Aug. 20, 1976

REPORT

OF

NEUTRON QUALITY FACTOR TASK GROUP

7904250314

9-26

73-126

NEUTRON QUALITY FACTOR TASK GROUP

Mr. Glenn W. Zimmer, Chairman, SD

Dr. Allen Brodsky, SD

Dr. John Nehemias, NRR

Dr. Wayne R. Hansen, NMSS

Dr. Shlomo S. Yaniv, RES

Mr. Lemoine J. Cunningham, IE

Mr. Robert E. Baker, Consultant, SD

Dr. J. Kastner, Consultant, SD

OUTLINE

1. Review of NCRP recommendations to date

2. Origin of current NRC Limits

3. Preliminary Analysis of Rossi's Presentation Regarding the Risks of Neutron Radiation Exposure

4. Alternative actions

5. Preliminary Value/Impact Appraisal

6. Recommendation

73-128

REVIEW OF NCRP RECOMMENDATIONS TO DATE

The principal recommendations of the NCRP with regard to neutron exposures have been contained in:

- NCRP Report No. 20 (Handbook 63), "Protection Against Neutron Radiation up to 30 Million Electron Volts", November 22, 1957;

- NCRP Report No. 38, "Protection Against Neutron Radiation", January 4, 1971.

NCRP Report No. 20, Table 2, pages 15 (Enclosure A), recommended particular QF's (then termed "RBE") and maximum permissible neutron fluxes for neutron energy ranges up to 30 MeV., and recommended a QF value of 10, if sufficiently detailed information on neutron energy is not available.

In NCRP Report No. 38, Table 2, page 16 (Enclosure B), some of these QF's were modified somewhat, although the recommended value for situations involving unknown energies remained at 10. These are the current NCRP recommendations.

With regard to limitations on whole body dose, NCRP representatives took part in a meeting at Chalk River with their British and Canadian counterparts, September 29/30, 1949. At that meeting, it was agreed to reduce the then existing whole body dose limit of 0.1 r/day by a factor of about 2, and to express it as a weekly limit of 0.3 r/week, which was re-affirmed by NCRP Report 17 (Handbook 59), "Permissible Dose From External Sources of Ionizing Radiation," September 24, 1954. However, in an insert to accompany Handbook 59, dated January 8, 1957, and an Addendum dated April 15, 1958, the NCRP introduced the concept of limiting cumulative career dose, in effect a limit on average annual dose, set at 5 rems/year. This is the current NCRP recommendations, reaffirmed in NCRP Report No. 39, "Basic Radiation Protection Criteria", January 15, 1971.

Enclosure "A"

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
0.001	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		[a] 10	[a] 30

[a] Suggested limit.

9-32 73-131

ENCLOSURE "B"

TABLE 2-Mean quality factors, $\overline{QF}$,[a] and values of neutron flux density which, in a period of 40 hours, results in a maximum dose equivalent of 100 mrem.

Neutron Energy	$\overline{QF}$	Neutron Flux Density
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.

ORIGIN OF CURRENT NRC LIMITS

The principal provisions of the Commission's radiation protection regulations are contained in 10 CFR Part 20, "Standards for Protection Against Radiation".

The Commission implemented the recommendations in NCRP Report 17 (Handbook 59) and NCRP Report 20 (Handbook 63) by including exactly the NCRP values for QF and neutron flux in §20.4(d), see Enclosure "C", and incorporating the new NCRP whole body dose recommendations in §20.101 (a) and (b), see Enclosure "D", both published in effective form on September 9, 1960. The regulations have not been amended to incorporate the current NCRP neutron flux values published in NCRP Report No. 38.

ENCLOSURE "C"

NEUTRON FLUX DOSE EQUIVALENTS

Neutron energy (Mev)	Number of neutrons per square centimeter equivalent to a dose of 1 rem (neutrons/cm^2)	Average flux to deliver 100 millirem in 40 hours (neutrons/cm^2 per sec)
Thermal........................	970×10^6	670
0.0001........................	720×10^6	500
0.005........................	820×10^6	570
0.02........................	400×10^6	280
0.1........................	120×10^6	80
0.5........................	43×10^6	30
1.0........................	26×10^6	18
2.5........................	29×10^6	20
5.0........................	26×10^6	18
7.5........................	24×10^6	17
10........................	24×10^6	17
10 to 30........................	14×10^6	10

73-134

ENCLOSURE "D"

§20.101 Exposure of individuals to radiation in restricted areas.

