Comments from C Burke

File Effluent Tech Specs.

Processing of TMI-2 Accident Liquids To
Meet the 10CFR50 App I Cost-Benefit Criterion

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by

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The provisions of 10CFR50 Appendix I require that radioactive waste treatment systems be designed to keep radiation doses from effluents "as low as reasonably achievable." One criterion which must be met is that processing systems must be designed in such a way that any processing steps which might be added to the system would cost more than $1,000 per person-rem saved. The demonstration that this criterion is met for TMI Units 1 and 2 in normal operation was made in reports filed with NRC in May, 1976. There has been no similar demonstration that this criterion is met for systems being designed to process contaminated liquids related to the TMI-2 accident.

In the on-going discussions related to standard radiological effluent technical specifications, there has been disagreement over a specification designed to assure operational compliance with the ALARA criterion (Tech Spec 3.11.1.3 for liquids and 3.11.2.4 for gases) Unfortunately, the wording of the specification leaves considerable latitude for interpretation and presents implementation difficulties. As a result, an alternative specification has been proposed (Attachment 1). The alternative specification simply requires that waste processing equipment be used if the cost of processing (excluding capital cost) does not exceed $1,000 per person-rem saved.

It may be necessary to demonstrate that the design of the system used to treat TMI-2 accident liquids meets the criterion. A simple method for making this demonstration is illustrated here:

1) Concentrations of isotopes in accident liquids are reasonably well known, and are summarized in Table 1, along with envelope concentrations used for the illustration herein. (Other isotopes were also measured, but these isotopes would not be significant contributors to population dose if system decontamination factors (DF) for these isotopes are similar to DF values for strontium and cesium or if these isotopes are relatively short-lived, such as iodine-131.)

2) The population dose per unit volume of accident liquid is calculated using the methodology in Attachment 2. Results for accident liquid containing the envelope isotope concentrations are shown in Table 2.

3) Residual population dose per unit volume after processing through a system with a specified decontamination factor (DF) is easily calculated from results in Table 2, and is shown as a function of system DF in Table 3.

4) The maximum justifiable cost per unit volume for any additional processing is determined from the residual population dose per unit volume and the $1,000 per person-rem saved criterion. The maximum justifiable cost per unit volume for additional processing is also shown as a function of system DF in Table 3.

5) System DF is plotted against maximum justifiable cost per unit volume for additional processing in Figure 1.

6) Processing options which are candidates for addition to the treatment system (i.e., one more stage of cation exchange, etc.) are reviewed to determine the cost per unit volume of the option with the minimum unit cost option. USNRC Regulatory Guide 1.110 ("Cost-Benefit Analysis for Radwaste System for Light-Water-Cooled Nuclear Power Reactors," March, 1976) can be used as a guide. In general, unit processing costs range from about five to about fifty cents per gallon for different processing options.

7) If one assumes that the candidate process removes most of the residual activity (not a bad assumption if the additional DF exceeds four or five), one can use the cost estimated in step 6 with the curve of system DF versus the justifiable additional processing cost per unit volume (step 5) to determine the minimum system DF required to meet the ALARA criterion.

For the illustration here, it is seen that the system DF must be at least about 50,000, but probably not more than about 500,000 to meet the ALARA criterion if the minimum incremental processing cost is in the range of five to fifty cents per gallon.

In the illustration above, three simplifying assumptions have been made:

1) Envelope concentrations from Table 1 were used. If auxiliary building, primary coolant, and containment sump inventories were considered separately, residual person-rem and justifiable cost of added processing would be lower by a factor of about 2 for primary coolant contents, a factor of 5 for containment sump contents (assuming Sr-89 to Sr-90 activity ratio of 25 to 1) and a factor of at least 12 for auxiliary building contents.

2) Process decontamination factors (DFs) were assumed to be the same for all isotopes. While this is common practice, and may be reasonable in this application, there are differences (See NUREG-0017, Table 1-3, Enclosed here as Attachment 3.) These differences may be accommodated if necessary.

3) It is assumed that the process which is a candidate for addition to the system removes essentially all of the residual radioactivity. To the extent that this assumption is unwarranted, the required system DF obtained using this approach is higher than rigorous analysis would support. That is, the cost-benefit criterion would be met with some margin to spare. If the additional DF exceeds about 4, however, this margin is essentially insignificant.

