BNWL-SA-5501
CONF-750822--4

DEVELOPMENT OF DISPOSITION CRITERIA DEVIATION METHODOLOGY FOR COMMERICAL FUEL CYCLE FACILITIES

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* This paper is based on work performed under U.S. Energy Research and Development Administration Contract No. AT(45-1):1830

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BNWL-SA-5501
CONF-750822--4

DISPOSITION CRITERIA FOR DECONTAMINATION AND DECOMMISSIONING OF A MIXED OXIDE FUEL FABRICATION PLANT

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INTRODUCTION

This report discusses the development and definition of acceptable criteria for release of nuclear sites and/or facilities under specified use restriction categories--disposition criteria. Previous reports have defined site and facility characteristics before major decontamination or decommissioning. With this background information, disposition criteria were developed to facilitate decision-making regarding disposition alternatives, (see Figure 1).

To develop these disposition criteria, existing guidance was reviewed, philosophy and objectives were identified, and mechanisms were developed and applied to a generic mixed oxide fuel fabrication plant.

STATEMENT OF PROBLEM

Useful disposition criteria must 1) be based on a consistent system of rationale, 2) give quantitative guidance on acceptable levels for site or facility usage, 3) be applicable to all of the use restriction categories, and 4) be adaptable to other types of nuclear facilities.

In order to determine if existing guidance on acceptable criteria for release met these requirements, an extensive literature search was conducted. This review revealed that existing criteria for release

