The Impact of a Proposed Change in the Maximum Permissible Dose Limit for Neutrons to Radiation Protection Programs at DOE Facilities

September 1981

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

The views, opinions and conclusions contained in this report are those of the contractor and do not necessarily represent those of the United States Government or the United States Department of Energy.

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
Under Contract DE-AC06-76RLO 1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151

Price: Printed Copy \$_____*; Microfiche \$3.00

*Pages	NTIS
	Selling Price
001-025	\$4.00
026-050	\$4.50
051-075	\$5.25
076-100	\$6.00
101-125	\$6.50
126-150	\$7.25
151-175	\$8.00
176-200	\$9.00
201-225	\$9.25
226-250	\$9.50
251-275	\$10.75
276-300	\$11.00

THE IMPACT OF A PROPOSED CHANGE IN THE
MAXIMUM PERMISSIBLE DOSE LIMIT FOR
NEUTRONS TO RADIATION PROTECTION
PROGRAMS AT DOE FACILITIES

B. L. Murphy, Principal Investigator
L. H. Munson, Contributor
J. M. Selby, PNL Project Manager
E. J. Vallario, DOE Project Manager

September 1981

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

CONTENTS

ACKNOWLEDGEMENTS	vii
FOREWORD	ix
SUMMARY OF FINDINGS	xi
INTRODUCTION	1
CURRENT DOE PROGRAMS AND PRACTICES	7
SOURCES OF NEUTRON EXPOSURE	7
NUMBER OF PERSONNEL MONITORED FOR NEUTRONS	8
DOSIMETRY	8
INSTRUMENTS	10
Calibration of Dosimeters and Instruments	10
PARAMETERS USED IN DOSE ASSESSMENT	11
Neutron Spectra	11
Surface Versus Depth Dose	12
Use of Conservative Factors	13
Data Systems	14
POTENTIAL IMPACTS	15
PERSONNEL	15
DOSIMETRY	16
INSTRUMENTATION	18
DATA SYSTEMS	18
FACILITY MODIFICATIONS	18
GENERAL CONTROLS	20
TRAINING	20
PROGRAM CONTINUATION	21

ANTICIPATED YEARLY COSTS ASSOCIATED WITH CHANGES IN RADIATION PROTECTION PROGRAMS	21
ADDITIONAL COMMENTS	21
REFERENCES	23
APPENDIX A - SURVEY FORM	A.1
APPENDIX B - SURVEY PARTICIPANTS	B.1

FIGURES

1	Anticipated Increase in Yearly Costs for Survey Respondants Associated with the Anticipated Increase in Manpower	15
2	Estimated Costs Associated with Facility Modifications for 25% of the Respondents	20
3	Anticipated Yearly Cost Associated with Changes in Radiation Protection Programs	22

TABLES

1	Chronology of Radiation Standards Occupational External Whole Body Dose Equivalent Limits, 1947-1977	2
2	Practical Quality Factors Recommended by the NCRP for Quick, Rough Calculations of the Dose Equivalent	3
3	Mean Quality Factors, QF, and Values of Neutron Flux Density Which, in a Period of 40 Hours, Result in a Maximum Dose Equivalent of 100 mrem	4
4	Sources of Potential Neutron Exposure Within the 24 DOE Facilities Surveyed	7
5	The Number of Personnel Who Received Neutron Exposures in Specified Ranges During Calendar Year 1979 at the 24 DOE Sites Surveyed	8
6	The Number of Personnel Who Received Neutron Exposures in Specified Ranges During Calendar Year 1979 at Sites Which Perform Defense-Related Work as Compared to Sites Which Perform Minimal or No Defense Work	9
7	Personnel Dosimeters Used to Monitor Neutron Exposure at the 24 DOE Facilities Surveyed	9
8	Calibration Sources Used for Neutron Detection Instruments and Dosimeters at the 24 DOE Sites Surveyed	11
9	Number of Facilities Surveyed That Estimate Surface Dose as Compared to Depth Dose in Determining Neutron Exposures and the Number of Personnel for Whom the Determinations Were Made in CY-79.	13

10	Anticipated Changes in Personnel Protection in Order to Measure 50 mrem of Fast Neutrons if the Q was Changed by a Factor of 3, 6, or 10	17
----	--	----

ACKNOWLEDGEMENTS

The authors wish to acknowledge the cooperation and technical assistance from the Field Offices and individual contractors who provided the basic data used in this report. Recognition is also given to Lois Peter, Pacific Northwest Laboratory, for her assistance in typing, reviewing and editing this report.

FOREWORD

The National Council on Radiation Protection and Measurements (NCRP) has issued a statement advising that it is considering lowering the maximum permissible dose for neutrons. This action would present substantive problems to radiation protection programs at DOE facilities where a potential for neutron exposure exists. In addition to altering administrative controls, a lowering of the maximum permissible dose for neutrons will require advances in personnel neutron dosimetry systems, and neutron detection and measurement instrumentation. Improvement in the characterization of neutron fields and spectra at work locations will also be needed. DOE has initiated research and development programs in these areas. However, problems related to the control of personnel neutron exposure have yet to be resolved and investigators are encouraged to continue collaboration with both United States and international authorities. We believe there is an urgent need to initiate programs oriented to the resolution of problems associated with personnel exposure to neutrons. This report is intended as a basic reference point for the identification of potential problem areas.