Table 1

TMI-2 Accident

Liquid Inventories and Isotope Concentrations

	Aux Bldg Tanks (1)	Reactor Coolant (1)	Containment Sump (2)	Envelope Concentration (3)
Volume (gal)	245,000	90,000	540,000	
Concentration µCi/ml				
Sr-89	1 to 50	305 to 330	42 to 45 (Sr-89 + Sr-90)	330
Sr-90	0.04 to 2	17 to 19		45
Cs-134	0.5 to 8	18 to 22	40	40
Cs-137	2 to 35	90 to 110	174 to 179	179

(1) Responses to Susquehanna Valley Alliance Interrogatories 7/20/79

(2) Preliminary analysis 9/5/79

(3) Maximum of concentrations measured in any inventory

Table 2

Maximum Population Dose Per Unit Volume of Accident Liquid*

Population Dose $\left(\frac{\text{person-rem}}{\text{gallon}}\right)$

Isotope	Water Pathway	Fish Pathway	Total
Sr-89	8.85E-1	1.32E-3	8.87E-1
Sr-90	2.06E+1	3.63E-2	2.06E+1
Cs-134	9.33E-1	1.20E-1	1.05E+0
Cs-137	2.46E+0	3.19E-1	2.78E+0
Total	2.49E+1	4.77E-1	2.54E+1

*Doses based on envelope concentrations in Table 1 and methodology from Attachment 2.

Table 3

Maximum Residual Population Dose and Justifiable Additional Processing Cost Versus System DF

System DF	Residual Population Dose (person-rem per gallon) (1)	Justifiable Cost of Additional Processing (cents per gallon) (2)
1E0	2.5E+1	2.5E6
1E1	2.5E+0	2.5E5
1E2	2.5E-1	2.5E4
1E3	2.5E-2	2.5E3
1E4	2.5E-3	2.5E2
1E5	2.5E-4	2.5E1
1E6	2.5E-5	2.5E0
1E7	2.5E-6	2.5E-1

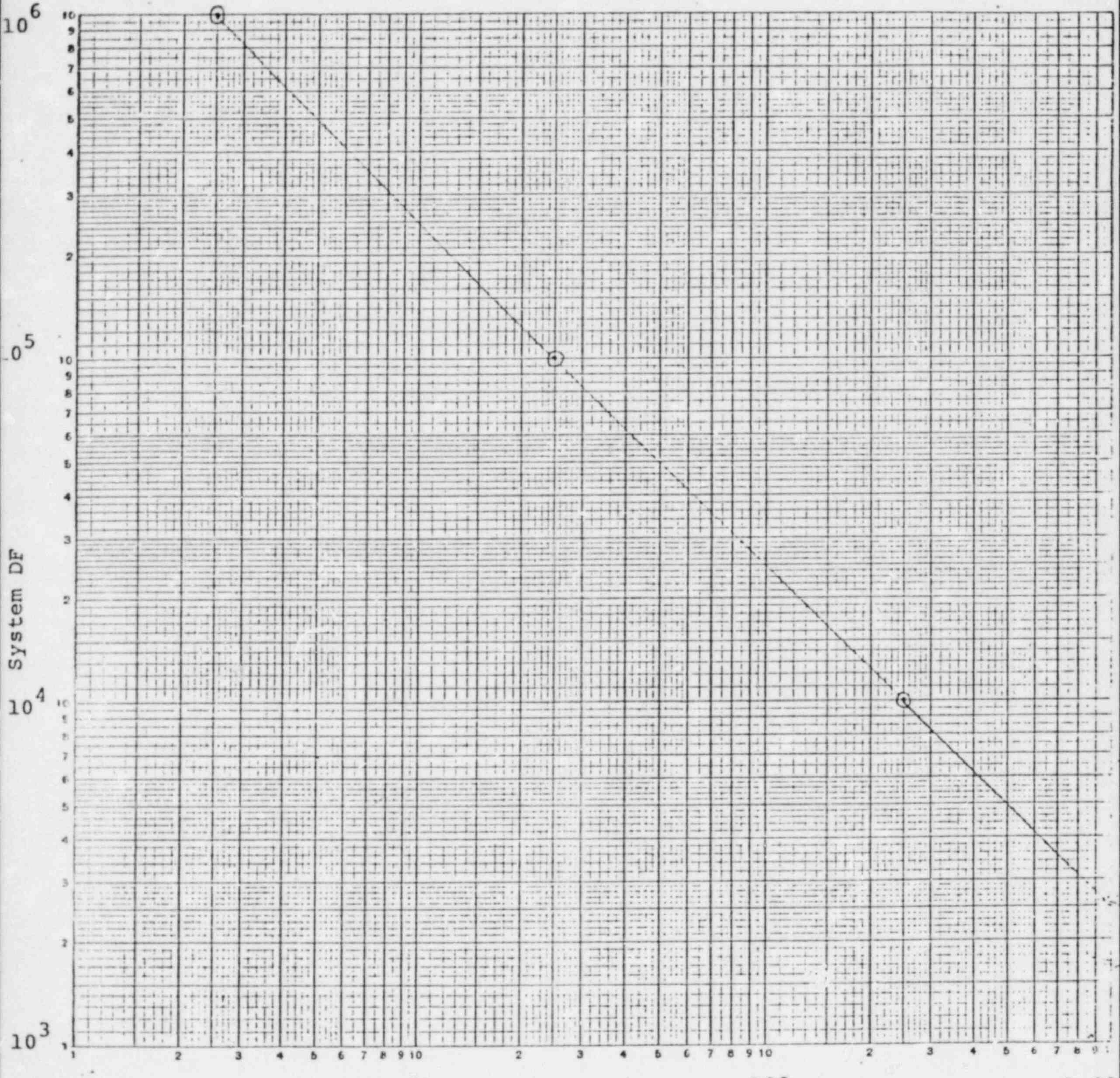
(1) Residual person-rem per gallon after processing liquid containing Table 1 envelope concentrations through system with specified DF