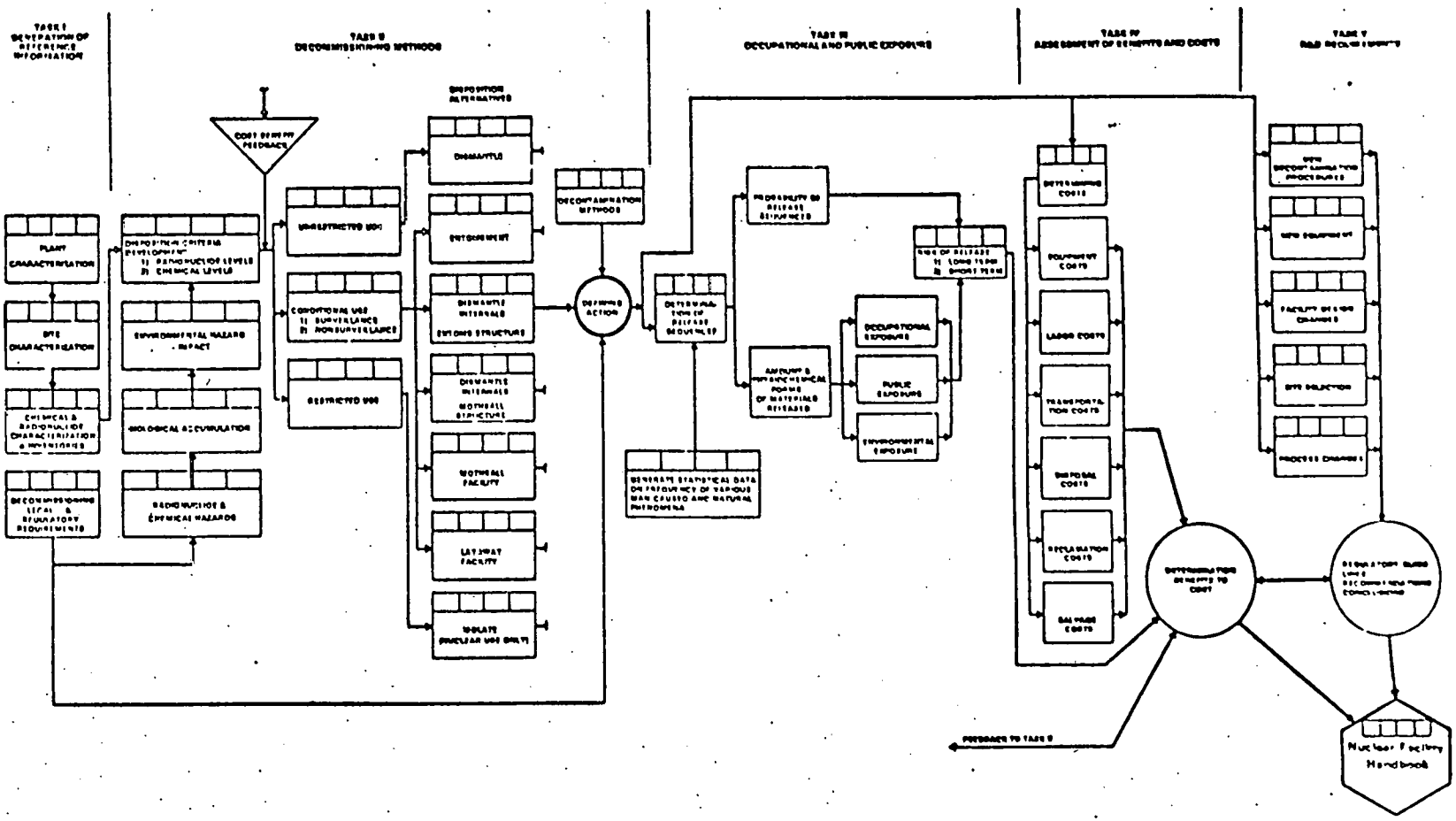

FIGURE 1. Commercial Nuclear Facility Decommissioning Study

for plutonium and other transuranics were inadequate but could be used as one element in determining the acceptability of derived disposition criteria.

The quantitative requirement was met by the inconsistent array of existing criteria but the requirements for rationale, applicability and adaptability could only be met by further development.

EXISTING GUIDANCE

A search of the literature for previously derived criteria revealed that decontamination limits for plutonium and other transuranics have tended to be derived piecemeal and independent of one another. Documented incidents, such as the cleanup of a plutonium contaminated truck terminal[1] or the cleanup of plutonium contamination spread from damage to several nuclear explosive devices involved in an airplane crash in Spain, required immediate action and decisions on acceptable criteria for release of the site.

Necessity has focused much more attention on contaminated surfaces than on contamination of liquids or solids. However, from the basic population dose criteria, ICRP and NCRP promulgated a nonoccupational water standard for soluable plutonium. Also, an assessment by Colorado of the plutonium contamination from the Rocky Flats Plant resulted in a plutonium-in-soil standard for unconditional release.

Examples of existing criteria for release of plutonium contaminated materials include:

- "Guides for Decontamination of Facilities and Equipment --------" were established by USAEC Division of Materials Licensing on April 22, 1970. Criteria were established for average and maximum amount of nonremovable plutonium contamination as well as maximum removal contamination. These are:

	$d/m\ \alpha/100\ cm^2$
Removable	100
Average fixed	500
Maximum fixed	2500

- The draft on ANSI Standard N13-3A dated September 1973 contains criteria for total and removable plutonium contamination levels. These are:

	d/m α/100 cm^2
Total	100
Removable	20

- A review[2] of the draft ANSI standard suggested alternates for total contamination as

	d/m α/100 cm^2
Total	500
Removable	50

- In a study for Regulatory Standards on "Considerations in the Assessment of the Consequences of Effluents from Mixed Oxide Fuel Fabrication Plants," BNWL-1697, a cutoff between contaminated and noncontaminated was established and related to criteria for surface and volumetric contamination. The definition of plutonium contamination was:

Surface	10 nCi/m^2
Volumetric	10 pCi/g

Other than the 1970 "Guides for Decontamination of Facilities and Equipment --------" no legal or regulatory requirements exist that are directly applicable to decontamination or decommissioning. The following legal or regulatory guidance are at least indirectly applicable or useful in evaluating proposed criteria.

- AEC Appendix 5301 Part VI - Real Estate Management for Pu states a detection level of 100 dpm/100 cm^2 should be used. It further states that proposed radiological decontamination and cleanup plans shall be designed to achieve a range of levels down to lowest practicable.
- DOT - Provides a vehicle smearable contamination limit of 20 nCi/m^2 49CFR.
- The 10 CFR provides specific release limits in several of its sections.