E. J. Vallario
Assistant Chief/Manager
Health Physics Programs
Division of Operation and
Environmental Safety
U.S. Department of Energy

SUMMARY OF FINDINGS

The purpose of this study was to assess the impact of the proposed NCRP (National Council on Radiation Protection and Measurements) change in the maximum permissible dose limit for neutrons on radiation protection programs at DOE facilities. To accomplish this, a series of questions concerning specific aspects of radiation protection programs was sent to selected DOE contractors. Findings of this study were:

- The total number of personnel monitored for neutrons during the calendar year 1979 was 24,787. Of the number monitored, 342 received a neutron exposure equal to or greater than 10% of the DEI (assuming a DEI of 5 rem).
- All of the respondents, with the exception of one, have data systems which distinguish between neutron exposure and exposure to other types of radiation. Most of the contractors could distinguish between beta, gamma and neutron exposure. However, three respondents could only distinguish neutron exposure from exposure to all other types of radiation. Retrieval of the type of historical data requested would require extensive computer programming or hand searching of records.
- A major research and development effort to provide neutron dosimeters and routine survey meters capable of detecting 50 mrem of fast neutrons will be required by a majority of the respondents if the Q is changed by a factor of 3, 6, or 10. Many respondents hoped to upgrade the accuracy of current neutron measurements by tightening of quality control procedures and taking more neutron spectra.
- Extensive facility modification such as the installation of intrusion detectors, permanent barricades, expanded change rooms and additional shielding will be required by many of the contractors. Concern was expressed that additional shielding could severely limit available

space and inhibit technical operations. In one case, additional shielding could force a complete shutdown of a program because of a lack of space.

- Assuming that funding is available for facility modifications and additional personnel, probably none of the respondents would have to abandon current operations if the Q value were changed by a factor of 3, 6, or 10. As indicated above, one of the respondents thought his operation could be in serious difficulty. Facility modifications would delay some programs and some activities would be reduced in order to minimize personnel exposure.
- An increase in the work force will be required by most contractors. The extent of the increase varied with the change in Q value and the size of the operation.
- Strengthening of radiation protection programs will be necessary if the Q value is changed by a factor of 3, 6, or 10. Purchase of additional neutron survey meters and neutron spectrometers will be needed. The dosimetry system will need to be altered, record keeping systems revamped and general controls tightened. Additional training will be required.

INTRODUCTION

The National Council on Radiation Protection and Measurements (NCRP) and the International Commission on Radiological Protection (ICRP) have furnished guidance concerning occupational exposure limits for radiation workers for nearly five decades. The quantities and units used in radiation protection practice have been recommended by the International Commission on Radiation Units and Measurements (ICRU). Since the establishment of these groups, the recommended limits have been revised constantly downward. A brief chronology of the development of radiation protection standards is shown in Table 1.

Radiation dose limits have historically been based on a limited knowledge of effects that occur at relatively high doses. The risk of exposure to any one type of radiation has been assumed to be directly proportional to the radiation dose (the so-called "linear hypothesis"). The application of the linear hypothesis to both high-LET radiation and low-LET radiation has recently been challenged (Rossi 1977a, 1977b; Rossi and Mays 1978). Some scientists have indicated that data are available to demonstrate that exposure to neutron radiation may be more hazardous than currently believed. However, the data are not conclusive and considerable controversy has arisen in the scientific community as to the interpretation of the data (Bond 1977; Roberts 1979; Mole 1979; Beebe and Land 1974; Jablon 1979).

The NCRP continually examines the risks associated with exposure to all forms of ionizing radiation. Thus, this organization has closely followed the controversy over the interpretation of the data used to assess the risk of induction of leukemia and other cancers from exposure to neutrons. As a result, the NCRP has issued a statement advising that it is reviewing the data and considering lowering the dose limit for neutrons by at least a factor of 3, but not greater than a factor of 10 (NCRP 1980a). One method of effecting this change would be to increase neutron quality factors by factors of 3 to 10. However, the quality factor may be completely redefined on the basis of the microdosimetric quantities of lineal energy or specific energy. Until the controversy concerning neutron dose limits is resolved, the NCRP has recommended that "interim precautionary steps be taken to reduce the potential

TABLE 1. Chronology of Radiation Standards-Occupational External Whole Body Dose Equivalent Limits, 1947-1977 (U.S. Department of Energy 1979)