(2) Assumes added process has DF greater than about 5 (i.e., most of the residual person-rem is removed by the added process). Cost is equivalent to $1,000 spent per person-rem saved.

Figure 1

System DF vs Maximum Justifiable Cost per Unit Volume for Additional Processing

(TMI-2 Accident Liquid Envelope Concentrations)



Maximum Justifiable Cost per Unit Volume for Additional Processing cents/gallon

Plotted from data in Table 3

Attachment 1

Standard Radiological Effluent Technical Specifications 3.11.1.3 and 3.11.2.4 to Assure Operation of Radwaste Systems in Compliance with 10CFR50 Appendix I Cost/Benefit Criterion.

One provision of the NRC standard technical specifications for radiological effluents which has been universally criticized by licensees is the requirement that the decision whether or not to process waste must be based upon the maximum individual dose anticipated from releases projected into the future for a specified period of time (Standard Radiological Effluent Tech Specs 3.11.1.3 (liquid effluents) and 3.11.2.4 (gaseous effluent)). If the projected dose exceeds an NRC criterion value, the waste must be processed. If the projected dose does not exceed the criterion value, the waste need not be processed. The specifications are intended to assure that radwaste treatment systems are operated when the cost/benefit ratio is favorable (less than $1,000 spent for each person-rem saved), and to provide some flexibility so that wastes may be released without treatment under appropriate conditions. While most licensees believe that a specification which clearly addresses the need for treatment is desirable, the consensus is that the specification, as written, fails to meet that goal.

Specific criticisms are as follows:

1) It seems to most that the decision to process the batch of waste should be based on the characteristics of the waste batch in question rather than on characteristics of waste batches projected for the future from historical experience. The specification, as presently worded, seems to state that batches of clean waste must be processed now if there is reason to expect significant releases in the future.

2) There are many substantial implementation questions related to the specification as written which are not clearly answered:

Project next 30 days based on past 30 days experience modified with expected occurrences in next 30 days

2.1 What is an acceptable basis for projection?

2.2 What is the licensee's vulnerability if the projection turns out to be inaccurate? A report as specified in Action a.

The spec is clear that no report is required for this case. There is no penalty.

