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"PERMISSIBLE LIMITS FOR REACTOR COOLING WATER
 ASSIMILATED BY HUMANS"

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5/28/93

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PERMISSIBLE LIMITS FOR REACTOR COOLING WATER
 ASSIMILATED BY HUMANS

ABSTRACT

A permissible limit for the release of waste cooling water from the Hanford reactors into the Columbia River must be determined not only from the effect on humans of assimilation of the radioactive isotopes in the water, but also from the effects of temperature, submersion dose, and metabolism of radioisotopes on fish and other aquatic life in the river, and of concentration in plants of the radioisotopes in irrigation water from the river, with eventual consequences to humans. This report derives permissible limits for human assimilation.

When measured as the total activity density of beta-gamma emitters in bioassay, air, or water samples, the corresponding maximum permissible amount in the human body and maximum permissible concentrations in breathing air and drinking water of the mixture of radioisotopes found in reactor cooling water are recommended as follows:

Exposure

Maximum Permissible Limits in
 Body Air Water
 mc mc/cc mc/cc

~~Intermittent~~ Plant Workers

2.5 1.5 x 10⁻⁶ 5 x 10⁻²

Continuous "Public" Public

2.5 affecting 5 x 10⁻⁷ 1.5 x 10⁻²

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PERMISSIBLE LIMITS FOR REACTOR COOLING WATER
ASSIMILATED BY HUMANSIntroduction

in a review of the problem of setting permissible limits for release of reactor effluent to the Columbia River, (1) H. M. Parker expresses the present opinion that "there may be two sets of testing criteria - one applicable to river water as it leaves the reservation and governed mainly by the content of long-lived activities, - the other applicable to local conditions around the injection points in the river, and governed mainly by immersion dose-rate or gross activity density at release. We believe that the first set of criteria are applicable today."

The recommendations of that report were adopted as an operating standard (2); to continue monitoring the gross radioactivity of the cooling water before its release to the river, determining the ratio and the total of the beta and gamma immersion dose rates. If either exceeds specified limits, to take water samples for radiochemical analysis and comparison with limits based on effects of the individual radioisotopes on humans and aquatic life.

Since that report, the National Committee on Radiation Protection has released recommendations (3) for permissible limits of radioisotopes assimilated by humans, and suggested a method for calculating the permissible limits for a mixture of radioisotopes (Appendix A). By this method, permissible limits for the radioisotopes in reactor cooling water have been calculated and the effects of variations due to seasonal changes in the incoming river water, the water treatment, increasing power levels, radioactive decay, and dilution after the cooling water re-enters the river, have been evaluated.

Most of the limits for the individual radioisotopes are as recommended by the National Committee on Radiation Protection; the sources of the others are noted in Table I. Radioisotopic concentrations are according to published (4,5) and unpublished results of radiochemical analyses by the Control Unit, Radiological Sciences Department, over many months of reactor operation.

The permissible limits given in this report have been derived on the basis of continuous exposures for a lifetime, or for the equilibrium condition in which the rate of elimination has become equal to the rate of deposition in the body. In the case of occupational exposure of 8 hours per day (assuming half the daily consumption of air and water in the 8-hour work period), 5 days per week, and 49 weeks per year (considering time out for vacations, holidays, etc.), the values of maximum permissible concentrations in air and water in the working area may be increased by a factor of 3 above the values for continuous exposure (3). The permissible amount in the body may not be so increased, since there is no interruption of exposure from radioisotopes deposited internally.

The limits for the public are to be applied to other "non-radiation" workers at Hanford, including major construction, collateral contractor, U.S. Geological Survey, U.S. Public Health, and military personnel. Visitors, whether occupationally engaged in radiation work or not, may be permitted exposure up to the occupational limits under radiation protection controls comparable to those for occupational workers at Hanford.

In setting limits for the radioactivity of reactor cooling water released to the Columbia River, the permissible limits for human assimilation should be compared with limits derived for effects such as the following:

1. Mortality of commercial and game fish receiving whole body exposure to radiation, maximum at the discharge end of the pipe in the river.
2. Disruption of biological chains among the aquatic life caused by increased water temperatures.
3. Consumption by humans, and mortality, of fish and other aquatic organisms which metabolically concentrate radioisotopes from the water.
4. Consumption by humans, and productivity, of plants irrigated by river water, and domestic animals feeding on the plants⁽⁶⁾.

