83. Petitions that fail to provide required information may not be considered by HHS.

Table of Contents

Letter of application for SEC status

Special Exposure Cohort Petition

Petitioner, Surviving Spouse of
Representative

Documents Supporting SEC Petition

A1 Mendell, Rosalind B. (March 25, 2005), physicist, former colleague of Burrell W. Brown in Radioactivity Lab at NBS. No monitoring done during mid 1940s, several unusual exposures, concern for health. (*Correspondence*)

A2 U. S. Department of Commerce, National Bureau of Standards (1957) Protection Against Neutron Radiation Up To 30 Million Electron Volts, Handbook 63 p.11-14 (Source: FOIA request)

A3 Miller, James N. (1936) *Scientists Find Device To Protect Radium Workers From Death-Remote Laboratory Is Used for Research Activities With Valuable Metal* The Sunday Star, Washington, D.C. (From private archive)

A4 *Hunting Priceless Radium* (1934) clipping from unknown newspaper picture of Burrell Brown with caption describing his use of a radium detector (From private archive)

A5 *Giant Balloon Tests Weather Device.* Newspaper picture and caption. Dr. Astin, Dr. Curtiss and LL. Stockmann. The Sunday Star, Washington, D.C.

A6 *Uncle Sam's Radium Girl* picture of Miss Constance Torrey of the Bureau of Standards measuring and testing radium, bare hands, within six inches of her torso. (From personal archive)

A7 Schwebel, Abraham (1968) *Memorandum: Release of Buildings at Van Ness Street After Decontamination*, U. S. Department of Commerce, National Bureau of Standards. Information on decontamination of the Radioactivity Lab and levels of radioactivity before and after decontamination p.6-10 (Source: FOIA request)

A8 Little, Marshall S (1968) Radiological Health Division. *Final Report of Radiation Protection Evaluation of Washington Technical Institute Buildings, Formerly Occupied by NBS.* (Source: FOIA request)

A9 Brink, J.V., Bureau of Public Health Engineering (1968) Letter to Robert S. Wallegh, Associate Director for Administration, NBS, Gaithersburg, Maryland. expressing concern that after the District of Columbia took possession of six buildings from the General Services Administration it was found that building #2, the former Radioactivity Lab, had several rooms sealed with CRM warning tape, monitoring disclosed significant alpha contamination in rooms 519,520 and 521, beta-gamma contamination on the floor and significant alpha contamination on one rafter. (Source: FOIA request)

A10 Mendell, Rosalind B. (April 18, 2005), physicist. Email regarding high levels of radiation in Building #2. (Correspondence)

A11 Turcic, P.M. (2003), Director of EEOICPA, *Additional Cancers Considered as Primary Cancers*. EEOICPA Bulletin No. 03-11. "Action: The CE should consider: (1) myelofibrosis with myeloid metaplasia…to be bone cancer, which is a specified primary cancer per EEOICPA Section 73841 (17) (B)."(NIOSH web site)

A12 NIOSH (March 15, 2005) Case Status Report for Burrell W. Brown, NIOSH tracking number 009908. Myelofibrosis with myeloid metaplasia verified by DOL. Report sent to Elizabeth L. Brown (surviving spouse) and Virginia (Ginny) L. Bond (personal representative for Elizabeth Brown and daughter of Burrell W. Brown. (Correspondence)

A13 Curtiss, L.F., Astin, A.V., Stockmann, L.L.& Brown, B.W. (1930). An improved radio meteorograph on the Olland principle. Journal of Research of the National Bureau of Standards, Volume 22, January 1939. (Source: NIST Library)

A14 Curtiss, L.F., Astin, A.V., Stockmann, L.L. & Brown, B.W. (1939). Cosmic-ray observations in the stratosphere with high-speed counters. Journal of the National Bureau of Standards, Volume 23, November 1939. (Source: NIST Library)

A15 Curtiss, L.F.& Brown, B.W. (1945). Frequency meter for use with the Geiger-Muller Counter. Journal of Research of the National Bureau of Standards, Volume 34, January 1945. (Source: NIST Library)

A16 Brown, B.W. & Curtiss, L.F. (1945). Thin-walled aluminum beta-ray tube counters. Journal of Research of the National Bureau of Standards, Volume 35, August 1945. (Source: NIST Library)

A17 Curtiss, L.F. & Brown, B.W. (1946). An arrangement with small solid angle for measurement of beta rays. Journal of Research of the National Bureau of Standards, Volume 37, August 1946. (Source: NIST Library)

A 18 Photo taken on the roof of the National Bureau of Standards. Burrell W. Brown is the man on the left. (From private archive)

A19 Photo taken by Burrell W. Brown. Notation on back: "May 27, 1936. Equipment on the upper shelf is the receiver and automatic recorder. Dr. A. V. Astin shown at the controls." (From private archive)

A20 Photo taken by Burrell W. Brown. Notation on back: "May 27, 1936. The penthouse on the roof of the West Bldg. At the National Bureau of Standards. Dr. L. F. Curtiss inspecting the record." (From private archive)

A21 Photo of Dr. L.F. Curtiss, August 1937. (From private archive)

A22 Photo taken by Burrell W. Brown. Shows roof of National Bureau of Standards with balloon, device, men. (From private archive)

A23 Photo taken by Burrell W. Brown of roof of NBS. (From private archive)

A24 Photo taken by Burrell W. Brown from National Bureau of Standards. (From private archive)

A25 Photo of Burrell W. Brown as a young man at the National Bureau of Standards. (From private archive)

A26 NYU Physics Department web site, Dr. Rosalind Mendell. Photo with contact *information listed. (New York University)*

A27 Wilson, J.W., Simonsen, L.C., Shinn, J.L., Dubey, R.R., Jordan, W. & Kim, M. (1997). *Radiation analysis for the human lunar return mission. NASA Technical Paper* 3662, p.6. September 1997. (*See reference #15, Mendell, Rosalind*)

A28 Wilson, J.W., Goldhagen, P., Rafnsson, V., Clem, J.M., De Angelis, G. & Friedberg,W. *Overview of atmospheric ionizing radiation (air) research: SST-present.* Authors from: NASA Langley Research Center, DOE Environmental Measurements Laboratory, University of Iceland, Bartol Research Institute, Old Dominion University, Istituto Superiore di Sanita', Rome, Italy, Civil Aerospace Medical Institute, FAA. (*See p.11, reference: Mendell.*)

A29 Google search results for Rosalind Mendell. American Physical Society Review.C2, 793 (1970) "*... and to Rosalind Mendell,..for their patience and encouragement.*.Rev 101, 329

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A42 DOE Office of Worker Advocacy. Facility List, National Bureau of Standards, Van Ness Street. July 11, 2001. (Source: FOIA request)

A43 Document "WORKING DRAFT not for release" "The Former National Bureau of Standards Buildings, Van Ness Street, Washington, D.C. This document describes the site function, site description. Owner history, radiological history and status of Building 2. (Source: FOIA request)

A44 This appears to be the final product of document A41. (Source: FOIA request).

A45 *Army Service Forces (April 11, 1946)* Subject: Work Required by other Sites to be done by the Bureau of Standards. Memorandum. *"Following is the summary of the work expected to be done by the Bureau of Standards for the Manhattan District Research Contract during the coming fiscal year."* (Source: FOIA request)

A46 Kelley, W.E., Lt. Col.(March 26, 1946). Corps of Engineers, Area Engineer, Letter to Dr. Condon, Director, National Bureau of Standards, U. S. Dept. of Commerce, Washington, DC. This document lists work to be done by the NBS, including "shotgun" (neutron absorption) test facilities to be started during July of 1946 through arrangements with Dr. L. F. Curtiss. (Source: FOIA request)

A47 Linking Legacies.This is a flow chart labeled "Flow of Materials Through the Nuclear Weapons Complex" National Bureau of Standards (NBS) is listed under Chemistry & Met., Ordnance. (Source: FOIA request)

A48 Wallo, Andrew III. (1979) Letter to Mr. John P. Allen, Project Director, Special Projects Division, General Services Administration, Washington, D.C., from A. Wallo of The Aerospace Corporation. Subject: National Bureau of Standards Building, Washington, D.C." As I stated in our telephone conversation of April 5, 1978, Aerospace is summarizing the status of sites which were formerly utilized for the processing and storage of principally uranium and thorium for the Atomic Energy Commission and the Manhattan Engineer District. The purpose of the task is to obtain complete records for these sites that will verify their radiological safety." The letter lists the use of building 3 and states that it was approved for destruction in August of 1976 and it was demolished in September of October of 1976. "It is expected that most of the area (Lot 14 or 8) will be open area (street or park)." (Source: FOIA request)

A49 Uranium Inventory as of 31 December 1946. These documents list the uranium and thorium at the NBS and other facilities. (Source: FOIA request)

A50 Memo "Thru: Robert W. Ramsey Jr., Assistant Director for Nuclear Programs Division of Environmental Control Technology, DOE-HQ. "Decontamination and Decommissioning: Review of Manhattan District History (Classified Documents) – Med" (Source: FOIA request)

A51 Mott, Wm. E, Director (January 1978) Letter to J.L. Liverman, ASEV, S.H. Greenleigh, GC, E.G. Hewlett, Historian's Office, XS. "Summary of Manhattan Project Uranium Flow Sheet." (Source: FOIA request)

A52 "Preliminary History of AEC Thorium Research and Development" (Source: FOIA request)

A53 Database Report Site: DC.01 National Bureau of Standards (Source: FOIA request)

A54 Proof of employment at the National Bureau of Standards, Van Ness Street, Washington, D.C., for Burrell W. Brown, May 1931-May 1948

A55 Letter to selective service. States that "Mr. Brown was engaged in research problems in radioactivity concerned with national defense of a confidential nature…author unknown but believed to have been Dr. Leon Curtiss. (From private archive)

Doc A1

From: Rbmendell@aol.com **[Add to Address Book] [View Source]**
To:
Subject: , and Radiation
Date: Fri, 25 Mar 2005 20:29:56 +0000

To whom it may concern:

and I shared the same laboratory on Van Ness Street in the National Bureau of Standards during World War II. I did remember in years gone by that our laboratory was located on Van Ness Street. I did not remember the building number, but the documents which I have now seen show that it was the notorious Building Number 2.

I arrived in Washington in when my husband was transferred from Camp Crowder in Neosho, Missouri, to Washington D.C., where the army trained him first at Catholic University in Japanese and then in Vint Hill, Virginia, in preparation for cryptography. I left Washington in when my husband was released from the US army six months after the end of WWII.