Year	NCRP National Council on Radiation Protection & Measurement		ICRP International Commission on Radiological Protection		FRC (1960) Federal Radiation Council		Atomic Energy Commission (AEC) Energy Research and Development Administration (ERDA) Department of Energy (DOE)	
	Criteria	Reference	Criteria	Reference	Criteria	Reference	Criteria	Reference
1947	0.1 R/day 0.5 R/wk	NBS Handbook #18	0.2 R/day 1.0 R/wk				0.1 R/day	NCRP NBS Handbook #18
1949	0.3 R/wk	NBS Handbook #42	0.2 R/day 1.0 R/wk				0.1 R/day	
1950	0.3 R/wk		0.3 R/wk				0.3 R/wk	NBS Handbook 47
1951	0.3 R/wk		0.3 R/wk				3.9 R/13 wk	AEC (DBM)
							3.0 R/13 wk	AEC (LASL/WT 204)
							2.0 R/13 wk	AEC (Ranger/ Greenhouse)
							3.9 R/13 wks	AEC (DBM)
1952	0.3 R/wk		0.3 R/wk				3.9 R/13 wks	AEC (DBM)
1954	3.0 R/13 wks 0.3 R/wk Max 15 rem/y	NBS Handbook #59	0.3 R/wk				3.0 R/13 wks	NCRP
							0.3 R/wk Max	NBS Handbook #59
							15 rem/y	
1957	5 rem/y Ave 12 rem/y Max	Addendum NBS Handbook #59	0.3 R/wk				3.0 R/13 wks	
							0.3 R/wk Max	
							15 rem/y	
1958	0.3 rem/wk Max 3 rem/13 wks 12 rem/y Max 5 (N-18) rem	Addendum NBS Handbook #59	0.1 rem/wk 3.0 rem/13 wks 5 (N-18) rem	ICRP Report #1			0.3 rem/wk	NCRP
							3.0 rem/13 wk	NBS Handbook #59
							12 rem/y Max	
							5 (N-18) rem	
1959	0.3 rem/wk Max 3 rem/13 wks 12 rem/y Max 5 (N-18) rem		0.1 rem/wk 3.0 rem/13 wks 5 (N-18) rem				0.3 rem/wk	
							3.0 rem/13 wks	
							12 rem/y Max	
							5 (N-18) rem	
1960	0.3 rem/wk Max 3 rem/13 wks 12 rem/y Max 5 (N-18) rem		0.1 rem/wk 3.0 rem/13 wks 5 (N-18) rem		3 rem/13 wk 5 rem/y Ave 12 rem/y Max 5 (N-18) rem	FRC Report #1	3 rem/13 wk 5 rem/y Ave 5 (N-18) rem	FRC Report
1965	0.3 rem/wk Max 3 rem/13 wks 12 rem/y Max 5 (N-18) rem		3 rem/13 wk 5 rem/y Max	ICRP Report #9	3 rem/13 wk 5 rem/y Ave 12 rem/y Max 5 (N-18) rem		3 rem/13 wk 5 rem/y Ave 5 (N-18) rem	
1971	3 rem/13 wk 5 rem/y	NCRP Report #39	3 rem/13 wk 5 rem/y Max		3 rem/13 wk 5 rem/y Ave 12 rem/y Max 5 (N-18) rem		3 rem/13 wk 5 rem/y Ave 5 (N-18) rem	
1974	3 rem/13 wk 5 rem/y		3 rem/13 wk 5 rem/y Max		3 rem/13 wk 5 rem/y Ave 12 rem/y Max 5 (N-18) rem		3 rem/13 wks 5 rem/y	NCRP #39
1977	3 rem/13 wk 5 rem/y		5 rem/y acceptable risk	ICRP #26	3 rem/13 wk 5 rem/y Ave 12 rem/y Max 5 (N-18) rem		3 rem/13 wks 5 rem/y	

exposure of individuals who may receive neutron doses that are a substantial fraction of the current maximum permissible dose."

Currently, the quality factor is defined as a function of the linear energy transfer (LET) of charged particles within an irradiated medium. Procedures for the determination of the Q value may be found in NCRP Report 39 (NCRP 1980b). As presently defined, the quality factor for neutrons may vary from a value of 2 to a value of 11, depending on the energy of the neutron. For quick, rough calculations of the dose equivalent, the NCRP has established "Practical Quality Factors" for each of the different types of radiation. These are presented in Table 2. When the neutron spectra is known, quality factors based on the energy are used. Table 3 presents these Q values.

A decrease in maximum permissible dose limit for neutrons could have serious and far reaching impacts on Department of Energy (DOE) programs where a

TABLE 2. Practical Quality Factors Recommended by the NCRP for Quick, Rough Calculations of the Dose Equivalent (NCRP 1980)

<u>Radiation Type</u>	<u>Rounded QF</u>
X rays, gamma rays, electrons or positrons, Energy <0.03 MeV	1
Electrons or positrons, Energy <0.03 MeV	1 ^(a)
Neutrons, Energy <10 keV	3
Neutrons, Energy >10 keV	10
Protons	1-10 ^(b)
Alpha particles	1-20
Fission fragments, recoil nuclei	20

(a) In 1966 the ICRP recommended a value of 1.7 for the QF of low energy electrons or protons. A rounded value of 1 is believed to be more commensurate with the accuracy of our knowledge and the requirements of radiation protection. In 1969 the ICRP amended its 1966 recommendations, specifying that the QF should be taken as 1 for all β^- , β^+ , e^- , and x radiations, and for conversion electrons.)

(b) Use the higher value for round-off or calculate by the methods of ICRP Publication 4.

TABLE 3. Mean Quality Factors, $\overline{QF}(a)$, and Values of Neutron Flux Density Which, in a Period of 40 Hours, Result in a Maximum Dose Equivalent of 100 mrem (NCRP 1980)

<u>Neutron Energy</u>	<u>$\overline{QF}$</u>	<u>Neutron Flux Density</u>
Mev		cm-2 s-1
2.5×10^{-8} (thermal)	2	680
1×10^{-7}	2	680
1×10^{-6}	2	560
1×10^{-5}	2	560
1×10^{-4}	2	580
1×10^{-3}	2	680
1×10^{-2}	2.5	700
1×10^{-1}	7.5	115
5×10^{-1}	11	27
1	11	19
2.5	9	20
5	8	16
7	7	17
10	6.5	17
14	7.5	12
20	8	11
40	7	10
60	5.5	11
1×10^2	4	14
2×10^2	3.5	13
3×10^2	3.5	11
4×10^2	3.5	10

(a) Maximum value of $\overline{QF}$ in a 30-cm phantom.

potential for neutron exposure exists. In order to assess the extent of the impact, the DOE office of Operational and Environmental Safety (OES) sent a survey to selected contractors (Appendix A). The survey (Appendix B) posed a series of questions concerning specific aspects of a radiation protection program. Contractors were asked if any programs would have to be abandoned and to consider necessary changes in the areas of dosimetry, instrumentation, data systems, personnel, training and general controls.