There are several factors which may cause the permissible limits for reactor cooling water to vary. In Table II permissible limits for human assimilation are calculated for the average analysis of the water over the entire year 1951. Seasonal variations are observed⁽⁵⁾ in the amounts of manganese, silicon and arsenic in the water. The use of aluminum sulfate instead of ferric sulfate in water pre-treatment causes an increase in manganese and a decrease in copper; chlorination affects the manganese content, as does a manganese impurity in the lime used after coagulation treatment. Increased power levels of the reactors may indicate a trend to decreased percentage of manganese and a corresponding increase in percentage of fission products.

Significant and most predictable is the effect of radioactive decay on the permissible limits. As the shorter-lived isotopes decay away, the permissible limits for the mixture shift toward the permissible limits for the longer-lived isotopes, which are most restrictive for those isotopes with half-lives in the range of 5 to 50 years.

Dilution of the cooling water by unirradiated river water has no effect on the permissible limits, since the ~~relative percentages of the radioisotopes remain the same~~, but it is a means of reducing the activity density to less than the permissible limits. Dilution may be more than offset, however, by concentration in aquatic organisms and silt⁽⁷⁾. It has been suggested that if concentration is the limiting factor, then isotopic dilution -- adding relatively large amounts of stable, non-radioactive isotopes -- may minimize the amount of radioisotopes concentrated.

A factor not further analyzed in this report, but which must not be overlooked when setting permissible limits for water taken from wells replenished by the Columbia River, is the effect of selective sorption of radioisotopes by soil on the percentage composition and gross activity density of radioactive materials in the water. A similar effect occurs when the water, after irradiation, is treated by settling, flocculation, filtration, and chlorination to prepare it for the sanitary water system and human consumption.

In the following pages, permissible limits for an average annual cycle are calculated, and the effect of the variables described above are evaluated.

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Permissible Limits Based on Period Of December 1950 Through December 1951

Analysis of cooling water from 100-B, D, DR, F, and H reactors during the above period, when power levels were reasonably constant and the seasonal variations spanned the entire cycle, were reported by E. E. Larkin in private communication, agreeing generally with references (4) and (5), but including much more detailed breakdown. The isotopes and their fractions in the total activity density of the reactor cooling water four hours after discharge from the pile are given in Table I. The permissible limits for each critical organ are summarized below, and the permissible limits for the mixture are indicated by the word "least".

Critical Organ	MPL		
	Body - μ c	Air* - μ c/cc	Water - μ c/cc
Kidney	7.4 (least)	5.1×10^{-7}	.048
Liver	78.5	8.1×10^{-7}	.044
Blood	91.	1.17×10^{-7}	.049
Thyroid	90.	1.1×10^{-7}	.028
Whole Body	91.	1.26×10^{-7}	.052
Bone	42.	7.5×10^{-7} (least)	.019 (least)

* It should be noted that the permissible concentrations in air derived in this report for reactor cooling water may not be the permissible concentration for "effluent vapors" arising from the water, since it is believed that not all radioisotopes in the water appear in the vapors.

Effect of Variation of Manganese⁵⁶

The percentage of manganese in reactor cooling water has been published as varying between 14% and 56% (4). Analyses as recent as April 1953 indicate that 75% may be about the maximum. Inspection of Table II shows that the critical organ for manganese is the kidney, which also sets the permissible limit for the body.

If the manganese is found by analysis to be 60% of the total activity and the percent of other kidney-critical isotopes is assumed unchanged from the Table II values, then the maximum permissible limits, compared to the 1951 average, will be:

	MPL in:	Body μ c	Air μ c/cc	Water μ c/cc
60% Mn		3.2	3.6×10^{-6}	.043
1951 Average		7.4	7.5×10^{-7}	.019

This shows that the permissible limits for air and water for the total activity in reactor cooling water will not be affected by changes in manganese⁵⁶ content, but the body permissible limit is very significantly dependent on the manganese. If the manganese reaches 75% of the total, and the other five isotopes critical in the kidney are adjusted to reasonable values, the body permissible limit will decrease further, to 2.6 μ c. If 100% of the activity were due to manganese, the limit would be 2 μ c. It appears that a reasonable permissible limit for the radioisotopes of reactor cooling water in the body might be 2.5 μ c.