Shortly after I arrived in Washington, I was hired by Leon Curtiss of the National Bureau of Standards to work on the alpha particle spectroscopy of "W Metal." Such was the degree of secrecy (classification) of the Manhattan Project in our area. In principle, I was not kept informed about the nature of my research. I knew that I was working on a project involving artificially induced fission of uranium only because I knew the energy of alpha particles from U235 and U238, because I could see the occasional huge pulses from natural fission of uranium, and because I was measuring the gradual enrichment of U235 alpha particles relative to those from U238. After all, my M.S. from Cornell University was in experimental nuclear physics.The information that I needed for my hypotheses had appeared in the physics journals before all such information became classified. As time progressed, I observed the enrichment of U235 relative to U238 from my measurements. My data was being used by Oak Ridge in relation to their enrichment program that used gaseous diffusion of uranium. Uranium enriched with U235 was eventally used in the fission bomb that fell on Hiroshima.

xperiment involved special Geiger counters. My brief record of that period tells me that I also did some work with special Geiger counters, but my chief recollection was of electroplating the solutions of uranium salt and then putting the samples in my ionization chamber for measuring the energy and counting rates of the alpha particles.

In those days, there were no badges to monitor our exposure to radiation; and samples were brought into the laboratory without information as to the nature of the materials delivered. I do remember one incident of frightening proportions. One day a large glass case, about 5 feet high, was rolled into our laboratory not too far from my equipment. The case contained rather large thin pieces of shiny metal. At some point during the day, began to fill his experimental geiger counter with gas generated in his glass apparatus. The laboratory was rather large and experiment was at the other end of the laboratory from my apparatus and the glass case. When urned on his electronics, he was shocked to find no geiger counts from natural background radiation. He said that something was wrong with his apparatus; he began making tests. Nothing worked.

Eventually I made a suggestion. "Let me roll the glass case out of the room, and we'll see what happens." What *did* happen was that ounter began to count furiously once the case was out of the laboratory, with the door closed. In short, the radiation coming from the glass case had swamped the geiger counter across the laboratory and was causing maximum geiger counts even when removed from the laboratory. I do not know how many other cases we had of exposure to unusual doses of radiation from apparatus rolled into the laboratory, but this one was enough to cling to my memory for 60 years.

Another incident has clung to my memory over the years. I was not involved with a room that was used to store radium in vials. Evidently, was still working with radium. One day over the box-lunches that we ate in our laboratory, expressed his concern over the radium room. He told me that vials of radium had burst from the build-up of gas in the vials (it must have been mostly alpha particles turned into helium gas and some radon), and now there was a radium spill all over the room. He was concerned that he might have to be the person to clean it up, and he was most unhappy at the prospect because he wanted to have children. I fear for the extent of radium clinging to clothes during that period.

Our other exposure came from handling radioactive material from Oak Ridge. I do know that in addition, was involved in the radium program, with which I had no involvement. I was shocked to learn recently from the documents of the degree of contamination in Buildng #2. But I suspected the hazards of our exposure over that time, I was especially concerned because as the war was drawing to a close, I wanted very much to begin having children. I finally thought that I was pregnant just about the time that my husband was given a furlough.

Back in New York, I visited my family physician, who had become a gynecologist.

[redacted] I had much more faith. It took eighteen months for me to finally hold my daughter Laura in my arms. After Laura, I had a miscarriage. And after giving birth to Henry, I suffered three more miscarriages efore accepting the reality that I would never have another live child.

I have recently heard that [redacted] was diagnosed to have zero sperm count after his years in the Radiation Lab and that their desire for children led [redacted] and his wife to adopt his lovely daughter. Later on [redacted] and his wife did have one biological child. Did he long for more children.? I only know that I did long for at least one more live birth that never came. I recently read Barbara Goldsmith's book on the sad life of Marie Curie and what radium did to her body. It is sad that while we did take precautions, we were not yet well enough informed to fully understand the risks that we were encountering.

Rosalind B. Mendell

Doc. A 2

Henry Spitz

PROTECTION AGAINST NEUTRON RADIATION UP TO 30 MILLION ELECTRON VOLTS

Handbook 63

U. S. Department of Commerce
National Bureau of Standards

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U. S. Department of Commerce Sinclair Weeks, Secretary
National Bureau of Standards A. V. Astin, Director

PROTECTION AGAINST NEUTRON RADIATION UP TO 30 MILLION ELECTRON VOLTS

H Spitz
Univ. of Cincinnati

National Bureau of Standards Handbook 63
Issued November 22, 1957

For sale by the Superintendent of Documents, Washington 25, D. C. - Price 40 cents

Preface

In recent years the number of neutron sources in this country has increased greatly. It has also become evident that, because of their physical properties and biological effects, neutrons must be regarded as a special type of radiation hazard. On the other hand, the formulation of adequate protection regulations is made difficult because of the limited experience available and because of the variable output of many neutron sources. The contents of this Handbook are based on what is believed to be the best information presently available, and as some of this information is not easily obtainable it has been set forth in some detail. Because of the rapid development of neutron technology it was felt advisable to state recommendations rather than rules in many instances. However, the rules provided (section IV) are deemed essential for proper protection.

Subcommittee I of the National Committee on Radiation Protection and Measurements has recommended limits for the maximum permissible dose of ionizing radiations in NBS Handbook 59. Since the publication of this Handbook the limits have again come under consideration by both the National and the International Committees on Radiation Protection. In addition, the National Academy of Sciences and the British Medical Research Council have executed detailed reviews on the effects of ionizing radiations on human beings. The four groups have made quite similar recommendations.

The recommendations of this Handbook take into consideration the statement of January 8, 1957, by the National Committee on Radiation Protection and Measurements recommending a substantial lowering of the maximum permissible levels for radiation workers.[1] The requirements in section 21.5 are somewhat more stringent than those given in the January statement. In addition, the RBE's used for neutrons are those given previously, although there is some evidence that they are too high. At the present time, Subcommittee M-4 of the NCRP is considering the RBE problem. At some future time, the RBE's in this Handbook may need to be revised. This conservative attitude is considered desirable because much less is known about biological effects of neutron radiation as compared with X- and gamma rays.

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[1] NBS Technical News Bulletin 41, 17, 1957; Radiology 68, 260, 1957.

[redacted]

The scope of this Handbook extends to neutron energies up to 30 Mev. Although both theoretical and experimental information is sparser beyond about 10 Mev, the higher limit was chosen because many neutron generators operate within the wider range. The comparatively few sources producing neutrons in excess of 30 Mev usually attain energies several times as great, and a substantially different protection problem is involved.

The subject of neutron protection at reactors has been limited to considerations arising in routine operations. The problems of safe design and construction are outside the scope of this Handbook.

The National Committee on Radiation Protection and Measurements (originally known as the Advisory Committee on X-ray and Radium Protection) was formed in 1929 upon the recommendation of the International Commission on Radiological Protection. The Committee is sponsored by the National Bureau of Standards and governed by representatives of participating organizations. Eighteen subcommittees have been established, each charged with the responsibility of preparing recommendations in its particular field. The reports of the subcommittees are approved by the Main Committee before publication.

The following parent organizations and individuals comprise the Main Committee:

American College of Radiology: R. H. Chamberlain and M. D. Schulz.
American Dental Association: R. J. Nelsen.
American Industrial Hygiene Association: E. C. Barnes and J. H. Sterner.
American Medical Association: P. C. Hodges.
American Radium Society: T. P. Eberhard and E. H. Quimby.
American Roentgen Ray Society: T. C. Evans and R. R. Newell.
Health Physics Society: K. Z. Morgan and J. W. Healy.
International Association of Government Labor Officials: A. C. Blackman and I. R. Tabershaw.
National Bureau of Standards: L. S. Taylor, Chairman, and S. W. Raskin, Secretary.
National Electrical Manufacturers Association: J. A. Reynolds and E. D. Trout.
Radiological Society of North America: C. B. Braestrup and R. S. Stone.
U. S. Air Force: R. M. Lechausse, Col.
U. S. Army: E. A. Lodmell, Col.
U. S. Atomic Energy Commission: W. D. Claus and C. L. Dunham.
U. S. Navy: S. F. Williams, Capt.
U. S. Public Health Service: H. L. Andrews and C. Powell.
Representatives-at-large: J. C. Bugher, G. Failla, Shields Warren, J. L. Weatherwax, and E. G. Williams.
Subcommittee chairmen: See below.

The following are the subcommittees and their chairmen:

Subcommittee 1.	Permissible Dose from External Sources.
Subcommittee 2.	Permissible Internal Dose, K. Z. Morgan.
Subcommittee 3.	X-rays up to Two Million Volts, T. P. Eberhard.
Subcommittee 4.	Heavy Particles (Neutrons, Protons, and Heavier), H. H. Rossi.
Subcommittee 5.	Electrons, Gamma Rays and X-rays above Two Million Volts, H. W. Koch.
Subcommittee 6.	Handling of Radioactive Isotopes and Fission Products, H. M. Parker.
Subcommittee 7.	Monitoring Methods and Instruments, H. L. Andrews.
Subcommittee 8.	Waste Disposal and Decontamination, J. H. Jensen.
Subcommittee 9.	Protection Against Radiations from Radium, Cobalt-60, and Cesium-137 Encapsulated Sources, C. B. Braestrup.
Subcommittee 10.	Regulation of Radiation Exposure Dose, L. S. Taylor.
Subcommittee 11.	Incineration of Radioactive Waste, G. W. Morgan.
Subcommittee 12.	Electron Protection, L. S. Skaggs.
Subcommittee 13.	Safe Handling of Cadavers Containing Radioactive Isotopes, E. H. Quimby.
Subcommittee 14.	Permissible Exposure Dose Under Emergency Conditions, L. S. Taylor, Acting chairman.
Subcommittee M-1.	Standards and Measurement of Radioactivity for Radiological Use, W. B. Mann.
Subcommittee M-2.	Standards and Measurement of Radiological Exposure Dose, H. O. Wyckoff.
Subcommittee M-3.	Standards and Measurement of Absorbed Radiation Dose, H. O. Wyckoff.
Subcommittee M-4.	Relative Biological Effectiveness, W. Langham.

The present Handbook was prepared by the Subcommittee on Heavy Particles (Neutrons, Protons, and Heavier). The following are the subcommittee members:

H. H. Rossi, Chairman, Columbia University.
E. P. Blizard, Oak Ridge National Laboratory.
R. S. Caswell, National Bureau of Standards.
F. P. Cowan, Brookhaven National Laboratory.
D. B. Cowie, Carnegie Institution.
T. C. Evans, State University of Iowa.
D. J. Hughes, Brookhaven National Laboratory.
L. D. Marinelli, Argonne National Laboratory.
W. S. Snyder, Oak Ridge National Laboratory.
C. A. Tobias, University of California.

A valued contribution to the early work of the Committee was made by T. N. White, Los Alamos Scientific Laboratory, now deceased.

A. V. Astin, *Director*.

Contents

Protection Against Neutron Radiation up to 30 Million Electron Volts

I. Introduction

1. Definition of Terms

The following definitions are given for purposes of clarification of the contents of this Handbook. In some instances they may differ somewhat from common use.

Shall. Necessary or essential to meet currently accepted standards of protection.

Should. Is recommended. Indicates advisory requirements that are to be applied when practicable.

Absorbed dose. Absorbed dose of any ionizing radiation is the energy imparted to matter by ionizing particles per unit mass of irradiated material at the place of interest. The absorbed dose is measured in rads. In this Handbook the term will be used to express the energy absorbed per gram of tissue of composition given in 5.1.