Existing guidance, detection levels, etc. for plutonium contamination were correlated to determine what meaningful relationships exist (see Figure 2).

PHILOSOPHY AND OBJECTIVES

The basic guiding philosophy for the disposition criteria development is that once radiological protection parameters are quantified, the resulting degree of protection level will be met in every category. That is, under no circumstance will offsite population exposures exceed those specified at the unrestricted use level. Where higher residual contamination levels are allowable, prevention of increased exposure potential will be maintained through use restrictions specified for each use category. The objectives are to provide a rationale and methodology that are consistent and adaptable, yet provide definitive technically based numerical guidance for acceptable criteria for release.

Acceptability of numerical guidance derived through this methodology is determined by analysis on the basis of 1) detectability in the field by portable instrumentation, 2) dose commitment potential to individuals or populations, 3) by comparison with previously suggested guidance as shown in Figure 2.

The collective function of these assessment parameters is to establish an acceptable contamination level range for each use category. The requirement that specified contamination levels must be detectable in the field with portable instrumentation provides a simple means of establishing an upper bound for the unrestricted use category. Limitation of dose commitment potential to individuals or populations, practically interpreted, also establishes an upper bound to the unrestricted use category. This value also is explicitly considered in deriving upper bounds for other use categories. The practicality of derived disposition criteria numbers are assessed by comparison with the previously suggested guidance offered in Figure 2.