Effect of Variation of Arsenic, Copper, Silicon or Sodium

The critical organ for arsenic is the kidney and for copper the liver, while sodium and silicon are distributed rather uniformly throughout the whole body and must be considered in the calculation of permissible limits for each critical organ. Arsenic⁷⁶ may vary from the average of 2% up to about 6%, but such variation will have negligible effects on permissible limits. Copper⁶⁴ may vary from the average of 22% up to 50% of the total activity, but since it is unlikely that the liver will ever be the "most critical" organ, the effect of increased percentage of copper is to decrease the percentage of other isotopes which makes all other permissible limits less restrictive.

The large permissible limits for the silicon³¹ isotope cause it to have little effect on permissible limits for the mixture of radioisotopes in reactor cooling water, even though its concentration may increase from the average of 6.4% up to the observed maximum of 9.5%.

Sodium²⁴ however is a significant constituent in the radioisotopes seeking the critical organ, bone. It has been observed to vary from the average of 15.2% up to 26% of the total activity. Bone sets the air and water permissible limits for reactor cooling water, essentially unapproached by the limits for other organs. Assuming that the percentages of other radioisotopes listed under "bone" in Table II are unchanged, increasing the Na²⁴ content to 26% has the following effect on permissible limits for reactor cooling water:

MPL in:	Body mc	Air mc/cc	Water mc/cc
26% Na ²⁴	31	7.7×10^{-7}	.0156
1951 Average	42	7.5×10^{-7}	.019

~~The water limit is the most restrictive of any calculated, and setting the~~
~~limit at 1.5 x 10⁻² is recommended.~~
 The water limit is the most restrictive of any calculated, and setting the
 limit at 1.5×10^{-2} is recommended.
 n/c

Effect of Higher Reactor Power Levels

It was noted previously that higher power levels of the Hanford reactors may cause a decrease in manganese and an increase in fission product concentrations, although experimental evidence is as yet scanty and inconclusive. The previous discussion of the effect of variation of Mn⁵⁰ shows that decreasing the manganese makes the body permissible limit for the mixture of radioisotopes in reactor cooling water less restrictive.

The range of uranium fission products includes all isotopes of elements from atomic numbers 30 to 64. Of those radioisotopes, in reactor cooling water, these are included: As⁷⁶, Sr⁸⁹, Sr⁹⁰, Sr⁹¹, Sr⁹², Y⁹⁰, Y⁹¹, Y⁹², Y⁹³, Mo⁹⁹, I¹³¹, Te¹³², Ba¹³⁹, Ba¹⁴⁰, La¹⁴⁰, La¹⁴¹, Ce¹⁴¹, Ce¹⁴³, Pr¹⁴², Pr¹⁴³, Pr¹⁴⁵, Pr¹⁴⁶, Pm¹⁴⁹.

As⁷⁶ and Te¹³² are among those which set the body permissible limit, but even if the average percentage for each was five times as great, they would have negligible effect on the limit.

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Taking a value of 0.01 $\mu\text{c/cc}$ as the permissible limit for drinking the reactor cooling water, the IBI would have to increase more than four times as much as the 1951 average of 0.004 to control the permissible limit. Examination of analytical data indicates that IBI will probably never exceed twice the 1951 average.

The remainder of the radioisotopes listed above are critical in the bone. They may come from neutron irradiation of stable isotopes in the water entering the reactor or from fission of uranium present naturally in the entering water, as contamination on slugs loaded into the reactor, or from the slug material itself escaping from ruptured slugs into the cooling water system. In Table II, these isotopes are 12.7% of the total activity. The analytical data indicates that they will probably not exceed 15% of the total, but if they should reach 20%, each increasing proportionally and all other isotopes listed under "bone" in Table II remain the same, then the permissible limits would be:

MPL in:	Air	Water
	$6 \times 10^{-7} \mu\text{c/cc}$	.016 $\mu\text{c/cc}$

Effect of Radioactive Decay

The permissible limits for reactor cooling water in the Columbia River are dependent upon the point where water is subsequently withdrawn from the river for human consumption. There is public access to the river along the east shore as far up as Ringold, although large quantities are first withdrawn at the Pasco irrigation pumping station just above 300 Area. The city of Richland is six miles below the pumping station, and Pasco and Kennewick are about twelve miles further downstream.