Accelerator. A device for imparting large kinetic energy to charged particles such as electrons, protons, deuterons, and helium ions.

Accessible location. Any region around a source of ionizing radiation that can be reached without rupture of structures or without use of specially designed tools not generally available.

Anemia. Abnormally low number of red blood corpuscles or low haemoglobin.

Barn. A unit of area used in expressing a nuclear cross section. 1 barn $= 10^{-24}$ cm^2. Cross sections per atom are customarily measured in barns.

Capture. A process in which a neutron becomes part of the nucleus with which it collides without release of another heavy particle.

Controlled area. A defined area in which the occupational exposure of personnel to radiation or to radioactive material is under the supervision of a radiation safety (protection) officer.

Cross section. Effective target area for specified nuclear interaction. The cross section is a measure of the probability for the interaction. It is expressed in barns.

Dose. As used in this Handbook, either *absorbed* dose or RBE dose. Doses and dose rates will be said to exist at some point in space even if tissue may not actually be located at such a point. In such instances such doses and dose rates are the maximum ones that would be obtained in a 30-cm-thick infinite slab of tissue. (see appendix 1).

Dose rate. The rate of dose delivered averaged over a stated period. This may be different from instantaneous dose rate (e.g., in the operation of a pulsed generator the instantaneous dose rate greatly exceeds the dose rate averaged over 1 hour. This in turn may be higher than the dose rate averaged over 1 week if generator operation is intermittent).

Elastic scattering. Collisions in which the kinetic energy of neutron plus nucleus is unchanged by the collision, and the nucleus is left in the same state as before the collision.

Electron volt (ev). A unit of energy equal to the energy gained by a particle having one electronic charge when it passes in a vacuum through a potential difference of 1 volt; 1 ev=1.60×10^{-12} erg.

Epilation. Temporary or permanent removal of hair.

Epithelium. The purely cellular, nonvascular layer covering all the free surfaces of the body, cutaneous, mucous, and serous, including the glands and other structures derived therefrom.

Erythema. Reddening of the skin, primarily due to dilation of small blood vessels and also due to other tissue damage.

Exposure dose. Exposure dose of X- or gamma radiation at a certain place is a measure of the radiation which is based upon its ability to produce ionization.

Fast neutrons. Neutrons of energies between 10 kev and 10 Mev.

Gamete. A mature germ cell, such as an unfertilized ovum or spermatozoon.

Inelastic scattering. Scattering collision of neutron with attendant loss of kinetic energy which causes excitation of the target nucleus, and subsequent release of gamma rays.

Intermediate neutrons. Neutrons of energies between 0.5 ev and 10 kev.

Kilo electron volt (kev). 1,000 ev.

Kilovolt (kv). A unit of electrical potential equal to 1,000 volts. The term is also used to characterize the radiation emitted by X-ray tubes operating at this potential.

LD_{50}. Dose of ionizing radiation required to kill 50 percent of the animals in a given group. A time limit of 30 days is usually applied ($LD_{50/30}$).

Leukemia. Disease of blood-forming organs, usually with greatly increased production of white blood cells; these cells are invasive, and body deterioration may be either chronic (slow) or acute (rapid).

Leukocyte. White blood corpuscle.

Linear energy transfer (LET). The linear rate of loss of energy (locally absorbed) by an ionizing particle traversing a material medium.

Lymphocyte. A variety of white blood cell formed in lymph glands and other lymphoid tissue. The nucleus is single and is surrounded by a thin layer of cytoplasm which is nongranular. Average life span is relatively short.

Million electron volt (Mev). 1 million electron volts.

Moderator. Material used in a nuclear reactor to moderate, i.e., slow down, neutrons from the high energies at which they are released. Neutrons lose energy by scattering collisions with nuclei of the moderator.

Neutron flux. The number of neutrons which, per unit time, traverse a sphere of unit cross-sectional area centered about the point of interest. It is usually expressed in n cm^{-2} sec^{-1}. The correct term for this quantity is neutron flux density, but in common use the incorrect term "flux" is almost invariably employed.

Nuclear reaction. Collision between nuclear particles leading to release of different particles.

Platelet. A small colorless corpuscle present in large numbers in the blood of all mammals, believed to play a role in the clotting of blood.

Qualified expert. A person suited by training and experience to perform dependable radiation surveys, to oversee radiation monitoring, to estimate the degree of radiation hazard, and to advise regarding radiation hazards.

Rad. Unit of absorbed dose. 1 rad is equal to 100 ergs/g.

Radiation safety (protection) officer. An individual in charge of radiation protection.

RBE dose. Product of absorbed dose (as measured in rads) and RBE. The RBE dose is measured in rems.

Radioactive neutron source. A neutron source consisting of a combination of radioactive nuclides and suitable target materials. Neutron production occurs as a result of an (α,n) or (γ,n) reaction.

Relative biological effectiveness (RBE). Biological potency of one radiation as compared with another. It is numerically equal to the inverse of the ratio of absorbed doses of the two radiations required to produce equal biological effect. The standard of reference used in this Handbook is 200 kv X-radiation, which thus has an RBE of 1.

Relativistic neutrons. Neutrons of energies above 10 Mev.

Rem. Unit used in the description of radiobiological effects on man. The dose in rems is numerically equal to the product of the absorbed dose in rads and the value of the RBE applicable for the radiation in question.

Thermal neutrons. Strictly, neutrons in the thermal equilibrium with their surroundings. In this Handbook, all neutrons with energies of less than 0.5 ev are included in this category.

Thrombocytopenia. Decreased number of platelets per cubic millimeter of circulating blood.

Week, calendar. 7 consecutive days.

Week, work. Any combination of time intervals adding up to 40 hours within 7 consecutive days.

II. Present Status of Physical and Biological Information

2. Classification of Neutrons and Primary Modes of Interaction

2.1. Neutrons are available from various types of sources in an energy range (per particle) from about 10^{-4} to 10^{9} ev, a variation in energy of a factor of 10^{13}. The types of interaction vary markedly with energy. It is therefore convenient to base the classification of neutrons on energy intervals where certain interactions predominate. The transition between these ranges is, however, not sharp, and consequently there is a certain degree of latitude in the choice of limits. The classification set forth below shall be adopted for the purposes of this Handbook.

2.2. *Thermal neutrons.* These are neutrons in thermal equilibrium with matter, usually at room temperature, which therefore have a Maxwellian distribution of velocities. The most probable velocity per unit velocity in this distribution is 2,200 meters per second, corresponding to an energy of 0.025 ev. In most instances it is sufficiently accurate to consider thermal neutrons as monoenergetic with this energy. The most important interaction with matter is capture—usually with emission of gamma radiation.[1] Occasionally, nuclear reactions such as (n,p) or fission may occur. The N^{14} $(n,p)C^{14}$ reaction is important in tissue.

2.3. *Intermediate neutrons.* The intermediate energy region is here defined as extending from 0.5 ev to 10 kev. The absorption spectrum of intermediate neutrons often exhibits resonant peaks and for this reason the term "resonance neutrons" is sometimes employed. Intermediate neutrons are usually obtained from a moderating material in which fast neutrons are slowed down by elastic collisions. This slowing-down process is the most important interaction between intermediate neutrons and matter, and it leads to a neutron flux inversely proportional to energy—the well-known dE/E spectrum. Capture and nuclear reactions may also occur.

2.4. *Fast neutrons.* The range of fast neutrons will be considered to extend from 10 kev to 10 Mev. The most important interaction with matter is elastic scattering. At the upper part of this energy range, inelastic scattering and nuclear reactions are comparable in frequency to elastic scattering. Although resonance phenomena may occur (particularly for light elements), cross sections vary slowly with energy in general.

2.5. *Relativistic neutrons.* All neutrons beyond 10 Mev energy will be considered relativistic neutrons. Their energy exceeds the binding energy of nucleons, and for this reason complex nuclear reactions such as spallation become important. In addition, the kinetic energy of neutrons is an appreciable fraction of the rest energy, and relativistic corrections must be applied. Elastic scattering also occurs, but it tends to be markedly asymmetric in the center-of-mass system.

2.6. The probability of any interaction between neutrons and matter is expressed quantitatively in terms of *cross sections*. The cross section, σ, may be considered as the *effective* target area of the nucleus if the neutron is assumed to have zero diameter. For a beam containing n neutron/cm^3 moving with velocity v (cm/sec) toward N nuclei, the rate of interactions per second will be $nvN\sigma$. The quantity nv is the neutron flux. The cross section is usually expressed in barns (10^{-24} cm^2).

2.7. There is a finite cross section for each possible nuclear interaction. In addition, cross sections for scattering

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[1] Actually, elastic collisions are more prevalent, but at thermal levels neither neutrons nor the matter traversed gain or lose energy on the average.

processes may be further divided into various *differential* cross sections that express the probability for scattering in a particular direction. The number of neutrons interacting is determined by the sum of all processes that can take place, that is by the total cross section, σ_T.

3. Absorbed Dose

3.1. The energy imparted to tissues is the physical basis for quantitative correlation between exposure and biological effect. The energy per unit mass that is imparted to any material by ionizing radiation is denoted as the *absorbed dose*. It is expressed in rads.

3.2. In the absolute CGS system of units, specific energy imparted to matter is expressed in ergs per gram. One rad equals 100 ergs/g. One millirad (mrad) is one-thousandth of 1 rad. The rad was adopted as the international unit of "absorbed dose" in July 1953, at the meeting of the International Commission on Radiological Units in Copenhagen [1].[2]

3.3. Heretofore, the rep (roentgen-equivalent-physical) has been used extensively for the specification of permissible doses of ionizing radiations other than X-rays or gamma rays. Several definitions of the rep have appeared in the literature, but in the sense most widely accepted it is a unit of *absorbed dose* in soft tissue with a magnitude of 93 ergs/g. The difference in magnitude between the rep (93 ergs/g) and the rad (100 ergs/g) is negligible in the estimation of permissible doses. Therefore, *the adoption of the rad to replace the rep does not necessitate a change in the numerical values of permissible doses stated in reps heretofore.*

4. Other Dose Units Employed to Define Exposure

4.1. Although the presently recommended unit of neutron dose is the rad, a variety of other units are employed or have been employed in the past.

4.2. One of the most commonly used quantities is the neutron flux. Since the absorbed dose rate delivered by a given neutron flux depends on energy, the latter must be specified (at least within certain limits) to make possible an estimate of the absorbed dose. The relation between flux and the absorbed dose received by a small amount of tissue (first collision dose) is given in figure 1.