This report is a summary of the information submitted by contractors on the impact of a change in the neutron dose limit. The first section of the report summarizes current programs and practices at DOE facilities. The second section considers potential impacts on DOE programs if the neutron dose limit is altered. The question of whether the neutron component of the dose equivalent should be lowered is not addressed in this report.

CURRENT DOE PROGRAMS AND PRACTICES

SOURCES OF NEUTRON EXPOSURE

Sources of neutron exposure at the DOE facilities surveyed varied with the nature of work performed at the site. One source of a potential neutron exposure within the facilities surveyed was the processing of plutonium and other transuranic material (including weapons development). Other major sources of exposure included reactors and particle accelerators.

Nearly all of the facilities reported having isotopic sources used primarily for instrument and dosimeter calibrations. Some sites also use isotopic sources for general research programs and for well logging. Plutonium-beryllium and Cf-252 sources were the most frequently used neutron sources. Other neutron sources mentioned included PuO₂, Pu-244, and Am-Be-241.

Other sources of neutron exposure reported included transuranic waste, neutron generators, critical assemblies, fusion devices, and biological research. Information concerning sources of potential neutron exposure is summarized in Table 4.

TABLE 4. Sources of Potential Neutron Exposure
within the 24 DOE Facilities Surveyed

<u>Sources</u>	<u>Number of Sites</u>
Processing of Plutonium and Other Transuranic Material (Including Weapons Development)	8
Reactors	7
Accelerators	12
Isotopic Sources	15
Fusion Device	1
Critical Assembly	2
General Research	2
Neutron Generator	3
Transuranic Waste	1

NUMBER OF PERSONNEL MONITORED FOR NEUTRONS

A total of 24,787 workers were monitored for neutrons at the sites surveyed during calendar year 1979. Of the personnel monitored, less than 1.5% received a neutron exposure equal to or greater than 10% of the dose equivalent limit (assuming a dose equivalent limit of 5 rem). The number of personnel who received neutron exposures in specific ranges is presented in Table 5.

As part of the data analysis, the facilities were divided into two groups. The first group contained all those sites involved with defense work. The second group did minimal or no defense work. The results of this analysis are presented in Table 6.

Almost 80% of the personnel monitored for neutrons were at facilities performing defense-related work. As can be calculated from Table 6, ~~14.6%~~ ^{1.46%} of the exposures at facilities which performed defense work were greater than 10% of the dose equivalent limit. This is in comparison to ~~10.2%~~ ^{1.02%} of the exposures at sites which performed minimal or no defense works.

DOSIMETRY

Two types of personnel dosimeters are commonly used at DOE facilities: 1) thermoluminescence (TLD-albedo) dosimeters, and 2) nuclear tracer emulsions (NTA film) dosimeters. The majority of the sites surveyed used TLD-albedo dosimeters, either alone or in combination with other types of neutron dosimetry systems, such as NTA film or track etch dosimeters. NTA film is used

TABLE 5. The Number of Personnel who Received Neutron Exposures in Specified Ranges During Calendar Year 1979 at the 24 DOE Sites Surveyed

<u>Range of Neutron Exposure</u>	<u>Number of Personnel</u>
0.0 - 0.5 rem	24,451
0.5 - 1.0	259
1.0 - 2.0	68
2.0 - 3.0	5
3.0 - 4.0	4
4.0 - 5.0	0

TABLE 6. The Number of Personnel who Received Neutron Exposures in Specified Ranges During Calendar Year 1979 at Sites Which Perform Defense-Related Work as Compared to Sites Which Perform Minimal or No Defense Work

Range of Neutron Exposures	Number of Personnel Who Received Neutron Exposures	
	Sites Which Perform Defense Work	Sites Which Perform Minimal or No Defense Work
0.0 - 0.5 rem	19,366	5,085
0.5 - 1.0	207	52
1.0 - 2.0	67	1
2.0 - 3.0	5	0
3.0 - 4.0	4	0
4.0 - 5.0	0	0
Total	19,649	5,138

exclusively at three of the sites surveyed and is combined with polycarbonate dosimetry at one site. Information concerning the type of dosimeters used is summarized in Table 7.

A lower detection limit for personnel dosimeters in this study ranged from 10 mrem to 50 mrem for TLD-Albedo dosimeters and 30 to 50 mrem for NTA film dosimeters. A lower detection limit of 30 mrem was reported by the sites which used track etch dosimeters, either routinely or experimentally. As noted at

TABLE 7. Personnel Dosimeters Used to Monitor Neutron Exposure at the 24 DOE Facilities Surveyed

Dosimeter Type	Number of Sites	Number of Personnel (CY 1979)
Thermoluminescence (TLD-Albedo)	16	21,033
Nuclear Track Emulsion (NTA Film)	3	2,667
Combinations		
TLD-Albedo + NTA Film	3	218
TLD + Track Etch	1	144
NTA Film + Polycarbonate	1	725

several sites, the lower detection limit is dependent on the energy of the neutrons being detected. These sites indicated a lower detection limit of 3 to 5 mrem for thermal neutrons and a limit of 40 to 50 mrem for more energetic neutrons. The reported upper error limits for specified detection limits varied from +30% to +200%. The lower error limit reported varied from -10% to -100%.

INSTRUMENTS

A variety of commercially available neutron detection instruments are in use at DOE facilities. Most use a rem-meter type instrument based on an Andersson-Braun or Hankin's design (Andersson and Braun 1964; Hankins 1963). Several sites reported using internally designed instruments to augment those they had purchased. One site used only internally designed neutron instrumentation. The minimum level of detection for the instruments varied from 0.01 mrem/hr to 20 mrem/hr. Error limits ranged from $\pm 10\%$ to $\pm 100\%$. The median minimum level of detection for all instruments combined was between 0.5 to 1 mrem/hr with an error limit of approximately $\pm 50\%$.