As mentioned previously, the effect of radioactive decay over a long period is to shift the permissible limits for a mixture of radioisotopes toward the permissible limits for the longer-lived isotopes. However, for short intervals in a long decay period the limits may temporarily increase, as some of the less hazardous, intermediate half-life radioisotopes dominate the mixture.

At Ringold, water from the reactor furthest upstream is found to have more restrictive limits than that from any reactor closer to Ringold. Decay time depends on hold-up in the retention basin and velocity in the river. In the Columbia River Survey (8), the fastest velocity observed was 5.9 MPH, and the slowest (mean of the whole cross-section of the river) was 2.2 MPH.

With only two hours hold-up time in the retention basin the fastest flow rate results in a decay time from the reactor furthest upstream to Ringold totaling four hours, corresponding to that for the 1951 average, and the slowest flow rate gives a decay time of 14.3 hours. During these periods the critical manganese decays and the body permissible limit shifts toward the sodium²⁴ limit. For the longer period, the air limit changes little, but the water limit becomes less restrictive.

However, in case the fission product component is unusually high, as might be caused by higher power levels, the air and water limits are more restrictive than the 1951 average. In fact, the air limit becomes the most restrictive of any calculated when the decay time to Ringold is 6.1 hours. Downstream from Ringold the limits become less restrictive, until at the mouth of the Columbia River where it enters the Pacific Ocean (the last point of public consumption) the limits are as shown in the following table:

	MPL in:	Body μc	Air $\mu\text{c/cc}$	Water $\mu\text{c/cc}$
4	Hour Decay (1951 Average)	7.4	7.5×10^{-7}	.019
14.3	Hour Decay	---	7.4×10^{-7}	.024
4	Hour Decay (20% FP)	---	6.0×10^{-7}	.016
6.1	Hour Decay (20% FP)	12.2	5.0×10^{-7}	.016
14.3	Hour Decay (20% FP)	---	5.3×10^{-7}	.019
130	Hour Decay	4.1	9.7×10^{-7}	.035

If the total beta-gamma activity density of the reactor cooling water is measured less than 4 hours after the water leaves the reactor, the short-lived radioisotopes may cause a higher total than that which should be compared to the permissible limits. It is therefore advisable to make the count, or a re-count, at least 4 hours and not more than 130 hours after the water left the reactor.

Effect of River Dilution

Excellent data on river dilution and decay is contained in the Columbia River Survey report⁽³⁾. The overall decrease in the activity of water from the time it leaves the retention basins until it reaches various points downstream is shown by the following table:

Date	Av. activity entering river - $\mu\text{c/cc}$	Mean Activity $\mu\text{c/cc}$ at	Decrease Factor
4-2-51	914×10^{-6}	2.4×10^{-6} Hanford	380
4-17-51	589×10^{-6}	1.1×10^{-6} Pasco	525
5-21-51	1395×10^{-6}	1.3×10^{-6} 500' below 100-F	1069
6-5-51	716×10^{-6}	$.85 \times 10^{-6}$ Richland	842

That part of the ³⁸⁰ "decrease factor" which is due to decay from the time the water leaves each basin until the composite mixture reaches Hanford calculates to about 0.5, which means that 379.5 is due to dilution (minor amounts may be removed by aquatic organisms or sorption on the river bed).

On such evidence, a dilution factor of 500 has been accepted as a rough working value, at least in that part of the river from Hanford to below Pasco.

For comparison, Davis and Cooper⁽⁷⁾ report the following conservative data on concentration of radioactive materials from the river by aquatic organisms:

<u>Organism</u>	<u>Concentration Factor</u>
Hydrobaeninae larvae	2300
Tendipedinae larvae	1700
Hydroptila argosa larvae	1700
Paroloes americana nymphs	1600
Spongilla lacustris	1500
Paraleptophlebia bicornuta nymphs	1300
Hydropsyche cockerelli larvae	1100
Brachycentrus occidentalis larvae	900
Fisherola nuttalli	400
Stagnicola apicina	300

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Conclusions

Because of differences in power level, water treatment, and corrosion products, the activity density of each radioisotope in the river water may depend upon which of the several reactors are operating at a given time. The effect on the permissible limits for human assimilation almost without exception should be negligible, since many radioisotopes do not influence the limits, and the limits recommended are the most restrictive expected for normal operation. See Table III for effect of variables.