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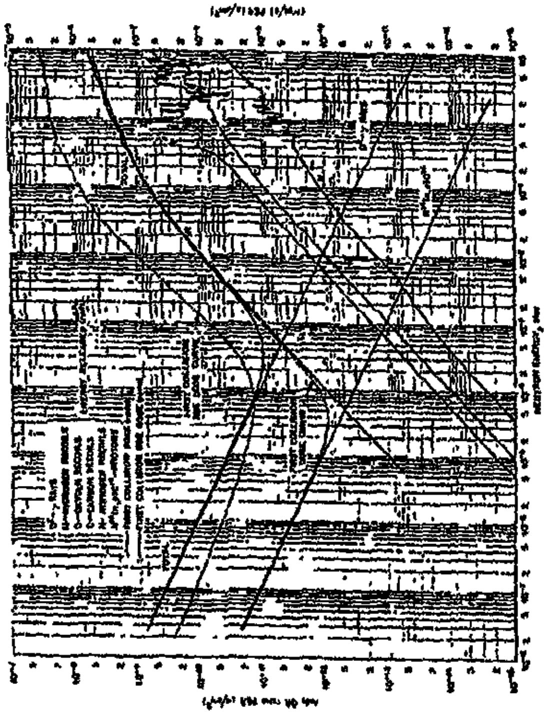
[2] Figures in brackets indicate the literature references at the end of this Handbook.

FIGURE 1. *First collision dose curve.*

Energy imparted to soft tissue by neutrons of energies between 10^{-9} and 10 Mev.

The curve marked "total" represents the entire energy deposited. Because of the penetration of the D^2 gamma rays most of their energy can escape from the point of neutron absorption. The energy dissipated in the immediate vicinity of the point of absorption is given by the "first collision dose", which includes all of the energy imparted to heavy ionizing particles. These include hydrogen, oxygen, carbon, and nitrogen recoils, as well as protons from the $N^{14}(n,p)C^{14}$ reaction. The individual contributions due to these particles are shown.

The "first collision RBE dose" curve was obtained by multiplying the "first collision dose" curve by the appropriate RBE. The ordinate is rems.



4.8. The Victoreen condenser r-meter, an instrument designed for X-ray measurement, has often been used to determine neutron exposure. The "n unit" is understood to be the amount of neutron radiation that discharges the ion chamber to the same degree as does 1 roentgen of X-rays. Sometimes a distinction is made between the 25-r chamber model (N unit) and the 100-r chamber (n unit). The number of rads corresponding to 1 n depends on neutron energy and may vary among individual chambers by ± 20 percent or more. For neutron energies above 1 Mev and up to several Mev, 1 n corresponds to approximately 2 rads. At lower neutron energies the number of rads per n probably becomes larger. The unit is now obsolete.

5. Interactions Between Neutrons and Tissue

5.1. The interactions that occur between neutrons and tissue depend upon the composition of the tissue involved. For purposes of this Handbook the atomic composition of the "standard man" has been used to evaluate the more probable interactions of neutrons and the atoms of tissue. The atomic composition of the "standard man" is given in table 1.

TABLE 1. *Atomic composition of the "standard man"*

Element	Weight, grams	Weight, percentage	Atoms per gram	Atoms, percentage
O	45,500	65	2.45×10^{22}	25.7
C	12,600	18	0.903	9.49
H	7,000	10	5.98	62.8
N	2,100	3	0.129	1.36
Ca	1,050	1.5	.0225	0.234
P	700	1.0	.0194	.204
S	175	0.25	.00470	.0494
K	140	.20	.00308	.0324
Na	105	.15	.00393	.0413
Cl	105	.15	.00255	.0268
Mg	35	.050	.00124	.0130
Fe	4	.0057	6.16×10^{17}	6.47×10^{-4}
Cu	0.1	.00014	1.35×10^{16}	1.42×10^{-5}
Mn	.02	.000029	3.18×10^{15}	3.29×10^{-6}
I	.03	.000043	2.03×10^{15}	2.13×10^{-6}
Total	69,500		9.52×10^{22}	

5.2. For both fast neutrons and relativistic neutrons up to 30 Mev, the most important interaction between neutrons and tissue is elastic scattering. The cross sections for absorption are small in comparison with the scattering cross sections, and inelastic scattering, although present at energies above several Mev, does not occur with hydrogen. Because the hydrogen cross section tends to decrease rather rapidly above 10 Mev, inelastic scattering and spallation become more important as the neutron energy increases. However, there are few, if any, quantitative data on this point at present. The energy absorbed in tissue due to elastic collisions is transferred largely as a result of scattering by hydrogen atoms. This is so both because the hydrogen atoms occur more abundantly, but also because the average fraction of the energy lost in an elastic collision is given by $2M/(M+1)^2$, where M is the mass number of the atom struck, and thus the heavier atoms dissipate only a small fraction of the neutron's energy. Figure 1 gives the energy absorbed per gram of tissue when exposed to neutrons of energy E (Mev) with 1 neutron/cm^2 incident on a small volume element of tissue. Taking into account only the first collisions of the neutrons, the dose in rads due to collisions with an element of mass number M_i, cross section σ_i (barns), and atomic abundance N_i (atoms/g), is given by

$$D_i = E\frac{2M_i}{(M_i+1)^2}N_i\sigma_i 1.6\times10^{-8}\ \text{(rads)}. \qquad (1)$$

Figure 1 indicates that, in general, elastic scattering by hydrogen accounts for 80 to 95 percent of the energy transferred to tissue by fast neutrons.

5.3. For a beam of neutrons incident on a large mass of tissue, the formulas (of 5.2) must be corrected to take account of the attenuation of the incident beam. The effect of the buildup (enhancement by multiple collisions) on the dose is very difficult to assess precisely but can, fortunately, be bracketed with sufficient accuracy for most practical cases of protection. Because the total dose always includes the first collision dose given by summing the above formulas, it is clear that the first collision dose is a lower bound for the total dose. In the case of neutrons of energies between 0.1 and 10 Mev impinging on a large convex mass of tissue, the maximum dose is at or near the irradiated surface and is never more than twice the first collision dose at the surface. It is to be emphasized that this rule only applies to the maximum or surface dose and does not apply deep within an irradiated body where the first collision dose may be a much smaller fraction of the total dose.

5.4. For neutrons of intermediate or thermal energy, most of the dose is imparted in the process of neutron absorption. The principal interactions are the H(n,γ)D and the N^{14}(n,p)C^{14} reactions. The energy released by the interaction with hydrogen is much greater, because the γ quantum has an energy of about 2.2 Mev whereas the proton has an energy of about 600 kev. In addition, the product of relative abundance and cross section is much larger in the case of the (n,γ) reaction. However, the γ-ray can travel through tissue for considerable distances before losing its energy, whereas the proton dissipates its energy in the immediate vicinity of its origin. Thus, for small masses of tissue the proton dose predominates, but for large masses of tissue the gamma dose is much larger. There is at present little precise information available about the variation of dose with the geometry of the irradiated body, or even a rough rule such as that given above for fast neutrons. For large masses of tissue (20 cm thick or more) the maximum dose is essentially independent of neutron energy up to 10 kev. Monte Carlo calculations have indicated that the percentage of neutrons that slow down to thermal energy in a thick slab does not vary greatly with the energy of the incident beam; and as, for energies up to 5 kev, these thermalized neutrons account for most of the dose, it follows that the dose is roughly constant.

5.5. The depth dose curves obtained by Monte Carlo calculations using a slab of tissue 30 cm thick are given in appendix 1. These may be regarded as useful approximations to the dosage patterns within the trunk of a human body.

6. Relative Biological Effectiveness

6.1. It has been found that equal absorbed doses delivered by different ionizing radiations may produce varying degrees of injury. The relative biological effectiveness (RBE) of one radiation with respect to another is defined as the inverse ratio of the absorbed doses required for equal effect. Thus, if induction of a given degree of damage requires an absorbed dose D_R by the reference radiation and D_N by the other radiation, the RBE of the latter is D_R/D_N.

6.2. The biological effectiveness of different kinds of ionizing radiation is usually indicated as relative to that of conventional therapeutic X-radiation (200 kv) as unity. In lethality studies it has been found that gamma radiation (from Co^{60} or from radium) apparently has an RBE from 0.6 to 0.8 of that of 250-kv X-radiation.

6.3. As measurements of RBE are based on comparisons of tissue dose, the chief physical variable which apparently accounts for the difference in RBE is the rate of loss of energy along the path of ionizing particles. It is assumed that biological effectiveness is dependent on spatial distribution of the energy transfer taking place in tissue. Consequently, it is now proposed to consider linear energy transfer (LET) as the physical factor responsible for the RBE.

6.4. The RBE for various biological effects varies with test objects, the type of effect studied, and often other factors (such as dose rate).

6.5. The term "rem" has been used as meaning "roentgen or rad equivalent man." The unit is used in an attempt to express dose in terms of biological rather than physical equivalence. It may be defined as the product of absorbed dose in rads times RBE. Thus an absorbed dose of 10 rads from a radiation having an RBE of 10 represents 100 rems. Because of the variability of RBE, equal doses of rads represent varying doses of rems depending on the effect under consideration. However, for purposes of this Handbook, the RBE dose in rems will be understood to be the absorbed dose in rads multiplied by the RBE (applicable for the radiation under discussion) pertaining to exposure of humans and as formulated for purposes of radiation protection.

6.6. Handbook 59 of this series recommends RBE values that are made dependent on the LET of the charged particles produced in tissue. An RBE of 1 is proposed for all LET values up to 3.5 kev/μ. The RBE is assumed to increase more or less linearly from 1 to 20 in the range from 3.5 to 175 kev/μ. No recommendations were made for values in excess of 175 kev/μ. Permissible doses in section 8 have been derived on the basis of these recommendations. The RBE of LET values beyond 175 kev/μ has been assumed to be 20.

6.7. Biological comparison based on $LD_{50/30}$ appears to indicate that the RBE of fast neutrons in acute exposures would be 2 to 4. Dose-effect ($LD_{50/30}$) curves for X-rays and neutrons are similar in shape for mice, rats, and other animals, but may differ for some such as the chick. Continuous low level of exposure (protraction) and fractionation appear to result in a higher RBE of fast neutrons, particularly in injury to the gonads or to the lens of the eye.

7. Biological Effects

7.1. Certain basic facts are generally accepted about the biological action of neutrons and other ionizing radiations: (a) The radiation penetrates throughout the cell; (b) the energy transferred is high enough to cause fundamental changes in atomic and molecular structures; (c) alterations are widely and randomly distributed throughout the cell.

7.2. The cellular changes due to single or multiple doses may not be grossly observable for some time, and may accumulate as time goes on. Tissues vary in radiosensitivity, and in ability to recover from radiation damage. They also vary in latent period (i.e., time from exposure to manifestation of change).

7.3. In man, effects that may appear early are (1) reduction in lymphocytes in blood and (2) damage to epithelial cells of intestine and skin. Other rather early changes are (1) reduction in leukocyte number in the blood, (2) erythema, epilation, and inhibition of gamete formation, and (3) damage to small blood vessels. Changes that occur more slowly and require more exposure are reduced production of erythrocytes (anemia) and of platelets (thrombocytopenia — leading to bleeding tendency) and general lack of new cells resulting in systemic deterioration. It should be pointed out that these effects are not necessarily indicative of radiation damage, because they may result from any of several abnormal conditions.