2.3 What is the licensee's vulnerability if the NRC criterion is exceeded even when all processing equipment is used?

2.4 What documentation is required? *Action in plant log and special report as required.*

2.5 Is it permissible to release a "hot" batch without treatment if releases projected for the next month are low overall? *Only if operability limit for month is met.*

2.6 Are projections necessary if all waste is routinely processed? *No. Projection is only needed to determine whether or not to operate equipment.*

2.7 If Stream B is expected to exceed the NRC criterion value, but Stream A is expected to be negligible, is it necessary to process Stream A? *The spec requires "appropriate" equipment to be used.*

The ETSB staff is implementing this spec as noted in above comments.

It is plain from our discussion with NRR staff that NRR does not yet have a clear idea of the implementation scheme for this specification. The same is true for licensees and it is undoubtedly true for I&E inspectors as well.

We do not perceive that implementation of this spec is this type.

3) The procedures which must be developed to implement the specifications are likely to be administrative nightmares, requiring a substantial accounting effort suitable for a sliding time scale. It should be possible to achieve the goal in a more simple way.

The proposal below is an attempt to resolve these problems without sacrificing the original objectives.

This does not appear any more straightforward than what we have in the spec now.

The most straightforward way of approaching the problem is to do a cost-benefit balance for each release. (For this purpose, continuous releases may be considered a series of batch releases.) When the isotopic concentrations in the waste have been determined, in accord with tech spec sampling analysis requirements, they may be used in the following equation to estimate a cost-benefit ratio applicable to a batch about to be either released or processed.

Using this method would not satisfy 10 CFR 50.36a(a)(1) or 10 CFR 20.106(b)(1). While 10 CFR 50.36a implies maintenance and use of radwaste equipment at all time, our spec provides the needed operational flexibility.

$$R = P * \sum_{i}^{isotopes} \frac{1}{C_i * F_i}$$

$$\frac{\$}{\text{person-rem}} = \frac{\$}{\text{unit volume}} * \frac{\text{unit volume}}{\text{Ci}} * \frac{\text{Ci}}{\text{person-rem}}$$

Fi changes with dilution flow, etc. therefore can't use single value and put in ODCM. Therefore, the straightforwardness is negated.

The values of F_i would be calculated once and listed in the ODCM. The values would be computed using GASPAR and LADTAP or equivalent codes, specifying the appropriate populations, pathways, and dilution or dispersion factors, running the code for one curie per year for each isotope. The value of P should be an estimate of a generally applicable minimum processing cost per unit volume for the types of waste of concern. It could be based on Regulatory Guide 1.110 estimates of operating and maintenance costs for the processing option, converted to a price per unit volume. The value used could be the cheapest of the various processing options. I would estimate that a minimum value for liquid waste would be about one cent per gallon since we are talking about thousand-gallon lots and you can hardly transfer one thousand gallons from one tank to another for ten dollars, let alone process it. I would estimate that a reasonable value for tech spec purposes would be in the range of ten cents per gallon. Of course, there is an implicit assumption that processing costs are directly proportional to volume processed. This assumption is probably reasonable for operating and maintenance costs.

These are variable

There are several alternatives for the wording of the technical specifications to implement this recommendation.

The first alternative allows most flexibility:

"The appropriate portions of the effluent treatment system shall be used to reduce the concentrations of radioactive materials in wastes when operating and maintenance costs associated with the treatment of the volume of waste in question do not exceed $1,000 per person-rem saved. The methodology for determining the population dose and processing cost is described in the ODCM."

The second method essentially fixes the processing cost in the technical specification by specifying an upper limit to the person-rem per unit volume for waste released without processing. A value of 1E-4 person-rem per gallon, which would be equivalent to a processing cost of ten cents per gallon, would be in the right range for a specification worded as follows:

Is this form NRC could dictate processing cost without regard to licensee's system ie a rock-bottom processing cost.

"The appropriate portions of the effluent treatment system shall be used to reduce the concentrations of radioactive materials in waste if release without treatment would result in population dose per unit volume of released waste exceeding __________ person-rem per gallon. The methodology for determining the population dose is described in the ODCM."