Despite the fact that at least 32 radioisotopes can be identified, the summary in Table IV shows that only 12 are significant in establishing the permissible limits. Continuously monitoring the gross emission from reactor cooling water by ionization chamber will give valuable information about large changes in radiation levels, but will not detect changes in the activity densities of individual radioisotopes which, as one rises and another falls, results in no change of gross emission. Periodic or continuous isotopic analysis is necessary to detect changes significant with respect to the permissible limits. As shown in Table IV, manganese⁵⁶ is one of the most important radioisotopes, and it might be practical to install continuous monitoring equipment to determine manganese concentration by means such as automatic, photo-electric titration. Periodic radiochemical analysis for only ~~some~~ other radioisotopes -- Na²⁴, P³², Ca⁴⁴, Sr⁹⁰, Y⁹⁰, Ba¹⁴⁰, and La¹⁴⁰ -- would permit an excellent accounting of the hazard to humans of assimilating the water.

For comparison with the total activity density of beta and gamma emission from the mixture of radioisotopes present in reactor cooling water (excepting abnormal amounts of fission products from ruptured slugs), more than 4 hours after the water left the reactor, the following permissible limits for human assimilation are recommended:

Exposure	Maximum Permissible Limits in		
	Body μc	Air μc/cc	Water μc/cc
Intermittent, "occupational"	2.5	1.5×10^{-6}	5×10^{-2}
Continuous, "public"	2.5	5×10^{-7}	1.5×10^{-2}

For comparison with these permissible limits, the average activity density of reactor cooling water, decayed 4 hours, in 1951 was 2×10^{-3} μc/cc, and at present is about 4×10^{-3} μc/cc. River water, sampled routinely about 5 miles upstream from Ringold averaged 1.3×10^{-6} μc/cc in July of 1951, 5.9×10^{-6} μc/cc in February of 1952(10), and is now about 11×10^{-6} μc/cc. These are well below the respective "occupational" and "public" limits for drinking.

TABLE T

Radiol isotopes in Reactor Cooling Water, 4 Hours after Discharge from Reactor

1. Total specific activity, beta-gamma emitters 2×10^{-3} μ c/cc

2. Radiol isotopes	Percent of Activity Density	Half Life	λ_{eff} Avg. Energy MeV	Critical Organ	MPL Ref. Doc.
Cu ⁶⁴	27.2	12.7 h	0.11	Liver	3
Mn ⁵⁶	24.3	2.59 h	1.1	Kidney	3
Na ²⁴	15.2	14.9 h	2.7	Whole Body	3
Rare Earths & Y(a)	10.	10% initial 60 h later	(See Breakdown below)		
Si ³¹	4.4	170 m	0.72	Whole Body	9
As ⁷⁶	2. (d)	26.8 h	1.1	Kidney	3
Fa ¹³⁹	1.8	85 m	0.84	Bone	3(f)
Sr ⁹¹ & Sr ⁹² (b)	.85	9.7h - 2.7h	1.8 - 2.9(e)	Bone	3(f)
Cr ⁵¹	.6	26 d	0.01	Kidney	3
P ³²	.3(d)	14.1 d	0.68	Bone	3
Mo ⁹⁹	.2	67 h	0.22	Bone	3
I ¹³¹	.05	8 d	0.22	Thyroid	3
Ca ⁴⁵	.03	152 d	0.085	Bone	3
Ba ¹⁴⁰	.02	12.3 d	1.06	Bone	3
Fe ⁵⁹	.01	46 d	0.54	Blood	3
Mn ⁵⁶	.007	26.8 d	0.084	Bone	3
Ta ¹⁸²	.007	67 h	0.90	Kidney	3(f)
Sr ⁹¹ & Sr ⁹² (c)	.002	54d - 26Y	0.55 - 1.0	Bone	3
La ¹⁴⁰	1.0	40 h	.72	Bone	3
Y ⁹⁰	.08	11 h	1.4	Bone	3(f)
Y ⁹²	.05	3.5 h	1.55	Bone	3(f)
La ¹⁴¹	.03	3.7 h	1.1	Bone	3(f)
Ce ¹⁴¹	.03	32 d	.21	Bone	3(f)
Pr ¹⁴²	.01	19.3 h	1.3	Bone	3(f)
Pr ¹⁴³	.08	13.5 d	.31	Bone	3
Ce ¹⁴³	.08	33 h	.54	Bone	3(f)
Y ⁹¹	.08	61 d	.57	Bone	3
Pr ¹⁴⁵	.77	4.6 h	1.25	Bone	3(f)
Pr ¹⁴⁶	.65	25 m	1.1	Bone	3(f)
Pm ¹⁴⁹	.23	55 h	.41	Bone	3(f)
	98.97				