7.4. General considerations regarding biological effects of radiation and maximum permissible exposure conditions usually include the following: (a) The most serious condition is exposure of the whole body to penetrating radiation; (b) in general, percentage survival and survival time increase markedly as (1) portions of the body are protected, (2) the exposures are fractionated, and (3) the penetration of the radiation is decreased; (c) hereditary effects are not easily detected but they are cumulative and must be considered, especially if large population groups are exposed; (d) repeated exposures (each too small to produce demonstrable injury alone) may eventually reduce life span.

7.5. Skin cancer and leukemia are hazards of overexposure. Such malignant changes usually, but not always, are preceded by other indications of radiation damage. Again, it must be pointed out that the presence of the malignancy does not necessarily indicate radiation as the causative agent.

7.6. Certain fast-neutron hazards appear to be related to a more pronounced accumulation of damage from multiple exposures than occurs in the case of X-irradiation. Thus, tissues not likely to be replenished by cells from other organs (such as the lens epithelium and germinal epithelium) are especially vulnerable to fast neutrons in multiple exposures. Although there is usually some recovery following exposure to neutrons, it is less than in the case of X-rays.

7.7. Much of our information concerning biologic effects of radiation comes from clinical experience and from animal experimentation, but occasionally an accidental overexposure yields valuable data in this regard [2 to 6]. Much more information is needed from all three sources.

8. Permissible Exposure to Neutrons

8.1. Due to the action of cosmic radiation, there exists a constant neutron flux of roughly 50 n cm^{-2} hr^{-1} at sea level. This increases with altitude, reaching a value approximated by 500 n cm^{-2} hr^{-1} at 10,000 feet. The resultant dose is of the order of 10^{-2} mrad/week at sea level and 10^{-1} mrad/week at 10,000 feet.

8.2. Permissible exposure to neutrons is the dose that may be received without undue risk to the health of the individual and that of the population. Certain basic rules are given in Handbook 59. These state that for radiation workers the weekly dose delivered to the skin must not exceed 600 mrems, and that, in addition, any portion of the body beyond a depth of 5 cm as well as certain critical organs must receive no more than 300 mrems/week. In the energy range covered here, absorbed doses of neutrons are for practical purposes always maximal at or near the body surface; and because some of the critical organs, such as the lens of the eye and the male gonads, are at little depth in the body, these rules require that in whole-body exposure the maximum permissible weekly dose be 300 mrems as measured at or near the body surface. The rules permit somewhat larger doses to be received by certain body regions. Thus, hands and feet may receive 1,500 mrems/week. However, these larger local limits shall not be permitted unless special efforts have been made to assure that the head and the trunk are not exposed in excess of 300 mrems/week. In exceptional cases when it is necessary for a person to receive more than 0.3 rem in 1 week, he may receive 3 rems in 13 weeks.

8.3. The 1957 recommendations of the National Committee on Radiation Protection impose additional restrictions on the dose that may be incurred by radiation workers over long periods of time [7]. These may be expressed by the formula

$$D = 5(N-18) \text{ rems,} \qquad (2)$$

where D is the RBE dose accumulated at age N years. The formula applies to all critical organs except the skin, for which the value 2D is permitted.

It will be noted that in the case of a radiation worker who, beginning at an early age, is routinely exposed to a substantially constant radiation level, the maximum yearly dose shall not exceed 5 rems and the average weekly dose shall not be more than 100 mrems. It will sometimes be necessary to plan radiation protection on the basis of these figures when protracted exposure of younger individuals is anticipated or must be considered likely. For this reason, certain data given below (e.g., table 2) are based on weekly exposures of 100 mrems as well as 300 mrems, although it will be understood that larger values are permissible as long as the restrictions in this and the preceding paragraph are adhered to.

8.4. Handbook 59 also contains a listing of applicable RBE values according to the specific ionization of the particles delivering the dose. Calculations taking into account the LET of secondary recoils arising from both primary and multiple scattered neutrons indicate that in a phantom 30 cm thick, the RBE depends both on neutron energy and, to some extent, on the depth in the phantom. However, in general, the highest RBE occurs near the regions where the dose is also maximal. Therefore, the highest RBE must be applied for purposes of protection. Figures 2 to 12 in appendix 1 show depth doses in both rads and rems for a number of neutron energies.[3] Table 2 gives RBE and maximum permissible average neutron flux as a function of energy for protracted exposure on the basis of a 40-hour week. Although an RBE of 10 might be slightly exceeded at neutron energies in the neighborhood of 1 Mev, it would seem sufficiently safe to derive maximum permissible doses for any neutron energy between thermal level and 10 Mev by linear interpolation between neighboring energies in table 2. In the absence of any definite information, a conservative limit has been adopted as the maximum permissible flux density between 10 and 30 Mev.

8.5. It must be realized that the values in table 2 apply only to monoenergetic neutrons incident normally on the major portions of the human body. Even when a neutron generator emits monenergetic neutrons, scattering by walls and other structures will cause degradation in energy. However, because this process will, *in the range of table 2*, almost always lead to decreased biological potency, it is safe to assume that all neutrons have the original maximum energy. Similarly, it may be assumed that all neutrons are incident normally (even if *some* may actually arrive obliquely).

TABLE 2. *Maximum permissible neutron flux*

Time-average flux for 40-hour week to deliver either 100 or 300 mrems.

Neutron energy	RBE	100 mrems	300 mrems
Mev		*n cm⁻² sec*	*n cm⁻² sec*
Thermal	3	670	2,000
0.0001	2	500	1,500
.005	2.5	570	1,700
.02	5	280	850
.1	8	80	250
.5	10	30	90
1.0	10.5	18	55
2.5	8	20	60
5.0	7	18	55
7.5	7	17	50
10	6.5	17	50
10 to 30		*10	*30

*Suggested limit.

8.6. In case sufficiently detailed information on neutron energy is not available, an RBE of 10 shall be assumed.

8.7. The maximum permissible weekly dose may be received within any time period within the week. Assuming a 40-hour work week, a steady exposure to 7.5 mrems/hr or the fluxes in the last column of table 2 represents the permissible limit.

8.8. It is clearly desirable to design neutron installations so that the above hourly rates are not exceeded in normally occupied areas, as it is then impossible for any personnel to be exposed beyond the permissible weekly limit. In areas where these values are exceeded, the occupancy by personnel or the duty period of the neutron generator must be restricted to avoid dosage in excess of the permissible annual limit. As failure to observe this restriction would create a hazard, the rules given below require certain safeguards. A greater potential hazard exists if the duty cycle of the equipment is such that a dose in excess of the *weekly* permissible limit may be received by a person who remains at the location for the full 40-hour work week. The rules below make a distinction between these conditions.

8.9. High dose rates, apart from inherent danger, often represent a psychological hazard because of anxiety or nervousness, and should be avoided whenever possible.

8.10. It may often occur that individuals who are in no way associated with the operation of the source are ex-

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[3] Subcommittee No. 4 is indebted to W. S. Snyder for having carried out the computations on which these figures are based.

posed to detectable amounts of radiation. If such locations are outside the controlled area and accessible to the public, it may be difficult or impossible to regulate or accurately predict the occupancy. Because in addition a comparatively large number of individuals (including children) might be exposed, special safeguards must be provided.

8.11. Considering all available evidence, no significant radiation effects have been demonstrated in animals or humans at or below the maximum weekly permissible dose levels. By extrapolation from observations at much higher dose levels, it seems possible that long-continued irradiation, even at permissible levels, may have some deleterious effect. The magnitude of such effects is believed to be less than that due to many other physical and chemical health hazards to which we are daily exposed. Nevertheless, efforts should be made to reduce exposure as much below permissible dose levels as practicable.

The 1957 recommendations of the NCRP (see page 33) stipulate that "the maximum permissible dose to the gonads for the population of the United States as a whole for all sources of radiation, including medical and other manmade sources, and background, shall not exceed 14 million rems per million of population over the period from conception up to age 30, and one-third that amount in each decade thereafter. Averaging should be done for the population group in which cross-breeding may be expected." To achieve this goal it is further recommended that for persons nonoccupationally exposed to radiation in the environs of a radiation source, the maximum permissible accumulated dose shall not exceed one-tenth that for radiation workers. This is equivalent to an average per capita dose of 500 mrems per year. It should be noted that this lesser figure has been set primarily because of genetic effects rather than the likelihood of personal injury. Exposure within the limits set for radiation workers is believed to be an entirely acceptable individual risk, but if a large fraction of the population were exposed at these levels, long-term genetic effects might be too great. This is the reason why the limit has been given in terms of a million individuals; larger doses might be imparted to a few individuals who are not radiation workers.

In this Handbook a limit of 125 mrems per 3-month period is recommended for uncontrolled areas.

Obviously the best way to attain this objective is to avoid delivery of such a dose to any part of the areas in question regardless of any occupancy factors, and this policy is strongly recommended. If more than 10 mrems can be received in such uncontrolled areas during a calendar week, regular checks are required to insure that individuals remain there for sufficiently limited periods of time so that exposure in excess of 125 mrems per 3-month period is unlikely. This limit applies equally if several generators contribute radiation to the same location.

8.12. It is to be noted that permissible exposure figures may be revised downward in the future, particularly if the number of persons exposed to radiation should increase markedly. Therefore, in the design of neutron protection it is advisable to make provision for more shielding to be added in the future. In the case of large permanent installations it may be much more economical to apply such additional protection at the time of original installation, i.e., to overdesign protection deliberately to insure compliance with possible future limits that may be lower. However, in the absence of definite knowledge no firm recommendations can be made on this point.

9. Gamma- and X-ray Hazards Arising in the Operation of Neutron Sources

9.1. In practice, the presence of neutrons in the laboratory is almost invariably accompanied by X- and gamma radiation. Because the relative intensity of this component may vary widely with experimental conditions, the hazard must be assessed directly by the operator and added to the neutron hazard with an RBE of unity. A brief description of the mechanism of photon production in various types of neutron installation is appended hereto for information of the reader.

9.2. *Low-voltage ion accelerators (400 kev).* Although used to produce neutrons free of gamma rays, such machines are usually strong sources of X-rays. These are engendered by electrons released at the walls and target of the apparatus by ion bombardment and accelerated toward the anode and supporting structures. This radiation may be reduced (but never entirely suppressed) by application of positive potential to the target assembly.

9.3. *High-voltage ion accelerators.* In addition to producing X-rays, these installations become sources of gamma radiation because of the increased likelihood of nuclear excitation of the target material and the walls of apparatus. The energies of the photon radiation are characteristic of the nucleus and may vary from a few hundred kev to about 20 Mev.

9.4. (α,n) *sources.* The (α,n) reactions are, with a few exceptions (e.g., Po^{210}, Pu^{239}), also sources of intense gamma radiation because of concomitant emission in the radioactive chain (Ra^{226}, Ra^{223}, Th^{228}, Ac^{227}, etc.).

9.5. *Photoneutron sources.* (γ,n) emitters, such as radioactive sources and betatrons, are particularly hazardous from this standpoint because the relatively small cross section of the reaction, as compared to the Compton and pair-production process, requires implicitly an overwhelming flux of photons for the production of a relatively small number of neutrons.