Calibration of Dosimeters and Instruments

Instrument and dosimeter calibration activities vary from dependence on vendor calibration services to extensive in-house capability. Nearly all of the contractors calibrate instruments in-house. Sites which process a large number of dosimeters tend to calibrate dosimeters in-house, whereas vendor calibration services are used when the number of individuals monitored for neutrons is relatively small.

The most common procedure for instrument calibration is to place the center of the detection instrument at a point near the source where the dose rate is known. The instrument is then set to read the correct rate. The calibration distance may be varied to provide a calibration over several decades. The procedure used for dosimeter calibrations is generally similar to that described for instruments except that the dosimeter is often placed on a phantom. Calibration sources for both instruments and dosimeters are selected according to the energy of the neutrons to which personnel may be exposed. Calibration sources are presented in Table 8.

TABLE 8. Calibration Sources(a) Used for Neutron Detection Instruments and Dosimeters at the 24 Sites Surveyed

Source	Number of Sites Using Source for Calibration	
	Dosimeters	Instruments
^{252}Cf	7	6
Pu-Be	10	13
Pu-Li	1	1
Pu-B	2	2
PuF_4	4	2
PuO_2	2	2
Am-Be	0	1
Accelerator	1	1
Reactor	1	1

(a) Sources may be either bare or moderated. In most cases they are NBS traceable.

PARAMETERS USED IN DOSE ASSESSMENT

Neutron Spectra

The NCRP has recommended quality factor values for various neutron energies. These values, along with the value of neutron flux density resulting in a maximum dose equivalent of 100 mrem during a period of 40 hours, are found in NCRP Report #39 and are presented in Table 2. The quality factors for neutrons in the range of energies specified in Table 2 do not exceed 10 except for a brief excursion between 0.5 and 1.0 MeV. This fact is the basis of a commonly used conservative practice in which the neutron-absorbed dose is always multiplied by a factor of 10, regardless of the energy of the incident neutron, to calculate the neutron dose equivalent limit. The NCRP also recommends using a quality factor of 10 whenever the detailed information on neutron energy is not available. To minimize the impact of a change in the neutron dose limit to DOE facilities, a knowledge of the neutron dose spectra will become increasingly important.

The neutron energy spectra found at DOE facilities is dependent on the source and is influenced by the degree of moderation, scattering conditions,

shielding geometry, materials, and operating parameters. As would be expected, a "typical" neutron energy spectra was not apparent among the DOE facilities surveyed. Neutron energy spectra with varying shapes was reported to range from approximately thermal to 15 MeV. One site indicated a spectra approaching 20 GeV on the high end.

The extent to which neutron energy spectra can be determined varies considerably among DOE facilities. A limited number of sites reported having extensive capabilities for obtaining spectra. The majority appeared to rely on relatively crude measurements or on neutron spectra published in the literature. Several facilities depended on spectra furnished by other contractors.

Multisphere spectrometers, systems such as the "Bonner Spheres", were used most frequently by the facilities that measured neutron spectra. In several instances, the spectrometer systems were used with computer unfolding codes. Other instruments reported in use included hydrogen proportional counters, polyethylene-line proportional counters used with moderated BF_3 counters, ^3He neutron spectrometers and proton-recoil spectrometers.

Surface Versus Depth Dose

In its statement concerning the dose limit for neutrons, the NCRP noted that in many instances exposure of personnel is assessed in terms of the absorbed dose at the body surface. For neutrons in the neutron fission range, the absorbed dose at the body surface is substantially greater than the absorbed dose to an internal organ. The example presented in the NCRP statement was that the surface dose is larger by a factor of 3 or 4 than the absorbed dose to bone marrow (critical organ for leukemia). This implies that if the neutron exposure to personnel has been determined on the basis of surface dose rather than depth dose, the action necessary to adjust to an alteration in neutron dose by a factor of 3 may be minimal.

Contractors were asked if they estimated surface dose or depth dose. Thirteen of the 24 sites surveyed estimated surface dose and six estimated depth dose. Five sites did not specify which type of dose estimation was used. At these five sites, the neutron exposures during CY 1979 for the 1,792

personnel monitored were less than 0.5 rem. Of the rest of the personnel monitored for neutrons during CY 1979, 12,820 employees were at sites that used depth dose estimations and 10,175 were at sites that estimate surface dose. The number of personnel who received a neutron exposure greater than 10% of the DEI (assuming a DEI of 5 rem) was fairly evenly divided between the sites using surface dose estimations as opposed to depth dose estimations. Information concerning the procedure used to estimate dose is summarized in Table 9.

Use of Conservative Factors

Contractors were asked if they used conservative factors in place of Q values based on energy spectra information. Approximately one-third of the respondents use spectra information in the determination of dose equivalence. Several sites derive calibration factors using 9" and 3" sphere ratios. Among the remaining contractors, conservatism was introduced to the estimation of neutron exposures in a variety of ways. For example, the use of a Q value of 10, regardless of the energy of the neutrons to which personnel are exposed, is considered by the NCRP to be a "conservative" practice. Five sites choose to use this procedure. One site uses a Q value of 10 for fast neutrons, but for thermal neutrons a Q value of 3 is applied.

TABLE 9. Number of the Facilities Surveyed That Estimate Surface Dose as Compared to Depth Dose in Determining Neutron Exposures and the Number of Personnel for Whom the Determinations Were Made in CY-79.