(Rare Earth Breakdown)

- (a) Decay curves indicate Y⁹⁰, if Y significant
(b) Probably in fission ratio; 5.4 Sr⁹¹; 5.8 Sr⁹²
(c) Decay curve indicates Sr⁸⁹ predominant, but ratio insignificant to MPC. Assumed equal.
(d) Seasonal variation; 0.03 to 0.9 for P³²
(e) E_{max} assumed 3.5 MeV
(f) Calculated from basic data in (3).

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TABLE II

CALCULATION OF PERMISSIBLE LIMITS FOR PERIOD DEC. 1950 - DEC. 1951

Isotope in Critical Organ	%	f	MPL _B μc	$\frac{f}{\text{MPL}_B}$	MPL _A μc/cc	$\frac{f}{\text{MPL}_A}$	MPL _W μc/cc	$\frac{f}{\text{MPL}_W}$
<u>KIDNEY</u>								
Mn ⁵⁶	24.3	.5010	2	.2505	3×10^{-6}	167,000	.15	3.33
As ⁷⁶	2.0	.0412	10	.0041	2×10^{-6}	20,600	.2	.206
Cr ⁵¹	.6	.0124	390	.00003	8×10^{-6}	1,550	.5	.025
Na ²⁴	15.2	.3134	15	.0209	2×10^{-6}	156,700	.008	39.2
Te ¹³²	.007	.0001	1	.0001	$.1 \times 10^{-6}$	1,000	.002	.050
Si ³¹	6.4	.1319	76	.0017	30×10^{-6}	4,400	.22	.60
Totals mMPL	48.507	1.0000		.27733 7.43		351,250 5.9×10^{-6}		43.4 .0475
<u>LIVER</u>								
Cu ⁶⁴	27.2	.5574	150	.0037	6×10^{-6}	92,900	.08	6.97
Na ²⁴	15.2	.3115	15	.0207	2×10^{-6}	155,800	.008	38.93
Si ³¹	6.4	.1311	76	.0017	3×10^{-5}	4,400	.22	.60
Totals mMPL	48.8	1.0000		.0261 78.5		253,100 8.1×10^{-6}		46.5 .0441
<u>BLOOD</u>								
Fe ⁵⁹	.01	.0005	11	.00004	1.5×10^{-8}	33,000	.0001	5.
Na ²⁴	15.2	.7034	15	.04659	2×10^{-6}	352,000	.008	87.9
Si ³¹	6.4	.2961	76	.00390	3×10^{-5}	9,900	.22	1.3
Totals mMPL	21.61	1.0000		.05083 91.0		394,900 1.17×10^{-5}		94.2 .0491
<u>THYROID</u>								
I ¹³¹	.05	.0023	.3	.00077	3×10^{-9}	767,000	.00003	76.7
Na ²⁴	15.2	.7021	15.	.04680	2×10^{-6}	351,000	.008	87.8
Si ³¹	6.4	.2956	76.	.00389	3×10^{-5}	9,900	.22	1.3
Totals mMPL	21.65	1.0000		.05146 89.75		1,128,000 4.1×10^{-6}		165.8 .0279
<u>WHOLE BODY</u>								
Na ²⁴	15.2	.7037	15	.0469	2×10^{-6}	352,000	.008	87.96
Si ³¹	6.4	.2963	76	.0039	3×10^{-5}	9,900	.22	1.35
Totals mMPL	21.6	1.0000		.0508 91.1		362,000 1.28×10^{-5}		89.31 .0518

TABLE II (Cont'd.)