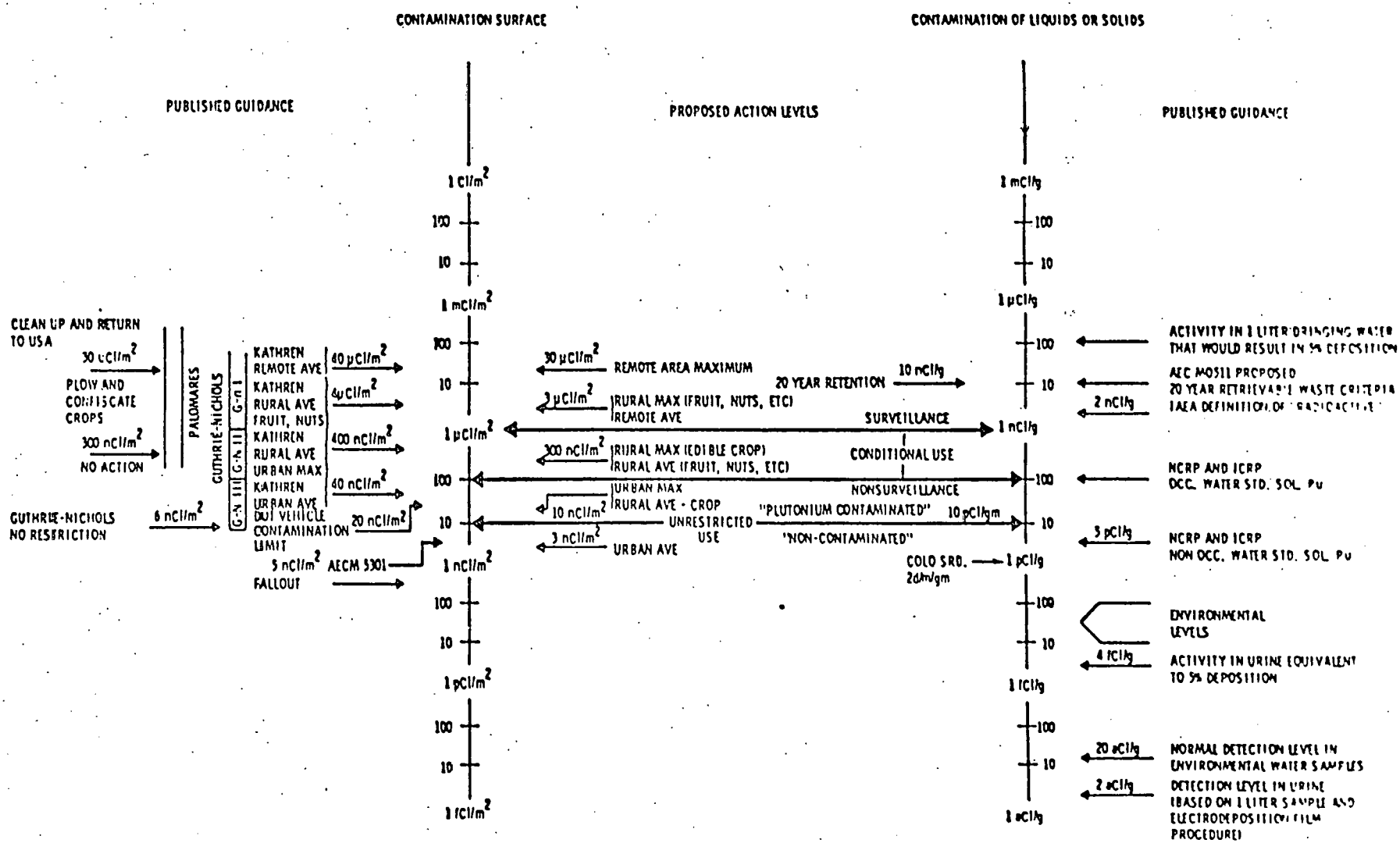

FIGURE 2. Plutonium Action Levels

Economic feasibility will affect the decontamination and decommissioning of specific sites and facilities, but this factor was not allowed to influence the establishment of acceptable disposition criteria.

USE RESTRICTION CATEGORIES

Use restriction categories for the disposition criteria development methodology began as 1) restricted, 2) conditional and 3) unrestricted. As investigation progressed, the conditional category was subdivided into (a) conditional uses needing continuing surveillance and (b) those not requiring such surveillance.

Conditional use categories were assessed on the basis of practical limitations affecting the availability of toxic materials by manipulation of active exposure pathways by either surveillance or nonsurveillance modes. For instance, restricting the availability of contamination by either restricting the use of drinking water or by physically restricting access of the contamination to the atmosphere would necessitate the active involvement of radiological monitoring personnel at the facility site and in its adjacent environment.

Conditional-nonsurveillance use is defined as the use of statutory law to limit land usage or to block significant exposure pathways; for instance, city zoning laws restricting agricultural use, drilling water wells, etc. Governmental maintenance commitments may also be involved, such as those associated with present day low-level radioactive waste surface burial.

The restricted use category denotes the limitation of the facility to "nuclear use only." Thus, voluntary or occupational exposure is allowed via the restricted use category specification while involuntary exposure is limited to the unrestricted category level.

The unrestricted use category denotes release of site and facility for unconditional access and use by the public.

MECHANISMS

In determining the appropriate use category of a specific site or facility, the site characteristics must be compared to technically based numerical guidance.

To aid in visualization of the derivation process, a matrix with use restriction category rows and contaminated medium columns was constructed (see Figure 3). The first number selected would be in column 1--row 1 (surface contamination--unrestricted use) which is based on detectability and serves as the easiest attainable upper bound number to the unrestricted use category. Assessment on basis of other criteria are discussed subsequently. Surface contamination guidance is intended to be used on any surfaces where such field measurements are feasible. Activity/mass contamination levels are intended to be applied to bulk materials such as water, soil, etc. Because of radical differences in availability factors or release fractions of smearable and nonsmearable surface contamination, appropriate levels are specified for each of these circumstances for each use category.

Figure 2 was organized in such a way that a comparable activity/mass contamination level appears across from each surface contamination value. An activity/mass value consistent with the row 1--column 1 number is selected by reading the number on the right axis with the same ordinant as the selected surface contamination value. This activity/mass value is entered into row 1--column 2.

Before values for row 2 can be derived, row 1 values (unrestricted use) must be examined on the basis of dose commitment potential to individuals or populations. Computer codes based on ICRP models for evaluating environmental consequences of releases of radionuclides are discussed as applied to this study in Appendix A. If the calculated dose exceeds established dose standards, a reduction in row 1 values is necessary. Therefore, development of more sensitive detection instrumentation is required to satisfy all acceptability criteria. If the calculated dose potentials are within existing standards, doses resulting from row 1 concentration values would serve as the basis for calculating remaining release criteria.