		<u>Dose Estimation Procedure</u>		
		<u>Surface</u>	<u>Depth</u>	<u>No Response</u>
Number of facilities using the procedure		13	6	5
Total number of personnel for whom estimates made		10,252	12,892	1,792
Number of personnel in specified dose ranges:	0-0.5 rem	10,013	12,718	1,792
	0.5-1	106	153	
	1-2	51	17	
	2-3	2	3	
	3-4	3	1	
	4-5	0	0	

Several locations use conservative procedures during the calibration of their dosimeters. The most frequently cited conservative procedure was to estimate surface dose rather than depth dose. One location established the Q values using unscattered $^{238}\text{PuF}_4$ spectrum in air. This procedure typically created a dosimeter overresponse by a factor of 1.5 due to spectrum degradations by shielding and moderators at the work site.

Data Systems

Exposure history records may need to be reevaluated to determine if any personnel have received neutron exposure in excess of the maximum if the neutron dose is lowered. This would be particularly important in the assessment of total lifetime exposure. All of the contractors, except one, have historical data systems capable of distinguishing between neutron exposures and exposures to other types of radiation. Twenty had systems that distinguished between beta, gamma, and neutron exposures. The systems of the other three contractors could distinguish only between neutron exposure and the total of the exposure to all other types of exposure. In some cases retrieval of this type of data would require extensive computer programming or hand searching of records.

POTENTIAL IMPACTS

PERSONNEL

A staff increase at 80% of the 24 DOE facilities surveyed will be required if the neutron dose limit is lowered. The extent of the increase varied with the change in Q value, the size of the operation and the nature of the work performed at the site. Thirteen contractors provided estimated yearly costs associated with an increase to the work force. The total cost (combined) for these 13 sites is presented in Figure 1.

Personnel with a variety of skills will be needed. Frequently mentioned were radiation protection technicians to handle the anticipated increase in survey and monitoring activities. Instrument technicians, data system clerks, and personnel trainers will also be needed to support health physics activities. Film scanners will be needed at sites which use NTA film. Other types of required personnel include quality engineers, security guards, construction

FIGURE 1. Anticipated Increase in Yearly Costs for Survey Respondants Associated with the Anticipated Increase in Manpower

labor, design engineers, technicians with unique skills and craftsmen. Professional staff to assist with the development of new dosimeters will also be needed.

Several respondents believed it undesirable to increase the work force in order to minimize exposure to an individual, as this practice could result in an increase in the overall man-rem exposure. However, realistically, all indicated that an increase in the quality factor would require either an increase in manpower or rotation of personnel.

DOSIMETRY

An innovative research and development program will be required to provide DOE contractors with an adequate dosimetry program should the dose limit for neutrons be lowered. A recent report discussed the status of personnel dosimetry at DOE facilities (Brackenbush 1980). According to this report, existing personnel dosimeters do not fully meet the current needs of radiation workers and the recommendations of regulatory agencies. Substantial improvements in the accuracy and sensitivity of neutron dosimetry systems will be necessary if changes in the neutron dose limits are made. The magnitude of the effort required would vary according to the nature of the work done by the contractor, the number of personnel who may potentially be exposed to neutrons and the factor by which the dose limit changes. In addition to the research and development efforts, dosimeter programs will be affected by an increase in the number of personnel to be monitored. Other anticipated changes are reviewed in Table 10.

Some contractors view a change in the neutron dose limit by a factor of 3 as a less significant problem than a factor change of 6 or 10. This is particularly true of sites that currently calibrate their dosimeters for surface rather than depth dose and can take advantage of the fact that the surface dose can be a factor of three or four times greater than the depth dose to the organ of interest. Other respondents hope to mitigate the effect of a factor of 3 change by improving the accuracy of their neutron dosimetry programs by tightening quality control procedures, upgrading equipment, and by increasing the number and precision of neutron spectra measurements.

TABLE 10. Anticipated Changes in Personnel Protection Programs in Order to Measure 50 mrem of Fast Neutrons if the Q was Changed by a Factor of 3, 6, or 10(a)

Factor Change in Neutron Dose Limit		
X3	X6	X10
Develop new dosimetry system	Develop new dosimetry system	Develop new dosimetry system
Recalibrate	Recalibrate	Recalibrate
Improve dosimetry handling procedures	Improve dosimetry handling procedures	Improve dosimetry handling procedures
Precise spectral measurements at work locations	Precise spectral measurements at work locations	Precise spectral measurements at work locations
Increase scan time for NTA dosimeters	Increase scan time for NTA dosimeters	Increase scan time for NTA dosimeters
Increase gamma shielding to reduce statistical interference of gamma with n readings	Try alternate dosimetry programs such as track etch	
Utilize a more bulky dosimetry system		
Use gamma:n ratios		
Time and motion studies		
Tight Administrative Controls		

(a) Three respondents indicated that no change would be necessary for a change of 3, 6, or 10. One indicated no change for a factor change of 3.

INSTRUMENTATION

Nearly all of the contractors will need to increase their inventory of neutron detection equipment to cope with a change in neutron dose limits. Neutron spectrometers will be required by most to more closely equate the neutron spectra with the Q value and to measure spectra at the work sites with increased frequency. However, many contractors questioned the availability of state-of-the-art nuclear detection instrumentation with sufficient sensitivity for routine programs. A developmental program for instrumentation may be required.

DATA SYSTEMS

Thirteen respondents did not anticipate a major impact to the record keeping system if the Q value was changed. Problems identified by the 11 contractors who indicated that their record keeping system would be changed included:

- re-programming computer dose calculations
- increased reporting for exposure control
- development of new record keeping system
- increase in the number of personnel monitored
- reevaluation of neutron dose assignments in existing personnel dosimetry records
- system expansion to include dose equivalent to red bone marrow.