9.6. *Thermal neutron sources.* Such sources as nuclear reactors present the added hazard of gamma rays, which almost invariably follow the capture of neutrons by nuclei. The cross sections for this process vary widely (10^6 to 10^{-5} barn), and the energy of the gamma radiation emitted varies from a few tenths to about 10 Mev. Frequently the product nucleus is radioactive and emits gamma radiation also.

9.7. *Inelastic scattering.* Fast neutrons, of energy greater than that of the lowest excitation levels of a nucleus, can lose energy by excitation. This process (of cross section usually below 3 barns) results in the emission of gamma rays characteristic of the disturbed nucleus. This type of gamma radiation must be anticipated in all installations producing fast neutrons.

9.8. *Fission sources.* Since the fission process—even when engendered by thermal neutrons—is accompanied by gamma rays and by the production of radioactive fission products, it is reasonable to expect a definite gamma-ray hazard.

10. Neutron Detectors

10.1. For practical purposes the processes that reveal the presence (or previous presence) of neutrons may be classified as instantaneous or as delayed processes. In most cases the phenomenon that is detected is ionization, or something that is caused by ionization.

10.2. *Examples of instantaneous radiations and their detection.*

a. Fission: Fission recoils may be detected by their ionizing effect in counters or ion chambers; the attendant release of gamma radiation may be detected by its ionizing effect.

b. Recoil from neutron collision: The recoiling nucleus may cause detectable ionization.

c. Inelastic collision: On collision, part of the kinetic energy of the neutron may be converted to gamma ray energy.

d. Capture: Capture of a neutron by a nucleus is followed by emission of one or more gamma rays. Also, the new nucleus that is formed by capture may be so unstable as to disintegrate immediately, giving rise to one or more of the ionizing phenomena.

10.3. *Delayed processes.* The principal delayed processes are radioactive disintegrations of fission products and of nuclei produced by neutron capture.

10.4. If the presence of neutrons has not been foreseen, and provision for immediate measurement has therefore not been made, the delayed process may sometimes be of special usefulness.

10.5. Neutron detectors utilize the same devices (counters, ionization chambers, photographic emulsions, etc.) that are used for the detection of other ionizing radiations, although, as in the case of X-rays, any direct ionizing effect of the primary radiation is inconsequential.

10.6. Discrimination between ionization due to neutrons and ionization due to gamma rays, when both are present, is not difficult in instruments that are designed solely for detection (as distinct from flux or dosage measurement). The burst of ionization that can be produced by a recoiling or disintegrating nucleus is much greater than any burst that is likely to be produced in a detector by gamma radiation. The latter can be discriminated against by the electrical circuit of an instrument. Very high sensitivity can be obtained in instruments based on these processes, but the sensitivity usually depends strongly on the energy of the neutrons, which is usually unknown. Devices that depend on the delayed process can usually be counted upon to discriminate against everything but neutrons, and can be made quite sensitive also, but they suffer from the same dependence on neutron spectrum. In spite of this deficiency, these high-sensitivity detectors are of value in rapidly delimiting large areas where the neutron flux is too low to justify any efforts at quantitative measurements.

10.7. One note of warning: Any instrument that depends upon the counting of ionization bursts that exceed some predetermined size must be suspected when it is used for surveying in the vicinity of a pulsed generator. It will read correctly only if capable of time resolution of the pulses received during the active part of the cycle of the machine. If these pulses are not resolved, the counting rate of the instrument may be independent of intensity and signify only the pulsing rate of the generator.

11. Measurement of Neutron Flux

11.1. In the case of monoenergetic neutrons of known energy, the flux may be determined provided the cross section for the interaction employed in detection is known and the number of interactions occurring in unit time can be measured in an absolute manner.

11.2. The flux measurement in neutron beams involving an unknown energy distribution can be made only if the detection efficiency is independent of neutron energy. This requirement is met in certain threshold detectors by the existence of substantially constant cross section above the threshold, and in the "long counter" by the adjustment of absorbing and scattering characteristics of the moderator surrounding the sensing element. The complex characteristics of this structure make it virtually impossible to determine the response absolutely, and a relative calibration must be performed. On the other hand, the comparatively wide range (about 0.1 to 3 Mev) in an important energy interval makes the long counter an important tool.

11.3. It is to be noted that the permissible flux figures given in table 2 apply to incident neutron fluxes rather than the combination of incident and reflected neutrons that exist near the body surface. The latter figure is higher, and if personnel monitoring is performed on the basis of flux at the body surface, data in appendix 1 should be applied.

11.4. The characteristics of various flux detectors as well as their calibration are discussed in appendix 2.

12. Dose Measurement

12.1. Because the permissible limit of exposure to neutrons is related to absorbed dose, it is obviously preferable to measure this quantity directly, particularly as this can usually be done with little or no information on neutron energy. Like other aspects of neutron technology, dosimetry has not been developed to the point where universally applicable methods of measurement are available. Nevertheless, in many instances dose determinations can be made more accurately by direct rather than by indirect means (such as flux determinations).

12.2. The most direct dose measurement may be performed utilizing the Bragg-Gray theorem. This relates the ionization produced in a cavity with the energy imparted by ionizing radiation to the walls surrounding the cavity. In the special case when wall and gas have the same atomic composition, the cavity may be of any size (provided the radiation field is constant in the region immediately surrounding the collecting volume). If the walls have the same composition as tissue (e.g., are made of tissue-equivalent plastic), the absorbed dose is proportional to the ionization per unit mass of gas and the factor of proportionality is W, the average energy expended in the production of an ion pair. This quantity is known within about 2 to 3 percent for all gases of interest and varies little with energy or nature of the ionizing particle.

12.3. This method has been used for the determination of fast neutron doses with the use of ionization chambers constructed of hydrogenous materials. Use of tissue-equivalent materials (i.e., substances having the same atomic composition as tissue) permits dose measurement of neutrons of any energy. The principal practical limitation of the technique is that such chambers do not discriminate against other radiations, and consequently the total tissue dose is measured in a mixed radiation field where gamma radiation is also present.

12.4. Chambers having nonhydrogenous walls may be employed in an effort to measure the gamma radiation selectively and to obtain the neutron dose by subtraction. However, if the atomic number of the wall material is low enough to exhibit an approximately air- or tissue-equivalent response at low photon energies, the chamber also has a certain neutron response beyond neutron energies of about 0.5 Mev. Theoretical computations indicate that between 1 and 10 Mev the response of a chamber having nonhydrogenous walls and filled with CO$_2$ should vary between 5 and 25 percent of that of a tissue-equivalent chamber. Because of the wide variation and the fact that it is an erratic function of neutron energy, corrections are difficult to apply. Therefore, in a mixed radiation field the response of such a chamber may be merely interpreted as an upper limit of gamma contamination. A subtractive measurement of neutron dose is consequently inaccurate, particularly when the relative amount of gamma radiation is large. However, at low neutron energies a graphite or Teflon chamber filled with CO$_2$ provides an excellent means of selective measurement of contaminating gamma radiation.

12.5. Methods of dosimetry have been developed in which an attempt is made to distinguish between electrons and heavy particles by employing proportional counters and discriminating circuits. Instruments of this type, such as the count-rate dosimeter and the pulse-energy integrating dosimeter, are discussed in appendix 4.

12.6. As explained in section 5, multiple scattering of fast neutrons leads to an increase in dose if the mass of tissue exposed is increased. Many neutron dosimeters contain only enough hydrogenous material to establish proton equilibrium, and thus record essentially only the first collision dose. In order to determine the tissue dose of interest here, it is necessary to use such devices in properly designed tissue-equivalent phantoms. For fast and relativistic neutrons, the use of such a phantom may be omitted if the curves used in figure 15 (appendix 1) are applied to the reading obtained with the bare dosimeter. However, with intermediate and thermal neutrons, geometrical exposure conditions are so critical that phantoms are essential.

12.7. Appendix 4 gives further information on instruments that may be employed in dose measurement.

III. Radiation Protection in Installation and Operation of Neutron Sources

13. Types of Sources

13.1. Radioactive sources are of two types, (α,n) and (γ,n). In an (α,n) source, the alpha emitter is mixed with the target material.

13.11. Polonium-210 and plutonium-239 are the most suitable radioactive alpha sources[4] from the standpoint of low gamma-ray activity and compactness. Both elements, however, are among the most dangerous ones when ingested or inhaled. Special precautions must be taken to prevent their escape by providing durably sealed containers.

13.12. Ra^{226}, in equilibrium with its daughters, is another source of α-rays of convenient half life, but of equally high toxicity. Its containment is exceptionally important because of the dangers due to its daughter product Rn. In addition, due to its copious photon emission, it represents a gamma-ray hazard.

13.13. The target materials most commonly used are Li, Be,[5] and B. These materials in powdered form, intimately mixed with the alpha emitters, are sealed in metal containers.

13.14. (γ,n) sources are usually called photoneutron sources. They consist of sealed containers enclosing emitters of gamma rays of energy high enough to detach neutrons from target nuclei. The latter, usually deuterium or beryllium, are placed in spheres or cylinders which surround the gamma emitter. Photoneutron sources have been used mostly to generate moderate fluxes of neutrons of fairly homogeneous energies below 1 Mev.

13.2. *Constant-voltage accelerators*, as used in the production of neutrons, are usually either Van de Graaff or Cockroft-Walton machines. They are essentially the same as those used for the production of X-rays, except that the polarity of the high-voltage electrode is reversed, and this electrode is provided with a positive ion source instead of a negative electron source. In the Van de Graaff generator the charge is conveyed to the high-voltage electrode mechanically by means of a belt; in the Cockroft-Walton it is conveyed by a cascaded sequence of voltage-doubling circuits, each comprising a condenser and a rectifier. Most Van de Graaff generators operate below voltages of 5 Mev; Cockroft-Walton generators below about 1 Mev.

13.3. *High-frequency accelerators* include the cyclotron, synchrocyclotron, betatron, synchrotron, microtron, and linear resonance accelerator.

13.31. The cyclotron, or magnetic resonance accelerator, is a device for accelerating light ions. The ions are kept in a spiral orbit by a constant magnetic field and are given successive acceleration when they traverse the gap between the dee-shaped electrodes. The operation is usually continuous in the sense that a beam is produced in each cycle. Light ions, particularly H^{+}, H^{2+}, and He^{4++}, are accelerated up to 15 Mev per nucleon.

13.32. The synchrocyclotron is a cyclotron modified to allow for the relativistic increase in the mass of the accelerated particles in higher energy ranges. In the frequency-modulated cyclotron the particles are accelerated in pulses of about 1 microsecond duration and the oscillator frequency is modulated. Particle energies range from 15 to several hundred Mev per nucleon. Usual particles accelerated are: H^1, H^2, and He^4.

13.33. The betatron is a circular electron accelerator that has been used to accelerate electrons to energies up to 100 Mev or more. Electrons are injected in a pulse about 1 microsecond in duration. After injection, the electrons are

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[4] In the polonium sources Po^{210} may be present as daughter product of long-lived RaD (Pb^{210}).