Row	Column 1	Column 2
1	Surface Contamination Unrestricted Use	Activity/mass Contamination Unrestricted Use
2	Surface Contamination Conditional Use Nonsurveillance	Activity/mass Conditional Use Nonsurveillance
3	Surface Contamination Conditional Use Surveillance	Activity/mass Conditional Use Surveillance
4	Surface Contamination Restricted Use	Activity/mass Restricted Use

FIGURE 3. Basic Disposition Criteria Matrix

Results of the dose calculation will also identify critical pathways. The relative importance of components of these pathways can be used to indicate which pathway adjustments can be made to restrict dose potential to unrestricted use levels. (A more detailed discussion of pathway components is included in Appendix A.)

Appendix A doses were calculated on the basis of 1 g/year released during routine operation. To calculate the doses resulting from the disposition criteria values derived in this study, the Appendix A values must be corrected by using facility inventory and release fraction data derived in Task III of this study. The applicable transformation equation is:

$$\frac{\text{Facility Contamination Inventory} \times \text{Release Fraction}}{\text{Routine Release}} \times \text{Appendix A Dose Calculation}$$

$$= \text{Disposition Criteria Dose}$$

The quotient term is, for this case, in the range of 10^{-6}. Disposition criteria doses used in the derivation of Figure 4 values can be expected to be 10^{-6} less than those indicated in the appendix.

The dose reduction which can be achieved by pathway restrictions are taken advantage of to equivalently increase acceptable concentration levels in row 2 (conditional use--nonsurveillance). The fact that more effective pathway restrictions are usually possible with active surveillance than without surveillance is incorporated into the derivation of values for row 3 (conditional use--surveillance). As a result, surveillance values may be higher than nonsurveillance without violating the unrestricted dose level criteria.

Since the restricted use category is defined as "nuclear use only," occupational exposure standards are used to determine the row 4 values.

	SURFACE CONTAMINATION	ACTIVITY/MASS CONCENTRATION
UNRESTRICTED	220 dpm/100 cm^2 fixed 220 dpm/m^2 smearable	10 pCi/g
CONDITIONAL NONSURVEILLANCE	2200 dpm/100 cm^2 fixed 220 dpm/m^2 smearable	100 pCi/g
CONDITIONAL SURVEILLANCE	22000 dpm/100 cm^2 fixed 220 dpm/m^2 smearable	1 nCi/g
RESTRICTED	>22000 dpm/100 cm^2 fixed 220 dpm/m^2 smearable	>1 nCi/g

FIGURE 4. Disposition Criteria Matrix

APPLICATION OF DISPOSITION CRITERIA

The derivation process for the generic mixed oxide fuel fabrication plant was begun by setting up the matrix and selecting a number in row 1--column 1 based on detectability in the field by portable instrumentation (see Figure 4). On this basis a number of 220 dpm/100 cm^2 fixed contamination was selected. A comparison of this value with Figure 2 shows this value (equivalent to 10 nCi/m^2) to be the interface between materials contaminated (by definition) with plutonium and materials not contaminated. A smearable contamination level two orders of magnitude more restrictive was also selected for unrestricted use surface contamination on the basis of greater release fraction potential as indicated in the discussion of release sequences presented elsewhere.

Figure 2 shows a value for contamination activity per unit mass of 10 pCi/g approximately equivalent to 10 nCi/m^2. This value was included in row 1--column 2 (activity/mass concentration--unrestricted use)(see Figure 4). The relationship of this number to relevant detection levels and to occupational and nonoccupational standards can be seen on Figure 2.

Inclusion of a total inventory limit was originally intended, but integration of the recommended surface contamination level over the approximately 4×10^5 ft^2 of facility surface in the reference mixed oxide fuel fabrication plant yielded a number for the total inventory of slightly less than 1 mCi plutonium. This quantity of plutonium could not be realistically determined for the purpose of site use restriction category selection purposes. Therefore, this column was dropped from the matrix.