In either case, the surveillance requirement would be an evaluation of every batch released showing that the condition was met. For continuous releases, a new evaluation could be performed upon each receipt of results from isotope concentration measurements. The specification may also require some wording warning that compliance with the specification will not assure compliance with specifications limiting maximum doses to individuals, since those specifications are likely to be more restrictive by a substantial margin.

As worded, the spec requires reprocessing processes waste if concentrations rem in high after the first pass. This assures effective cleanup even when the system is not operating efficiently, or when liquids outside the design envelope are processed.

Attachment 2

Methodology for Calculation of Population Dose per Unit Volume for TMI-2 Accident Liquids

1) General Expression for Populating Dose per Unit Volume of Waste.

The general expression for population dose per unit volume is given below. Terms on the right side of the expression are defined below and values used in this analysis are presented in subsequent sections of this attachment.

$$P = 1E\text{-}3 * 1E\text{-}6 * 3785 * \sum_i \sum_j N_j * \frac{1}{(F/M)_j} * D_{i,j} * C_i$$

$\frac{\text{person-rem}}{\text{gallon}}$	$\frac{\text{rem}}{\text{mrem}}$	$\frac{\text{Ci}}{\mu\text{Ci}}$	$\frac{\text{ml}}{\text{gallon}}$	$\frac{\text{persons}}{}$	$\frac{1}{\text{cfs}}$	$\frac{\text{mrem-cfs}}{\text{Ci}}$	$\frac{\mu\text{Ci}}{\text{ml}}$

Where

P = population dose per unit volume summed over pathway and isotope.

Nj = number of persons (total of all ages) exposed to effluents through pathway j.

$(F/M)_j$ = ratio of total waste flow, F (including cooling tower blowdown) at the point of discharge to the river to the mixing ratio, M, which is the inverse of the factor by which effluent to the river is diluted by river water at the receptor location. (This notation is consistent with notation in Regulatory Guide 1.109 (Rev. 1). The ratio F/M may be considered the "effective" flow rate" of diluted waste).

$D_{i,j}$ = age-weighted population total body dose conversion factor for isotope i and pathway j.

Ci = concentration of isotope i in liquid waste

2) Pathways and Isotopes

Inspection of potential pathways, number of people exposed through each pathway, the isotope concentrations in waste and dose conversion factors indicates that four isotopes Sr-89, Sr-90, Cs-134 and Cs-137 would account for virtually all of the population dose and that the water ingestion pathway is the only pathway contributing significantly to population dose. The fish ingestion pathway, the second ranking pathway, only contributes a few percent of the population dose but is included here for completeness.

3) Numbers of Persons Exposed, N_j

For the dose analyses in the TMI-2 10CFR50 Appendix I evaluation report[1], it was assumed that five million people were exposed to liquid effluents through the drinking water pathway because the water intake for the city of Baltimore, Maryland is on the Susquehanna River within fifty miles of the plant. The figure of five million is a conservative projection for the end of plant life and includes the relatively small population served by other water supplies downstream from the plant. The population consuming fish at average consumption rates specified in Regulatory Guide 1.109 was determined from fish catch data[1] 31,600 kg/yr, and the age-weighted average consumption rate, 5.9 kg/yr, (determined from age fractions and age-specific consumption rates in Regulatory Guide 1.109). The number of persons supplied by the fish catch is 5,400.

4) Dilution (F/M)j

The parameter (F/M)j is the ratio of effluent flow rate, F, to the receiving water mixing ratio, M. This notation is from Regulatory Guide 1.109 (Rev. 1). Since the mixing ration is simply the inverse of the dilution factor, the parameter (F/M) may be considered the product of the effluent flow rate and the dilution factor for the receiving water body, or the "effective flow rate" of diluted waste. For the TMI-2 Appendix I report, (F/M) was assumed to be 34,000 cfs for population doses from both the water and fish pathways. This flow rate is the annual average flow rate of the Susquehanna River near the plant. Thus, it is assumed that effluents are fully diluted in the river. In this report, the same value is used for the water pathway, but a lower figure of 10,000 cfs is used for the fish pathway because most fish are caught in the summer when river flow is lower than average[2,3] (This change turned out to be insignificant since population dose is determined almost solely by the water ingestion pathway).