(a) Except as provided in paragraph (b) of this section, no licensee shall possess, use, or transfer licensed material in such a manner as to cause any individual in a restricted area to receive in any period of one calendar quarter from radioactive material and other sources of radiation in the licensee's possession a dose in excess of the limits specified in the following table:

Rems per calendar quarter

1. Whole body; head and trunk; active blood-forming organs; lens of eyes; or gonads..............................1-1/4
2. Hands and forearms; feet and ankles..........18-3/4
3. Skin of whole body,...........................7-1/2

(b) A licensee may permit an individual in a restricted area to receive a dose to the whole body greater than that permitted under paragraph (a) of this section, provided:

(1) During any calendar quarter the dose to the whole body from radioactive material and other sources of radiation in the licensee's possession shall not exceed 3 rems; and

(2) The dose to the whole body; when added to the accumulated occupational dose to the whole body, shall not exceed 5 (N-18) rems

73 135

where "N" equals the individual's age in years at his last birthday; and

(3) The licensee has determined the individual's accumulated occupational dose to the whole body on Form AEC-4, or on a clear and legible record containing all the information required in that form; and has otherwise compplied with the requirements of §20.102. As used in paragraph (b), "Dose to the whole body" shall be deemed to include any dose to the whole body, gonads, active bloodforming organs, head and trunk, or lens of eye.

PRELIMINARY ANALYSIS OF ROSSI'S PRESENTATION

REGARDING THE RISKS OF NEUTRON RADIATION EXPOSURE

Dr. Rossi shows in his paper(1) and in his talk that the incidence of leukemia in Hiroshima appears to be linear with dose to bone marrow (as now re-calculated as described in another paper by Jones(2)) and most of the incidence of leukemia at Hiroshima can be accounted for by the higher biological effectiveness of the neutron exposure component. On the other hand, he points out that the (excess) leukemias in Nagasaki were almost entirely due to gamma radiation, with a negligible neutron component. A particular non-parametric statistical analysis published by Kellerer and Rossi shows (according to Rossi) that the incidence of leukemia in Nagasaki is more likely to be a quadratic rather than linear relationship, resulting primarily from gamma exposure.

An initial examination of Rossi's paper indicates that the resulting risk estimates for neutron irradiation as based on present methods of measuring neutron exposure and leukemia incidence would not be much

(1) Harald H. Rossi, "The Effects of Small Doses of Ionizing Radiation: Fundamental Biophysical Characteristics" presented at the joint annual meeting of the Health Physics Society/Radiation Research Society, San Francisco, June 29, 1976.

(2) T. D. Jones, "Radiation Insult to the Active Bone Marrow as Predicted by a Method of CHORD'S," Oak Ridge National Laboratory Report ORNL-TM-5337, 1976.

different than originally estimated 20 or more years ago when the occupational exposure limits were established, when proper correction is made for the average depth in bone marrow at which dose is defined. This impression is obtained from the following calculations. According to Rossi's own equations given in his preprint, but not presented in his verbal paper, the neutron and gamma-related leukemia incidence rates obtained from the Hiroshima and Nagasaki data are fitted by Equations (1) and (2), respectively:

$$R = 3 \times 10^{-5} D_{n}, \tag{1}$$

where R is the average number of leukemia cases per person-year,* and D_n is in rads to the bone marrow calculated as in the more recent sophisticated computer program.[2,3] For gamma radiation Rossi fits the following relationship to the data:

---

(3) G. D. Kerr and T. D. Jones, A Reanalysis of Leukemia Data on Atomic Bomb Survivors Based on Estimates of Absorbed Dose to Bone Marrow (Health Physics Division, Oak Ridge National Laboratory, Oak Ridge, TN 37830), presented at the Twenty-First Annual Meeting of the Health Physics Society, July 1, 1976.

*The unit cases per person-year for R is used to mean that the coefficient ($3 \times 10^{-5} \frac{\text{cases}}{\text{person-yr-rad}}$) is to be multiplied by dose. To obtain the total number of cases, R would be multiplied by the number of persons exposed, and by the average number of years at risk after exposure. To obtain the average incidence of cases/year, R would be multiplied by the dose and the population size.

$$R = 1.8 \times 10^{-8} D_{\gamma}^{2}, \qquad (2)$$

where D_{γ} is the gamma dose at the mean bone marrow depth in rads.