Procedures used to insure conservatism included, for plutonium, ageing the fuel mixture for 15 years to increase the dose potential because of ^{241}Am ingrowth and also to approximate the midpoint of plant life. Several mixed oxide isotopic mixtures representing different burnup fuel were also analyzed to establish a bracket of recognizable potential hazards. A detailed discussion of these mixtures and the resulting doses is included in Appendix A.

An examination of Appendix A dose calculations indicates that within the restrictions appropriate to the conditional use--nonsurveillance category a factor of at least 10 can be expected. Another factor of 10 can be expected under the surveillance condition. As a result, values in rows 2 and 3 are one and two orders of magnitude greater than those specified for unrestricted use. However, in no case were these calculated doses found to be the most limiting of the acceptability criteria.

The upper bounds indicated in row 3 serve also as the lower bounds for the restricted use category values. Upper bounds for this category must be established on the basis of specific comparisons of contamination conditions with occupational dose standards.

The relationships of all values shown in Figure 4 are graphically illustrated in Figure 2.

REFERENCES

1. Peter Logan "Economics of Building Decontamination," International Symposium on Surface Contamination, CONF-555-14, June 12, 1964.
2. Letter from J. F. Sommers to E. J. Vallario, "Comments on Proposed Standard-N328," SOM-93-74, dated December 13, 1974.

Appendix A

FIFTY YEAR ENVIRONMENTAL DOSE FROM ROUTINE OPERATION OF A PLUTONIUM FUELS FABRICATION PLANT

The radiological impact of releases of radioactive material as a result of routine operation of a "typical" plutonium fuels fabrication plant was evaluated. It was assumed that only airborne releases of radioactive materials occurred during routine operation of the nuclear fuels fabrication plant. Two source terms were used based on fuel material of different isotopic composition (see Table I). Case 1 was developed from the isotopic distribution assumed to exist in 1993 if only light water reactors (LWR's) presently scheduled for construction were in operation. Case 2 also took into account the forecasted LWR's. It was assumed that the postulated average isotopic composition for 1993 would be a reasonable approximation for a 30-year period beginning 15 years before 1993 and ending 15 years after. The Am-241 buildup was determined by decaying the Pu-241 release in 1993 for 15 years.

TABLE I

ESTIMATED RELEASE RATES TO THE ATMOSPHERE FROM A PLUTONIUM FUELS FABRICATION FACILITY

(Ci/yr)

Nuclide	Case 1	Case 2
Pu-238	3.60E-1	3.25E-1
Pu-239	3.06E-2	3.78E-2
Pu-240	1.52E-2	1.20E-2
Pu-241	6.54E+0	5.15E+0
Pu-242	2.90E-4	1.44E-4
Am-241	2.68E-1	2.33E-1

Radiation doses were calculated for two hypothetical individuals residing one kilometer from the plant where the atmospheric dilution was 4.2×10^{-6} s/m^3. One individual was postulated to live at the given location for the 30-year period the plant operated and then moved to another location remote from nuclear facilities. The other individual was postulated to live at the given location continuously for 50 years beginning with the time of plant startup.

The exposure pathways of primary interest are direct radiation exposure from the surrounding radioactive cloud, inhalation of airborne radioactivity and ingestion of food which would become contaminated by material deposited from the cloud. Results of the radiation dose calculations clearly identify the critical pathway and critical organs.

The radiation dose due to ingestion of contaminated food was calculated using an updated and revised version of the computer program FOOD.[1] Inhalation radiation doses were calculated using an unpublished computer code called GAUCHE. Radiation doses due to submersion in the radioactive cloud were calculated using dose factors derived from equations in BNWL-SA-3939.[2]

The radiation doses via the inhalation pathway are by far the largest (see Tables II and III). For all organs, except the gastrointestinal tract, the doses due to inhalation of airborne radioactivity are two to three orders of magnitude larger than the corresponding doses along the ingestion pathway. Bone is the critical organ via the inhalation pathway exceeding radiation doses to other organs by about a factor of ten. No additional dose was accrued by the individual who continues to reside near the facility after shutdown.