Isotope in Critical Organ	%	f	MPLB cc	$\frac{f}{\text{MPLB}}$	MPLA cc/cc	$\frac{f}{\text{MPLA}}$	MPLW cc/cc	$\frac{f}{\text{MPLW}}$
<u>ZONE</u>								
Ne ²⁴	15.2	.4367	15	.0291	2×10^{-6}	218,000	.008	54.6
Si ³¹	6.4	.1839	76	.0024	3×10^{-5}	6,100	.22	.84
Ba ¹³⁹	1.8	.0517	6.6	.0078	1.4×10^{-6}	36,900	.5	.10
Sr ⁹¹ (+Y ⁹¹)	1.29	.0371	43	.00086	1×10^{-5}	3,700	.09	.41
Si ⁹² (+Y ⁹²)	1.39	.0399	27	.0015	2×10^{-5}	2,000	.2	.2
P ³²	.2	.0086	10	.00086	1×10^{-7}	86,000	.0002	43.
Mo ⁹⁹	.2	.0057	50	.00011	2×10^{-3}	3	14.	.0004
Ca ⁴⁵	.03	.00086	65	.00001	3×10^{-8}	38,700	.0005	1.7
Ba ¹⁴⁰ (+La ¹⁴⁰)	1.02	.0293	5	.0059	6×10^{-8}	488,000	.002	14.7
Zn ⁶⁵	.007	.00020	430	.0000005	2×10^{-6}	100	.06	.003
Sr ⁸⁹	.001	.00003	2	.000015	2×10^{-8}	1,500	.00007	.4
Sr ⁹⁰ (+Y ⁹⁰)	.001	.00003	1	.00003	2×10^{-10}	150,000	8×10^{-7}	37.5
Y ⁹³	.98	.0281	6	.0047	2×10^{-6}	14,000	2.	.01
La ¹⁴¹	.93	.0267	16	.0017	7×10^{-7}	38,100	.7	.04
Ce ¹⁴¹	.93	.0267	36	.00074	1×10^{-8}	2,670,000	.07	.4
Pr ¹⁴²	.91	.0261	7	.0037	1×10^{-3}	26 590.		neg.
Pr ¹⁴³	.88	.0253	29	.00087	7.5×10^{-7}	33,700	.4	.06
Ce ¹⁴³	.88	.0253	9	.0028	4×10^{-7}	63,200	2.	.01
Pr ¹⁴⁵	.77	.0221	7	.0032	5×10^{-3}	4 2660.		neg.
Pr ¹⁴⁶	.65	.0187	8	.0023	6×10^{-2}	.3	32,500	neg.
Pm ¹⁴⁹	.23	.0066	55	.00012	6×10^{-6}	1,100	3.3	.002
Totals	34.799	.9996		.0687		3,850,000		154.
mMPL				42.		7.5×10^{-7}		.0187