FACILITY MODIFICATIONS

More than 50% of the respondents anticipated that facility modifications such as additional shielding, permanent barricades, installation of intrusion detectors and expanded change rooms would be necessary for compliance with the proposed change in neutron Q value. The extent of the necessary modifications increased with each incremental change in the Q value and varied with the nature of the work done by the contractor.

Additional shielding was mentioned most frequently at reactor and accelerator facilities. In some cases, additional shielding would create a severe lack of space that could inhibit technical operations and increase exposure time disproportionately. At one site, personnel would have to be relocated in order to provide room for additional shielding. The expense of providing new building space for such relocation was greater than the cost of proposed shielding modifications. At several facilities providing shielding additions that are earthquake-proof would incur considerable expense. Existing walls may not support the added weight of increased shielding and still meet seismic requirements.

Additional shielding was suggested as a means of reducing neutron exposures at processing facilities also. However, because of the nature of these operations, most indicated that other options would have to be taken to reduce personnel exposure. Suggestions included the rotation of the personnel through jobs which involved handling radioactive materials to reduce exposure time; incorporation of shielding into weapons assembly/disassembly tooling; provision of designs to reduce assembly time; provision of additional training and health physics supervision; reducing the quantity of radioactive materials in individual bays by relaxing production schedules, and distributing the material among a greater number of bays.

If the Q is increased by a factor of 10, one plutonium processing plant suggested that design of new production facilities would require modification from gloveport to remote handling operations. An increase in Q value by a factor of 10 would require gloveport shields greater than six inches. According to the contractor, shields of this thickness reduce the ability of an individual to handle glovebox equipment.

The survey questions dealing with facility modifications did not ask for cost estimates. However, six of the 24 facilities provided an estimated cost for anticipated facility modification. The total of their estimates is shown in Figure 2.

FIGURE 2. Estimated Costs Associated with Facility Modifications for 25% of the Respondents

GENERAL CONTROLS

Twelve respondents anticipated changes in the general controls if the Q value were changed. Two anticipated changes only if the Q value were changed by a factor of 10 and ten did not feel that general controls would have to be altered to any extent. Among the general controls listed were area access, posting, increased use of video to view operations, increased surveillance of neutron radiation areas, alteration of operating procedures and administrative controls, and addition of interlocks.

TRAINING

One-half of the respondents (12 out of 24) anticipated changes in the radiation protection training program. Changes included a redirection of existing training programs and an increase in the number of personnel to be trained. One individual indicated that dosimetry personnel would have to be retrained in more precise and controlled dosimeter handling and in understanding complex field situations. These personnel would need to be advised of changes in facilities and operations that influence neutron spectra.

PROGRAM CONTINUATION

Assuming that funding is available for facility modifications and additional personnel, none of the respondents would have to abandon current operations if the Q value were changed by a factor of 3, 6, or 10. One of the respondents indicated that his operation could be in serious difficulty from space problems created by additional shielding. Facility modifications would delay some programs and some activities would be reduced to minimize personnel exposure.

ANTICIPATED YEARLY COSTS ASSOCIATED WITH CHANGES IN RADIATION PROTECTION PROGRAMS

Anticipated yearly cost for changes in radiation protection programs (dosimetry, record keeping, instrumentation, general controls, and staff) varied with the size of the operation and the extent of change in the quality factor. Estimates for individual organizations ranged all the way from \$0 to \$4,588K. Total estimated yearly costs for all respondents was \$7,212K for an X3 change in Q, \$9,391K for a X6 change and \$12,230K for a X10 change. The most significant contribution to the cost increase was manpower followed by changes in instrumentation and dosimetry. One organization did not provide an estimate for either an X6 or X10 change in Q value because it did not think it was feasible to project the cost of a new dosimetry program. Another respondent estimated that \$800K plus the addition of four to six professionals to the staff would be needed to develop a new dosimeter. This expense was in addition to anticipated increases in operating expense. Total anticipated costs are shown in Figure 3.

ADDITIONAL COMMENTS

In addition to responding to specific questions, the following comments were received from contractors concerning the impact of a change in quality factors.

- A potential problem, not addressed in the question, is that of hand exposure. The NCRP warning addressed only the potential of modifying the quality factor for exposure to internal organs and not for body

FIGURE 3. Anticipated Yearly Cost Associated with Changes in Radiation Protection Programs

extremities containing little bone marrow. If the NCRP did not recognize the lack of bone marrow in the hands and insisted that the increase in quality factor applied to all parts of the body, even a factor of 3 increase in neutron exposure to the hands would present significant problems.

Remote handling manipulators would probably be required to reduce the hand exposures to acceptable limits. Operational personnel estimate that the use of such manipulators would increase the operating time by a factor of 2, thus requiring twice as many operators to accomplish the same output, while keeping the body neutron exposure within the limits.

- The proposed NCRP changes would restrict the loading limits on shipping containers.