TABLE II

FIFTY YEAR ACCUMULATED DOSES FROM ALL AIRBORNE PATHWAYS TO PERSONS RESIDING ONE KILOMETER FROM A PLUTONIUM FUELS FABRICATION PLANT HAVING RADIONUCLIDE RELEASES LISTED IN TABLE I - CASE 1

(mrem)

30-Year Resident

Pathway	Skin	Total Body	GI-LLI	Bone	Liver	Lung
Inhalation	----	1.2E+3	1.1E+0	4.0E+4	6.3E+3	2.9E+3
Ingestion	----	6.9E-1	2.2E+0	1.3E+1	2.6E-1	----
Air Submersion	2.9E-4	1.8E-4	(1.8E-4)	(1.8E-4)	(1.8E-4)	(1.8E-4)
TOTAL	2.9E-4	1.2E+3	3.3E+0	4.0E+4	6.3E+3	2.9E+3

50-Year Resident

Inhalation	----	1.2E+3	1.1E+0	4.0E+4	6.3E+3	2.9E+3
Ingestion	----	6.9E-1	2.3E+0	1.3E+1	2.7E-1	----
Air Submersion	2.9E-4	1.8E-4	(1.8E-4)	(1.8E-4)	(1.8E-4)	(1.8E-4)
TOTAL	2.9E-4	1.2E+3	3.4E+0	4.0E+4	6.3E+3	2.9E+3

TABLE III

FIFTY YEAR ACCUMULATED DOSES FROM ALL AIRBORNE PATHWAYS TO PERSONS RESIDING ONE KILOMETER FROM A PLUTONIUM FUELS FABRICATION PLANT HAVING RADIONUCLIDE RELEASES LISTED IN TABLE I - CASE 2

(mrem)

30-Year Resident

Pathway	Skin	Total Body	GI-LLI	Bone	Liver	Lung
Inhalation	----	1.1E+3	9.4E-1	3.5E+4	5.6E+3	2.6E+3
Ingestion	----	6.1E-1	2.0E+0	1.1E+1	2.3E-1	----
Air Submersion	2.5E-4	1.5E-4	(1.5E-4)	(1.5E-4)	(1.5E-4)	(1.5E-4)
TOTAL	2.5E-4	1.1E+3	2.9E+0	3.5E+4	5.6E+3	2.6E+3

50-Year Resident

Inhalation	----	1.1E+3	9.4E-1	3.5E+4	5.6E+3	2.6E+3
Ingestion	----	6.1E-1	2.0E+0	1.1E+1	2.3E-1	----
Air Submersion	2.5E-4	1.5E-4	(1.5E-4)	(1.5E-4)	(1.5E-4)	(1.5E-4)
TOTAL	2.5E-4	1.1E+3	2.9E+0	3.5E+4	5.6E+3	2.6E+3

The relative contribution of the different isotopes to the radiation dose to bone via the inhalation pathway is shown in Table IV. This table is given as an example of the dose distribution and how it changes with time. The longer-lived isotopes (Pu-238, Pu-239 and Am-241) contribute an increasing portion of the dose in the latter years. The relative contributions for other organs are similar to this illustration.

Parameters used for calculation of the radiation doses via ingestion of food are shown in Table V.

TABLE IV

CONTRIBUTIONS OF INDIVIDUAL NUCLIDES TO BONE DOSES VIA INHALATION OF RADIONUCLIDES RELEASED IN CASE 2

Nuclide	Based on Dose from Inhalation During 1st Year After Plant Startup (%)		Based on Dose from Inhalation During 30 Years of Plant Operation (%)	Based on Dose from Inhalation During 30 Years of Plant Operation Plus Body Burden Over the Next 20 Years (%)
Pu-				
Pu-238	32.6	2.25	50.6	53.6
Pu-239	3.5	.242	6.0	6.8
Pu-240	1.1	.076	1.9	2.1
Pu-241	55.0	3.80	29.3	23.7
Pu-242	0	0	0	0
Am-241	7.7	0.53	12.1	13.5
TOTAL (%)	100		100	100
TOTAL DOSE(mrem)	(6.9E+0)		(1.7E+4)	(3.5E+4)