TABLE III

SUMMARY OF EFFECT OF VARIATIONS ON REACTOR COOLING WATER PERMISSIBLE LIMITS

Case	Effect Of	On	Permissible Limits In		
			Body μc	Air μc/cc	Water μc/cc
1	Annual cycle ("1951 Average")		7.4	7.5×10^{-7}	.019
2	Critical organ - Kidney	1951 Average	7.4	59×10^{-7}	.048
3	Critical organ - Liver	1951 Average	78.5	81×10^{-7}	.044
4	Critical organ - Blood	1951 Average	91.	117×10^{-7}	.049
5	Critical organ - Thyroid	1951 Average	90.	41×10^{-7}	.028
6	Critical organ - Whole Body	1951 Average	91.	128×10^{-7}	.052
7	Critical organ - Bone	1951 Average	42.	7.5×10^{-7}	.019
8	Increasing Mn^{56} from 24.3% to 60%	1951 Average (Kidney)	3.2	36×10^{-7}	.043
9	Increasing Mn^{56} from 24.3% to 75%	1951 Average (Kidney)	2.6	-	-
10	Increasing Mn^{56} from 24.3% to 100%	1951 Average (Kidney)	2.	30×10^{-7}	.15
11	Increase As^{76} from 2% to 6%	1951 Average (Kidney)		Negligible	
12	Increase Cu^{64} from 22% to 50%	1951 Average (Liver)		MPL's less restrictive	
13	Increase Si^{31} from 6.4% to 9.5%	1951 Average (Body)		Negligible	
14	Increase Na^{24} from 15.2% to 24%	1951 Average (Bone)	31	7.7×10^{-7}	.0156
15	Increased Power Level - Mn^{56} decr.	1951 Average		MPL's less restrictive	
16	Increased Power Level - As^{76} incr.	5x1951 Average		Negligible	
17	Increased Power Level - Tl^{132} incr.	5x1951 Average		Negligible	
18	Increased Power Level - I^{131} incr.	4x1951 Average		Thyroid becomes critical for MPL	
19	Increased Power Level - PP incr. from 12.7% to 20%	1951 Average		6.0×10^{-7}	.0159
20	Radioactive Decay - 6.1 hr (at Ringold)	1951 Average (Kidney)	12.2	-	-
21	Radioactive Decay - 6.1 hr (at Ringold) Case 19		-	5.0×10^{-7}	.016
22	Radioactive Decay - 14.3 hr (at Ringold)	1951 Average (Bone)	-	7.4×10^{-7}	.024
23	Radioactive Decay - 130 hr (to ocean)	1951 Average (Kidney)	41.	7.3×10^{-6}	.147
24	Radioactive Decay - 130 hr (to ocean)	1951 Average (Bone)	-	9.7×10^{-7}	.035
25	Radioactive Decay - 14.3 hr (at Ringold) Case 19		-	5.3×10^{-7}	.019

TABLE IV

RADIOISOTOPES ESTABLISHING THE PERMISSIBLE LIMITS

<u>Isotope</u>	<u>Percent of Total Activity Density</u>	<u>Percent of Permissible Limit</u>
(BODY-Case 9)		
Mn ⁵⁶	75	96.8
Na ²⁴	5	.9
As ⁷⁶	3	.8
Cr ⁵¹	0.6	1.5
(WATER-Case 14)		
Na ²⁴	26.	50.11
Ba ¹⁴⁰ + La ¹⁴⁰	1.02	7.9
Ce ¹⁴¹	.93	.2
P ³²	.3	23.2
Ca ⁴⁵	.03	.9
Sr ⁹⁰ + Y ⁹⁰	.001	17.6
(AIR-Case 21)		
Na ²⁴	13.8	3.5
Ba ¹⁴⁰ + La ¹⁴⁰	1.61	13.5
Ce ¹⁴¹	1.46	73.4
Ce ¹⁴³	1.38	1.7
P ³²	.3	1.5
Sr ⁹⁰ + Y ⁹⁰	.0016	4.0

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APPENDIX A

Calculation of Permissible Limits for a Mixture of Radioisotopes

MPL Maximum permissible limit
% Percent of radioisotope in mixture, by analysis
S% Total of %'s of radioisotopes seeking one critical organ
f %/S%, fraction of isotope to all isotopes in one critical organ

Subscripts: B Human Body
A Breathing air
W Drinking water
Prescript: M Mixture of radioisotopes

Method of Calculation:

1. Obtain isotopic analysis of mixture, in percent of activity density, of all radioisotopes present in excess of 0.1%. (^{59}Co , Pb^{210} , Ra^{226} , U and the transuranic isotopes in excess of 0.001% should be included).
2. List all such significant isotopes according to the respective critical organ, together with %, MPLB, MPLA, MPLW, for each isotope.
3. Add %'s to find S% for each critical organ.
4. Calculate f, equals %/S%, for each isotope.
5. Calculate f/MPLB, f/MPLA, f/MPLW for each isotope.
6. Add all f/MPLB's for each critical organ; repeat for f/MPLA, f/MPLW. Call the sums FB, FA, FW.
7. Calculate:
 $m\text{MPL} = 100/(S\%)(F_B)$
 $m\text{MPL} = 100/(S\%)(F_A)$
 $m\text{MPL} = 100/(S\%)(F_W)$
8. The least $m\text{MPLB}$, $m\text{MPLA}$, and $m\text{MPLW}$ for all of the critical organs are the permissible limits for the mixture.

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