If one assumes a quality factor of 10 for neutrons for occupational exposure, as assumed in the NCRP standards that are incorporated in 10 CFR 20 (the former Handbook 63 values), one should use a factor of 3×10^{-6} (cases per person-rem-year at risk) as a risk factor in the first equation (1), if D_n were to be expressed in rem, since the risk is fixed by the actual observed cases of leukemia. This factor of 3×10^{-6} is not very different from the old factors of 1 to 2×10^{-6}/person-rem-year (PRY)*[(4),(5),(6),(7)] after exposure that we have used for about 20 years, since the rise in leukemia at Hiroshima and Nagasaki was first published in Science in 1958. This is particularly true since Rossi has used dose estimates at a bone marrow depth that includes recent calculations of attenuation showing that the dose at the average bone depth is 1/4 of that near the surface of the

---

* PRY means the risk factor must be multiplied by the population size exposed times the single dose in rem times the "years-at-risk" over which the given disease may appear after the exposures (and following the latent period), in order to obtain the total number of observed cases of leukemia (in excess of those naturally occuring).

(4) The Biological Effects of Atomic Radiation NAS-NRC Summary Reports (1960)

(5) United Nations Scientific Committee on the Effects of Atomic Radiation. Report. General Assembly, 19th Session.Supplement No. 14 (A/5814), p.85, 1974

(6) International Commission on Radiological Protection. Publication 14. Radiosensitivity and Spatial Distribution of Dose, Oxford, Pergamon Press, 1969.

(7) The Effects on Populations of Exposure to Low Levels of Ionizing Radiation, BEIR Report, NAS-NRC, (Nov. 1972).

body, and also about 1/4 of the neutron karma to a small volume of tissue in free air. With this factor of 4 incorporated in the denominator of the risk estimate obtained from the epidemiologic data, it is no wonder that the risk factor in Equation (1) is somewhat higher than it used to be. The exact derivation of Rossi's risk estimates thus bears further investigation.

If we use the gamma dose at Nagasaki from the highest group (where most of the earlier cases occurred), say about 100 rads, then the gamma risk would also come out consistent with about a 2×10^{-6} risk factor applied under the "linearity" assumption (with a D instead of D^2 dependence). Animal and micro-dosimetric data may show that the neutron response is more likely linear and that the gamma response is probably curvilinear, and that the conclusions are probably well-founded regarding the increase of RBE up to 100 or more as doses decrease to about 0.5 rad or below for neutrons. On the other hand, this increasing RBE at lower neutron doses may be due to a comparison of the neutron risk with the much more rapidly reduced risk as gamma exposures are lowered, rather than a risk of neutron exposures higher than had previously been assumed. This is another question that should be further investigated and clarified.

ALTERNATIVE ACTIONS

1. Do nothing.

2. Wait for NCRP action to determine what action NRC should take.

3. Accept new analysis and issue a Rule Change.

4. Reject new analysis as not valid.

5. Publish a Notice of Consideration of Rule Change and solicit comments.

6. Initiate a thorough review, soliciting comments and discussion from others in the scientific community to arrive at a valid decision, and recommended action.

PRELIMINARY VALUE/IMPACT APPRAISAL

The Nuclear Regulatory Commission as an independant agency should keep abreast of current developments in the nuclear area, develop its own independent judgments, and take action accordingly. This being the case, Alternatives 1 and 2 should not be considered as potential solutions. Due to the complexity, limited time allowable, and the lack of sufficient confirmed information, it is not possible to make a valid scientific decision to accept or reject the new analysis at this time. Thus, Alternatives 3 and 4 should be eliminated from further consideration. The task group is unanimous that additional information must be gathered, reviewed, and discussions held with others in the scientific community to arrive at a valid decision and to be able to recommend action. Since a decision cannot be made at this time, it is considered unwise to issue a public Notice of Consideration of Rule Change as this could create concern which might prove to be unwarranted. Thus, Alternative 6 is considered as the only viable alternative until a thorough review can be completed.

A thorough review and analysis is necessary to assure that valid occupational radiation protection limits exist to protect workers and the public. Although definitive data are not available it is estimated that there may be about 3000 workers in licensees' facilities receiving some neutron exposure, and the number of occupationally exposed individuals in activities not licensed by NRC, but which have chosen to follow NRC regulations for purposes of radiation protection may exceed 30,000 individuals.