TABLE V

PARAMETERS USED FOR CALCULATION OF RADIATION DOSES FROM CONSUMPTION OF FOODS

Food	Holdup (days)	Consumption (kg/yr)	Yield (kg/m^2)	Growing Period (days)
Leafy Vegetables	1	30	1.5	90
Potatoes	10	110	4.0	90
Orchard Fruit	10	265	1.7	90
Wheat	10	80	0.72	90
Eggs	1	30	0.84	90
Milk	1	274*	1.3**	30
Beef	15	40	0.84	90
Poultry	1	18	0.84	90

* liters/year

** liters/day

Using an iterative process, radiation doses from each year's intake plus the dose commitment from that intake out to the fiftieth year after facility startup were calculated. Results of these calculations are shown in Tables VI and VII.

Only an imperceptible increase in radiation dose via the ingestion pathway was received by the 50-year resident as compared to the 30-year resident. In addition, it is important to notice that essentially the total radiation dose along the ingestion pathway to all organs for both individuals was due to ingestion of produce. These two results demonstrate that for the ingestion pathway most of the dose from the actinides is due to contamination on the leaves of vegetation and is not due to uptake through the root system or transfer of the radionuclides to animal products.

As in the case of inhalation, bone is the critical organ for the ingestion pathway. The radiation dose to bone is almost one order of magnitude greater than the dose to the gastrointestional tract.

The air submersion radiation dose was insignificant when compared to the radiation doses received via either ingestion or inhalation.

TABLE VI

FIFTY YEAR ACCUMULATED DOSES FROM INGESTION OF FARM PRODUCTS GROWN ONE KILOMETER FROM A PLUTONIUM FUELS FABRICATION PLANT HAVING RADIONUCLIDE RELEASES LISTED IN TABLE I - CASE 1

(mrem)

30-Year Resident

Food	Total Body	GI-LLI	Bone	Liver
Produce	6.9E-1	2.2E+0	1.3E+1	2.6E-1
Eggs	1.8E-6	5.9E-6	3.3E-5	6.9E-7
Milk	6.7E-5	1.7E-4	7.5E-4	3.1E-5
Meat	3.3E-3	1.1E-2	6.3E-2	1.3E-3
TOTAL	6.9E-1	2.2E+0	1.3E+1	2.6E-1

50-Year Resident

Produce	6.9E-1	2.3E+0	1.3E+1	2.7E-1
Eggs	1.8E-6	5.9E-6	3.3E-5	7.0E-7
Milk	6.7E-5	1.7E-4	7.5E-4	3.1E-5
Meat	3.3E-3	1.1E-2	6.3E-2	1.3E-3
TOTAL	6.9E-1	2.3E+0	1.3E+1	2.7E-1

TABLE VII

FIFTY YEAR ACCUMULATED DOSES FROM INGESTION OF FARM PRODUCTS GROWN ONE KILOMETER FROM A PLUTONIUM FUELS FABRICATION PLANT HAVING RADIONUCLIDE RELEASES LISTED IN TABLE I - CASE 2

(mrem)

30-Year Resident

Food	Total Body	GI-LLI	Bone	Liver
Produce	6.1E-1	2.0E+0	1.1E+1	2.3E-1
Eggs	1.5E-6	5.2E-6	2.9E-5	6.1E-7
Milk	5.9E-5	1.5E-5	6.6E-4	2.7E-5
Meat	2.9E-3	9.8E-3	5.5E-2	1.1E-3
TOTAL	6.1E-1	2.0E+0	1.1E+1	2.3E-1

50 Year Resident

Produce	6.1E-1	2.0E+0	1.1E+1	2.3E-1
Eggs	1.6E-6	5.2E-6	2.9E-5	6.1E-7
Milk	5.9E-5	1.5E-5	6.6E-4	2.7E-5
Meat	2.9E-3	9.9E-3	5.5E-2	1.2E-3
TOTAL	6.1E-1	2.0E+0	1.1E+1	2.3E-1

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