REFERENCES

- Beebe, G. W. and C. E. Land. 1979. "Comments on 'Leukemia Risk From Neutrons,'" Letter to the Editor. Health Physics. 36:465.
- Bond, V. P. 1979. "The Risk From Fast Neutron Exposure." Health Physics. 37:391.
- Brackenbush, L. W., G. W. R. Endres, J. M. Selby, E. J. Vallario. 1980. Personnel Neutron Dosimetry at Department of Energy Facilities. PNL-2598, Pacific Northwest Laboratory, Richland, WA.
- Jablon, S. 1979. "Comments on 'Leukemia Risk From Neutrons' by H. H. Rossi and C. W. Mays," Letter to the Editor. Health Physics. 37:601.
- Mole, R. G. 1979. "RBE for Carcinogenesis by Fission Neutrons," Letter to the Editor. Health Physics. 36:463.
- National Council on Radiation Protection and Measurements. 1980a. "NCRP Statement on Dose Limit for Neutrons." Washington D. C.
- National Council on Radiation Protection and Measurements. 1980b. Basic Radiation Protection Criteria. NCRP Report No. 9, Washington, D.C.
- Roberts, P. B. 1979. "Comments on 'Leukemia Risk from Neutrons' by H. H. Rossi and C. W. Mays," Letter to the Editor. Health Physics. 37:601.
- Rossi, H. H. 1977a. "The Effects of Small Doses of Ionizing Radiation: Fundamental Biophysical Characteristics." Radiation Research. 71:1.
- Rossi, H. H. 1977b. "A Proposal for the Revision of the Quality Factor." Radiation and Environmental Biophysics. 14:275.
- Rossi, H. H. and C. W. Mays. 1978. "Leukemia Risk from Neutrons." Health Physics. 34:353.
- U.S. Department of Energy. 1979. "Study of Anticipated Impact on DOE Programs from Proposed Reductions to the External Occupational Radiation Exposure Limit." DOE/EU-0045, U.S. Department of Energy, Washington, D.C.

APPENDIX A
SURVEY FORM

APPENDIX A

SURVEY FORM

- 1) How many workers received neutron exposures equal to or greater than 10% of the DEI?
- 2) Give the total number of workers monitored for neutrons and the corresponding numbers of neutron exposures received in the following ranges:
0 - 0.5 rem, 0.5 rem - 1 rem, 1 rem - 2 rem, 2 rem - 3 rem, 3 rem - 4 rem, 4 rem or greater.
- 3) What is the exposure source (e.g., reactor, accelerator, etc.)?
- 4) Is your data system capable of providing historical data that enables one to distinguish between beta, gamma, and neutron exposure?
- 5) What type of neutron dosimeter is in use? Do you estimate surface dose or depth in tissue?
- 6) What type of neutron instrument(s) is in use?
- 7) Describe source and method of calibration.
- 8) What is the minimum level of neutron detection and what is your estimate of the error limits at that level for dosimeters and instruments?
- 9) Are there any provisions for obtaining neutron energy spectra information? Have such measurements been taken? What is the typical spectra associated with your operations?
- 10) Do you use conservative factors in place of Q values based on energy spectra information? Explain.
- 11) What changes in your personnel protection program would be required to enable you to measure 50 mrem of fast neutrons if the Q was changed by a factor of 3, 6, or 10?
- 12) Would facility modifications be required (additional shielding) to comply with the change in Q values, i.e., factor 3, 6, and 10?

- 13) Would it be necessary to increase the work force? If so, what is the anticipated increase in yearly cost?
- 14) Would any phase of current operations have to be abandoned if the change to Q was a factor 3, 6, or 10?
- 15) On the basis of these proposed changes, would you anticipate changes to radiation protection programs, specifically in the following areas?
 - a) instrumentation
 - b) record keeping
 - c) dosimeters
 - d) general controls
 - e) staffing
 - f) training

What is the anticipated yearly cost associated with these changes?

APPENDIX B

SURVEY PARTICIPANTS

APPENDIX B

SURVEY PARTICIPANTS

The following DOE contractors participated in the survey concerning the potential impact of the proposed NCRP changes to neutron maximum permissible dose limit.

Albuquerque Operations Office

Inhalation Toxicology Research Institution
Los Alamos Scientific Laboratory
General Electric, Neutron Device Department
Mound Facility
Pantex Plant
Rockey Flats Plant

San Francisco Operations Office

Lawrence Berkeley Laboratory
Lawrence Livermore Laboratory
Stanford Linear Accelerator Center

Nevada Operations Office^(a)

EG&G, Santa Barbara
Bendix Corp., Grand Junction
Nevada Test Site

Savannah River Operations Office

(a) The Operations Office provided a summary report for the contractors listed. These Operations Offices were considered as one site in this report.

Idaho Operations Office

EG&G, Idaho
Exxon Nuclear, Idaho
Radiological and Environmental Laboratory

Oak Ridge Operations Office

Oak Ridge National Laboratory

DOE Headquarters

Advanced Nuclear Systems and Projects Division

Teledyne Energy Systems
General Electric, Valley Forge Space Center

Richland Operations Office^(a)

Boeing Computer Services
DOE Office
Hanford Engineering Development Laboratory
J. A. Jones Construction Co.
Pacific Northwest Laboratory
Rockwell Hanford Operations
UNC Nuclear Industries, Inc.
Vitro Engineering Corporation

Chicago Operations Office

Argonne National Laboratory, East
Argonne National Laboratory, West
Fermi National Accelerator Laboratory
Brookhaven National Laboratory
Massachusetts Institute of Technology - Bates Laboratory
Princeton Plasma Physics Laboratory

(a) The Operations Office provides a summary report for the contractors listed. These Operations Offices were considered as one site in this report.

DISTRIBUTION

No. of
Copies

OFFSITE

A. A. Churm
DOE Patent Division
9800 S. Cass Avenue
Argonne, IL 60439

12 E. J. Vallario
DOE Division of Operational
Safety
Washington, DC 20545

27 DOE Technical Information Service

ONSITE

DOE Richland Operations Office

H. E. Ransom

27 Pacific Northwest Laboratory

L. W. Brackenbush
T. H. Essig
L. G. Faust
J. J. Fix
W. A. Glass
H. V. Larson
L. H. Munson

12 B. L. Murphy
J. M. Selby
2 Publishing Coordination
5 Technical Information