It is not intended to fully assess the impact of decreasing the allowable neutron exposure unless it is shown that a reduction is warranted.

73-143

RECOMMENDATION

The Neutron Quality Factor Task Group recommends that Alternative 6 be selected as appropriate action. Due to the complexity of the review, the following method would ensure thoroughness and reduce the commitment of resources needed to accomplish the task: assign an individual full time to the review and use the Task Group as a review committee to assure that technical questions/challenges would not be overlooked. It is tentatively estimated that such a review could require 6 months and that travel and use of consultants may be required.

ACTIVITIES UNDER NRC JURISDICTION

Type of Facility		# of Persons Under NRC Jurisdiction With Potential Neutron Exposure	
Cf^{252} (Hosp. & Res. & Schools) (not counting negligible exposure to students)[1]		400	
Research Reactors[2]	39 @ 15 people ea.	585	
Oil Well logging[3]		200	Assuming lic sources are then personn exposure is in NRC juriscion.
Accelerators[4]	81 @ 10 people ea.	810	
Fuel Fab and Reprocessing[5]		750	
Total number of persons with potential neutron exposure under NRC jurisdiction.		2745 ≈ 3000	

ACTIVITIES NOT UNDER NRC JURISDICTION

Activity	# of Persons with Potential Neutron Exposure	
ERDA[6]		
Reactor	2730	
Fuel Fab (~1/4 of total monitored)	250	
Fuel Processing (~1/2 of total monitored)	750	
Accelerators	2382	
Weapons	7846	
Irradiation Facilities	24	
	13982 ≈ 14000	
DOD[7] (Facilities not under NRC license)		
Army	500	
Navy	12000	
Air Force	1500	
	14000	= 1400
Total not under NRC Jurisdiction		= 2800

Total Number of Persons with Potential Neutron Exposure 3100

73-145

9-52

1. This estimate was obtained from the Demonstration Centers in Louisiana and San Diego, California. Each center estimated 100-300 individuals receiving neutron exposure from Cf^{252}. Therefore, the median estimate from each center was 200 individuals.

2. There are 70 research reactors in the United States. It is estimated that 39 of them have either neutron beams or thermal columns. Further, it is assumed that there may be 15 people occupationally exposed due to their work, or their research. Although there are 54 power reactors, 11 experimental reactors, 6 critical assemblies, 2 test reactors and 19 DOD reactors reviewed by NRC, it is assumed that neutron exposure would be minimal even though some occupationally exposed personnel may enter containment during operations.

3. This estimate was obtained from the Radioisotopes Licensing Branch.

4. In 1964 there were 224 accelerators in the U.S. The estimate is based on the fact that some accelerators have ceased operation and others have been built; therefore, it is assumed that at least 81 are in existence that can produce neutron exposure. Further, it is assumed that there are 10 operators and/or experimenters per machine that could be receiving some neutron exposure through the shielding.

5. In 1975 there were 5602 people that received measurable occupational exposure in these facilities. Currently there are probably less than 150 that receive neutron exposure as there is only one plutonium facility active. The estimate of 750 is based on the assumption that other licensees may again become active.

6. This information was supplied by the Health Protection Branch, Division of Safety, Standards and Compliance, and represents personnel with measurable exposure, some of which was assumed to be neutron.

7. Estimated numbers: Does not include any reactor exposure.

73 146

REACTORS

14 reactor facilities reported terminations with the personnel exposures shown by type of radiation.

207 people had neutron exposure.

If the quality factor were raised by a factor of ten, then the personnel exposure would be higher by a factor of ten and 6 people would have had a quarterly exposure to neutrons of:

3.1 Rem
4.05 Rem
5.2 Rem
7.4 Rem
10.0 Rem
10.5 Rem

FUEL FABRICATION

5 facilities reported terminations with the exposures shown by type of radiation.

114 people terminated had only neutron exposure.

Total number terminated by the 5 facilities was 143 people.

If the quality factor were raised by a factor of ten, then the personnel exposure would be higher by a factor of ten and 20 people would have had annual exposures to neutrons of:

5.86 Rem	9.88 Rem
6.69 Rem	10.5 Rem
7.32 Rem	10.81 Rem
8.70 Rem	11.06 Rem
9.04 Rem	12.46 Rem
9.13 Rem	12.61 Rem
9.14 Rem	13.72 Rem
9.20 Rem	19.20 Rem
9.51 Rem	22.35 Rem
9.78 Rem	22.40 Rem