5) Age-Weighted Total Body Population Dose Factors, $D_{i,j}$

Equations on RG1.109 (Rev. 1) were solved using RG1.109 (Rev. 1) default parameter values for average individuals and a release rate of one curie per year, a waste flow rate of one cfs, and a mixing ratio of one. The resultant dose rate (millirem/year) to an average individual for each age group organ, pathway, and isotope was tabulated. Results for isotopes and pathways of interest are given in Table A2-1. These factors can be used to calculate the dose to an average individual simply by multiplying the appropriate factor by the release rate (Ci/yr) and dividing by the "effective dilution flow rate" (cfs). The factors in Table A2-1 were weighted by the fraction of the population in each age group and the weighted values were summed over the four age groups to obtain age-weighted population total body dose factors for the water and fish ingestion pathways. Results are also given in Table A2-1. These results are used in the general expression given above to compute population dose. Because RG1.109 (Rev.1) gives 50-year dose commitments, the values in Table A2-1 may be considered equivalent to the committed dose (mrem) per unit activity (Ci) released at an "effective dilution flow rate" of one cfs for an average individual in the population.

REFERENCES

(1) Evaluation of the Three Mile Island Nuclear Station Unit 2 to Demonstrate Conformance to the Design Objectives of 10CFR50 Appendix I, May, 1976 (prepared for Metropolitan Edison Company by Nuclear Safety Associates).

(2) TMI-2 FSAR, Figure 2.4-17

(3) An Ecological Study of the Susquehanna River near the Three Mile Island Nuclear Station, Annual Report for 1978, July, 1979. (prepared for Metropolitan Edison Company by Ichthyological Associates, Inc.

Table A2-1

Population Total Body Dose Factors(1)

(mrem/year)

Isotope	Pathway	Adult	Teen	Child	Age-Weighted Factor(2)
Sr-89	Water	3.55E+00	3.55E+00	1.06E+01	4.82E+00
Sr-89	Fish	1.83E+00	1.96E+00	2.49E+00	1.96E+00
Sr-90	Water	7.57E+02	5.86E+02	1.23E+03	8.23E+02
Sr-90	Fish	4.23E+02	3.52E+02	3.13E+02	3.95E+02
Cs-134	Water	4.92E+01	2.61E+01	2.31E+01	4.19E+01
Cs-134	Fish	1.82E+03	1.04E+03	3.90E+02	1.48E+03
Cs-137	Water	2.91E+01	1.48E+01	1.32E+01	2.47E+01
Cs-137	Fish	1.08E+03	5.93E+02	2.24E+02	8.72E+02

(1) Derived from RG1.109 (Rev 1) equation with RG1.109 (Rev 1) default parameter values for population dose assessment for release rate of 1 ci/yr, and effective dilution flow rate of 1 cfs.

(2) Weighted for population distribution of 71% adults, 11% teenagers, 18% children, RG1.109 (Rev 1) p. 1.109-33.

Table 1-3

DECONTAMINATION FACTORS FOR PWR LIQUID WASTE TREATMENT SYSTEM

Treatment System	Decontamination Factor		
	Anion	Cs, Rb	Other Nuclides
Demineralizer			
Mixed Bed			
Primary coolant letdown (Li_3BO_3)	10	2	10
Radwaste (H^+OH^-)	10^2 (10)*	2 (10)	10^2 (10)
Evaporator condensate polishing	10	10	10
Boron recycle system feed (H_3BO_3)	10	2	10
Steam generator blowdown (H^+OH^-)	10^2 (10)	10 (10)	10^2 (10)
Caton bed (any system)	1 (1)	10 (10)	10 (10)
Anion bed (any system)	10^2 (10)	1 (1)	1 (1)
Powdex (any system)	10 (10)	2 (10)	10 (10)

Evaporators	All Nuclides Except Iodine	Iodine
Miscellaneous radwaste	10^4	10^3
Boric acid recovery	10^3	10^2
Detergent wastes	10^2	10^2

Reverse Osmosis	All Nuclides
Laundry wastes	30
Other liquid wastes	10

Filters	DF of 1 for all nuclides

*For demineralizers in series, the DF for the second demineralizer is given in parentheses.