[5] Be constitutes a recently recognized chemical toxicity hazard.

continuously accelerated and held in a circular path by a changing magnetic field.

13.34. The synchrotron operates on the same fundamental principles as the frequency-modulated cyclotron. The frequency of the oscillator is matched with the frequency of cycling charged particles being accelerated in a closed path. When the synchrotron is used to accelerate protons, both the oscillator frequency and the magnetic field are varied to allow for the large relativistic mass change. Particles to be accelerated are injected into the machine from a smaller accelerator, such as a Van de Graaff accelerator for protons. For electrons when the final velocity is near to the velocity of light, it becomes impracticable to change the oscillator frequency. The frequency is kept fixed and the magnetic field is varied.

13.35. The microtron is a variation of the electron synchrotron in which the magnetic field is held constant and the orbit radius is allowed to increase with increasing electron energy.

13.36. In a linear resonance accelerator the particles travel in a straight path and are accelerated by the electric field of an electromagnetic wave which travels down the accelerating tube. An advantage of the linear resonance accelerator over circular-orbit accelerators is the ease of bringing the beam into field-free space.

13.37. Although the primary hazard from high-energy electron accelerators is usually X-rays, the neutron dose may be comparable to or greater than the X-ray dose outside shielding material of high atomic number, such as lead, which is used to attenuate the X-rays. The chief sources of neutrons are the machine itself, and the point where the beam strikes the wall.

In designing a shield for an electron accelerator, both the X-ray and the neutron hazards must be considered. The neutron hazard may be neglected in comparison to the X-ray hazard for accelerators that operate only below 10 Mev, because the thresholds for the neutron-producing reactions are at about this energy. For quantitative information on neutron production and shield design at higher energies, see appendix 7. Detailed discussion of the shielding problems arising in the operation of electron accelerators is given in Handbook 55 of this series.

13.4. *Reactors.* Neutron production in reactors occurs as a result of the fission process, which is maintained at a high rate by means of a carefully controlled chain reaction. The usual operating mode is one in which the reactor is critical, in which case the number of fissions occurring is substantially constant in time. This is achieved by a definite arrangement of fuel elements (uranium or plutonium) and adjustment of neutron absorbers (control rods).

14. Neutron Production

14.1. Neutrons are produced in accelerators by the interaction of high-speed nuclear particles (usually positively charged) and target nuclei. Depending on the nature of the reaction involved, there may be evolution or absorption of energy. The net gain or loss of energy is usually denoted by the symbol Q. Q is defined by

$$Q = \sum_i m_i c^2 - \sum_r m_r c^2, \tag{8}$$

where m_i are the masses of the interacting particles, m_r the masses of the resultant particles, and c the speed of light. A list of important reactions used in neutron production as well as corresponding Q values is given in appendix 8.

14.2. *The fission process.* Given sufficient excitation energy, certain heavy nuclei are prone to divide into two or more large pieces. This energy can be obtained by absorption of a gamma ray, but is attained more commonly following production of a fissionable isotope by absorption of a neutron. In this case, the binding energy of the neutron constitutes the excitation energy to induce fission. The most notable example of this process is the absorption of a slow neutron by U^{235} to produce U^{236} in a highly excited state which immediately fissions. At the time of fission, neutrons, gamma rays, and occasionally a high-speed proton are given off, in addition to the two (and sometimes more) large fission fragments. The neutrons are, on the average, 2½ in number and of mean energy of about 2.5 Mev. The total gamma-ray energy per fission has an average value of about 7.5 Mev.

15. Other Radiation Hazards Associated with Neutron Production

15.1. In section 9, a brief description of the various types of reactions leading to associated gamma-ray hazards has been given. Protection against photon radiation per se is discussed in two publications of the NCRP. Specifically, Handbook 60, X-ray Protection, and Handbook 55, Protec-

tion Against Betatron-Synchrotron Radiation Up to 100 Million Electron Volts, should be consulted as guides to protective measures.

15.2. Radioactive photoneutron sources represent, from the protection standpoint, gamma-ray hazards exclusively. Thus, a Na^{24}-D_2O source delivers a neutron dose rate of the order of only 10^{-5} times the gamma-ray dose rate at the same distance. In most cases the gamma dose to be expected from a 1-curie source at 1 meter varies within narrow ranges, i.e., 0.1 to 2.0 rads/hour.

15.3. As mentioned, the transmutations produced by neutrons in the vicinity of sources lead to two modes of gamma-ray emission. One is capture radiation that is emitted simultaneously with neutron absorption. A list of the gamma-ray energies emitted in capture is given in appendix 4.

15.4. In addition, nuclei produced as a result of capture are often radioactive, and particle accelerators of high energy and particle flux—such as cyclotrons—represent producers of radionuclide sources of considerable activity and significant half lives. Any part of the accelerator or its surroundings is potentially a source of beta and/or gamma radiation, which must be evaluated by competent beta- and gamma-ray monitoring. In addition, the air and loose dust in the room can be activated sufficiently to require delay in entering the room. The responsible officer should in either case be guided by recommendations in Handbook 42 (Safe Handling of Radioactive Isotopes) and in Handbook 52 (Maximum Permissible Amounts of Radioisotopes in the Human Body) concerning the over-all operation of these machines.

16. Radiation Protection Considerations in the Design of Neutron Sources

16.1. Because of the diversity of source types and reactions it is impossible to furnish detailed instructions on the safe design of all types of neutron sources. The following recommendations are designed to cover the majority of conditions likely to be encountered in practice and to serve as a general guide for the remaining situations.

Neutron sources may be classed into essentially four groups of increasing output. As the protection problems involved are somewhat different, these types will be discussed separately.

16.2. *Radioactive sources.*

16.21. As mentioned above, these can be classed into (γ,n) and (α,n) sources. For (γ,n) sources, gamma radiation is usually the primary hazard and protection should be designed according to recommendations contained in other handbooks in this series. This is also true for Ra-Be sources where alpha particles are actually employed as bombarding particles. However, when the gamma radiation from a Ra-Be source is reduced by massive shielding, particularly lead which absorbs very few neutrons, the neutron hazard may become appreciable and should not be overlooked.

16.22. For the other (α,n) sources(Po-Be, Po-B, Pu-B, etc.), the neutron hazard is usually the primary one. Sources exceeding dose rates of 30 mrems/hr at the surface shall be stored in labeled containers (see Rules below). Usually paraffin in considerable thickness is employed for sources exceeding 100 μc (see appendix 5). The paraffin should be encased to facilitate handling.

16.23. Sources employed in routine use must be sealed hermetically because of serious problems of chemical toxicity. Recommendations on the design of sealed sources are given in Handbook 54 of this series.

16.3. *Constant-voltage accelerators.*

16.31. This group comprises Van de Graaff generators, Cockcroft-Walton generators, and similar installations that involve accelerating voltages up to 5 Mev and beam power up to about 100 watts. Machines of this type represent the most difficult problem in radiation protection because of the variety of possible reactions involved. Many of these may produce but a slight hazard, but others (such as $H^3(d,n)He^4$) make the installation a dangerous source of neutrons. There is often a frequent change from one type of reaction to another, and the schedule of operations may be intermittent or erratic.

16.32. It is beyond doubt safest and simplest to design the protection around such machines so that the dose rate of 2½ mrems/hr is not exceeded outside the shielding when the machine is run at maximum neutron output (usually $H^3(d,n)He^4$). The shielding required is of the order of a few feet of concrete, which adds comparatively little to the cost of a special building designed to house the machine. Such a structure is highly desirable because experience indicates that efforts to fit such generators into existing structures result in cluttered arrangements that tend to be inconvenient for purposes of research, and unsafe radiologically as well as otherwise (electrical and mechanical hazards).

16.33. On the other hand, it is realized that at many of these installations the provision of desirable shielding is structurally impossible or otherwise very difficult, particularly when it becomes necessary to fit them into existing buildings. Consequently the dose rate of 2½ mrems/hr might be exceeded at accessible locations, perhaps even at the operator's console. At present it does not seem warranted to categorically declare this practice unacceptable, but it certainly is not recommended. Furthermore, at installations where this condition exists it becomes *mandatory* that constant checks be performed, that operations be limited to insure that not more than the maximum permissible weekly dose is received by any personnel, and that operations be suspended if this would occur otherwise.

16.34. Location of the target below the ground level is usually preferable. Some experimenters prefer low-scatter flooring and building walls made of thin sheets or grids. Directing the beam away from occupied areas, and particularly the operator's console, often results in some shielding economy. Access to the region around the target should also be from other than the beam direction.

16.35. Because the ion beam produced by these machines can be "piped" over considerable distances with comparatively little effort, it is quite practicable to bring it into a shielded enclosure containing the target. However, such an enclosure should permit sufficient space for any experimentation that can be foreseen. In addition, effort should be made to shield any other structures that could intercept the beam.

16.36. In the design of these generators it should be kept in mind that secondary electrons are likely to produce X-rays and that modifications in basic design might lessen the protection requirements for this radiation.

16.4. *High-frequency accelerators.*

16.41. In virtually all of these machines massive shielding is mandatory, and few new installations can be planned that do not require a special building designed for the purpose. Because of structural considerations, there is a tendency to keep shielding of the space immediately above the machines at a minimum. As a result, a large fraction of the neutrons observed outside the shield may originally have escaped through the top and then been scattered downward by other structures or the air above. Most circular accelerators require shielding of the entire machine. The shielded enclosure should permit sufficient room for experimentation, particularly in the beam direction. It is highly desirable to provide space for additional shielding that may become necessary in case methods are found (as has been the case in the past) to boost the radiation output.

16.42. No installation should be designed in which the dose rate of 2½ mrems/hr is exceeded outside the shielding under conditions that can be foreseen. This is particularly necessary because additional exposure may be incurred during periods when the beam is off, as personnel, when working inside the enclosure, are likely to be exposed to gamma and beta radiation arising from induced activity.

16.43. Installations that are subterranean or built into a hillside are likely to result in appreciable economy because advantage may be taken of the shielding effects of soil.

16.44. Access to the shielded enclosure may be provided through either a maze or movable (usually power driven) shielding blocks. The latter design requires less space and is likely to be more economical.

16.45. Nuclear reactors: Because of the complexity of reactor design and the great variety of reactor types in existence, it appears impractical to provide any definite recommendations. Protection design should be based on pertinent experiences gained with existing types.

17. Stationary Shields

17.1. The shielding of neutron sources is at present not as well understood as that of gamma sources. Consequently the information on shield thicknesses is less exact, and shields should in general be more overdesigned. The formulas given below will include adequate safety factors for general use. It is a fact of practical importance that adequate shielding against neutrons will in general suppress gamma radiation to permissible levels at both reactors and accelerators. Water and other hydrogenous shields constitute an important exception to this rule. In the use of radioactive sources, and in particular photoneutron sources, gamma shielding is a separate and often more important problem.

17.2. In the design of buildings planned to contain neutron generators, shielding should be the first item considered because of both size and weight.

17.3. Ordinary or heavy aggregate concrete or earth are the recommended materials in most installations. Any economy by the use of water-filled tanks is likely to be offset by maintenance difficulties. In addition, evaporation represents a serious hazard, although it may be retarded by the addition of oil.

17.4. Paraffin or oil is a fire hazard, and neither should be used in large stationary shields.

17.5. Methods of shielding calculations are outlined in appendix 5.

18. Movable Shields

18.1. It is often necessary to operate with temporary shielding, in which the shield is not cast into place but rather is built up of separate blocks. As all such installations are subject to flaws or cracks which are left in the assembly, a detailed survey should be made prior to routine operation of the source. In general it is found that a carefully laid unmortared concrete block shield is nine-tenths as effective as a monolithic poured structure. Lead bricks laid with care show similarly reduced attenuation. All vertical cracks should be staggered to reduce leakage. Gravity is usually sufficient to keep horizontal cracks closed.

19. Unusual Hazards

19.1. Even though shields may be satisfactory when installed, they may deteriorate, either suddenly or gradually, so that it is necessary to monitor the radiation outside routinely. Examples of such deteriorations are the loss of water from a shield tank or from a hydrogenous shield material, the development of cracks in concrete due to settling, or the loss of hydrogen due to radiation damage in paraffin or oil. Reactors in water pools should be equipped with proper monitor systems to warn of lowered water level.

20. Procedures to be Implemented in Case of Overexposure

20.1. According to principles discussed at length in Handbook 59 of this series, the tolerance status of an individual is altered if, once in his lifetime and within a period of 1 month or less, he is exposed to absorbed doses exceeding 25 rems to the whole body or a major part thereof. For the purposes of this Handbook, one-half of this dose (12.5 rems) represents the limit above which exposures shall become a problem that must be referred, for joint consideration and appraisal, to recognized experts in medical radiology, radiobiology, and radiological physics.

20.2. Although the clinical management of such an individual is obviously the province of the physician, its form and course, as well as the individual's tolerance status, will be influenced by the magnitude of the dose received. Hence, every effort should be made to evaluate it as accurately and as soon as possible.

20.3. The extent of this effort will in turn depend on the availability of suitable personnel-monitoring devices on the body of the person involved. On the basis of the very scant information on the subject, and the unexpected nature of accidental exposures, no hard and fast rules can be given as to the experimental approach.

20.4. Ideally, a suitable personnel-monitoring device is an apparatus of ample dosimetric range capable of registering separately doses of gamma rays and of neutrons. Nuclear track emulsions, specially packed, tissue-equivalent and graphite-ionization chamber pairs, and other dosimeters that fulfill these requirements to a great extent, are described in appendix 4. If available, the readings given by these instruments can be interpreted directly in the evaluation of body doses, once the influence of shielding by the operator's body and the spatial characteristics of the radiation field are independently established. The unique merits of a true dosimeter are readily appreciated whenever the acute exposure is the consequence of sudden damaging overload of the neutron generator, leading to delay or to physical inability to undertake dosimetric studies under operating conditions duplicating those prevailing at the time of the accident.

20.5. Whenever true personnel dosimeters are, for any reason, unavailable, other integrating personnel detector readings can be used to advantage.

Dosimetric evaluation is then best done with proper dosimeters in the presence of radiations that are as nearly identical as possible to those emitted during the accident, and by relying on personnel detectors as integrating monitors. Because the spectral characteristics of a neutron generator may be critically dependent upon ion energy, particular attention must be paid to duplicating this factor. In this as well as in the previous case, the influence of the operator's body on the instrumental readings can be established with the use of experimental mock-ups simulating in size and composition the person's body.

20.6. Whenever personnel monitor readings are unavailable, dosimetric evaluations become much more difficult to obtain and approach the complexity of a research problem. The presence of area monitors, located in the radiation field, may be of substantial aid in establishing experimental conditions relevant to a dosimetric study, i.e., conditions of exposure bearing quantitatively known relation to those of the accident. Readings from area gamma-ray monitors should be sought and recorded because they may serve in some instances as integrator detectors.

20.7. Tools, apparatus, and other objects containing chemical elements such as Sn, Sb, Mn, Cu, Al, Cd, Hg, Ni, Au, Fe, may serve as neutron monitors if their induced radioactivity can be measured at known and preferably short times after the exposure. The movement of exposed individuals, however, must be established as accurately as possible, and pertinent questioning of personnel and witnesses should be undertaken promptly and testimony recorded with the least reliance on memory. Similarly, the radioactivity induced in any of the objects worn may serve the purposes of a neutron integrating detector, once the itinerary of the objects in the radiation field and its location on the person's body is established. Gold jewelry is particularly suited for this purpose; hence radioactivity in rings, wristwatch cases, bracelets, earrings, medals, etc., should be investigated. To a lesser extent, money (Cu, Ni, Ag) and other base metals likely to be on the person (in the form of identification badges, fountain pens, pencils, belt buckles, garters, costume jewelry, etc.) may serve the same purpose.

20.8. Because most of the radioactivities induced in these elements are short-lived and the result of small cross sections, speed and sensitivity of measurement are likely to prove critical in estimates of this sort. Very important also to ultimate interpretation is the critical analysis of the activities present, hence radiometric and spectrometric analysis of the samples are highly desirable.

20.9. The specific activity of Na^{24}—and to a lesser extent of P^{32}—in the blood serum and urine of the exposed individuals has been utilized for this purpose. The specific activity of the former should be evaluated by external gamma-ray measurements. This will require considerable accuracy and sensitivity, but will eliminate any uncertainty as to the rapidity of exchange with the other Na deposits. In procedures of this type care should be taken to remove contamination that may be present on the skin, hair, nails, and clothing of the individual.

20.10. It should be realized that most of the induced radioactivities thus far mentioned are caused in overwhelming measure by thermal neutrons and, therefore, they can be generated in part also by fast neutrons moderated by the body. A better indication of the fast neutron flux can be obtained from the threshold reaction P^{31} (n,p) Si^{31}. This element is readily available in matches and in urine.

IV. Rules for Protection against Neutron Radiation

Scope of rules. The rules set forth below are considered essential for the avoidance of hazards attending exposure to neutron radiation. They apply to other radiations only insofar as they might occur simultaneously with neutrons and add to the exposures incurred. Other handbooks in this series deal more explicitly with protection against other ionizing radiations. The present rules are not concerned with any electrical, mechanical, toxicological, and other nonradiation hazards that might arise in the operation of neutron sources, except as they affect radiation safety.

A further restriction applies to the case of reactors. The rules set forth below extend only to protection during normal operation at power levels anticipated. The prevention of abnormal conditions that entail particularly severe radiation hazards is a complex technological problem that will not be discussed here.

Finally, for obvious reasons, no specific recommendations can be made regarding protection in the vicinity of classified assemblies emitting neutrons.

21. Maximum Permissible Dose

21.1. For a radiation worker of age *N*, the accumulated RBE dose shall not exceed 5(*N*–18) rems in the blood-forming organs, the lens of the eye, and the gonads. In the skin it shall not exceed 10 (*N*–18) rems.

21.2. The weekly RBE dose incurred by a radiation worker shall not exceed 300 mrems. In exceptional cases where it is necessary for a person to receive larger doses, the unit of time may be extended to 13 weeks, provided that the dose accumulated during this period does not exceed 3 rems.

21.3. If detailed information on the nature of the ionizing radiations is not available, the RBE shall be assumed to be 10.

21.4. If the portion of the tissue dose contributed by the various radiations is known, each dose in mrads shall be multiplied by the appropriate RBE to obtain the dose in mrems. The RBE of electrons (whether primary or produced by electromagnetic radiation) shall be taken as 1.0. The RBE of neutrons shall be taken as 10, except that, if the distribution of neutron energies is known, the RBE values in table 2 may be applied.

21.5. Any person while occupying regions outside the controlled area shall not incur a dose of more than 125 mrems in a 3-month period. If such regions contain a residence or regular place of work, the dose rate in any building located therein shall be less than 125 mrems in a 3-month period. It is recommended that even in the absence of such buildings the dose rate should be less than 125 mrems in a 3-month period. If it is more, it shall be the duty of the radiation protection officer to assure himself that there is no likelihood that any person while remaining in these areas will receive doses in excess of 125 mrems in a 3-month period.

21.6. In *exceptional* cases where operations of the source would be virtually impossible otherwise, the permissible dose received outside the installation may be averaged over 1 year, provided the dose received in the period of 1 calendar week does not exceed 300 mrems.

22. Radiation Protection Officer

22.1. Personnel responsible for work with neutron sources shall also be responsible for radiation safety. If a neutron source is capable of delivering more than 300 mrems per work week due to all ionizing radiations emitted in accessible regions inside or outside of any externally applied shielding, a radiation protection officer shall be designated by the management concerned. His responsibilities shall include:

a. Furnishing of technical assistance in the planning and executing of work insofar as radiation safety considerations are involved.

b. Appraisal of operation of the source with regard to the radiation safety rules set forth below.

c. Notification to personnel working near the source of any special hazards that may exist.

d. Awareness of exposure of such personnel from additional sources of ionizing radiation.

e. Reporting of radiation hazards or unsafe practices to the proper authorities for suitable action whenever necessary.

The radiation protection officer should be familiar with the contents of this Handbook, and shall have sufficient training and experience to understand and apply pertinent provisions. A user of the source or a person employed in other capacities may qualify as radiation protection officer. A radiation protection officer may delegate duties but not responsibility. He shall be guided by advice from qualified experts if necessary.

22.2. The radiation protection officer shall be informed of any changes in the mode of operation of the source if these affect the radiation hazard.

22.3. The radiation protection officer should keep records of personnel exposure and area dose levels.

23. Radioactive Sources

23.1. Neutron sources containing materials that constitute a potential hazard of inhalation and/or ingestion due to their radiological toxicity shall be sealed securely or handled under conditions that otherwise eliminate the hazards involved.

23.2. A neutron source having a surface dose exceeding 10 mrems per calendar week, due to all ionizing radiations emitted, shall be marked with a label or stored in a labeled container. The label shall contain information on the nature and intensity of the source.

23.3. Any neutron source having a surface dose of more than 200 mrems/hr shall be normally stored in a labeled container conforming with 23.4.

23.4. When the source is in a storage container, less than 200 mrems/hr shall be delivered at container surface and less than 10 mrems/hr at 1 meter from the container.[4] These requirements need not be fulfilled if the regions around the source are marked as described in 23.5 and 23.6.

23.5. When such a source is removed from its storage container, any accessible location in which more than 7.5 mrems/hr are delivered shall be segregated by a clearly marked barrier or means equally effective in impeding unintentional access.

23.6. When the source is removed from a storage container, any accessible location in which more than 2.5 mrems/hr are delivered shall be clearly marked with signs that indicate the hazard.

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[4] These figures have been chosen so that containers may be used for purposes of source shipment in accordance with ICC regulations.