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REPORT
OF THE AD HOC STUDY GROUP

ON

INTEGRATED VERSUS DISPERSED FUEL CYCLE FACILITIES

April 1975

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Compiled by
M. R. Kreiter and A. M. Platt

April 1975

PATENT STATUS

PRELIMINARY REPORT

This draft report has been issued as a preprint for special distribution at the request of the International Working Group on High-level and Alpha Waste.

This report contains information of a preliminary nature prepared in the course of work under Atomic Energy Commission Contract AT(45-1)-1830. This information is subject to correction or modification upon the collection and evaluation of additional data.

NOTICE

On January 19, 1975, research and development programs of the U.S. Atomic Energy Commission (AEC) became part of the newly formed Energy Research and Development Administration (ERDA). In this report, since it refers to work done in 1974, most references are to AEC programs.

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REPORT OF THE AD HOC STUDY GROUP ON INTEGRATED VERSUS DISPERSED FUEL CYCLE FACILITIES

October 1974

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Atomic Energy Commission

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1.0 INTRODUCTION

The Ad Hoc Study Group on Spent Fuel Processing and Plutonium Fuel Fabrication first convened at Germantown on February 20-21, 1974. Terms of reference for the Group are listed in an attachment to Dr. F. K. Pittman's letter of February 1, 1974. (See the Appendix to this report.)

The first task the Group selected was to advise the Commission of potential long-range policy considerations, planning and programs related to: (1) the retention of long-lived radioactive nuclides in the fuel cycle to the extent practical and (2) the managment of long-lived radioactive nuclides in waste generated by nuclear fuel cycle operations.

Deliberations by the Group had established concepts for a number of systems which might reduce risks to man and reduce consumption of resources as compared to the base system. The common goals were to reduce the number of sites and the transport distance between sites and to minimize the processing and handling of radioactive materials requiring safeguards or additional containment.

For expediency, however, the Group decided at the May 29, 1974 meeting that an analysis of a single U.S. integrated fuel cycle facility (IFCF) or site containing the majority of nonreactor and post reactor fuel cycle facilities and a comparison of the IFCF with the dispersed fuel cycle facilities (DFCF) would highlight the desirability of continuing these analyses.

Prior studies had been integrated by the Group to develop a broad projection of the U.S. nuclear power system that might be expected to exist in the year 2000 if no significant change were made in policies or technical programs. Studies by AEC personnel are continuing which will evaluate regulatory and legal considerations concerned with energy centers, and other similar integrated facilities.

Other alternatives to the IFCF are briefly discussed in Section 7 of this report.

Conclusions and Recommendations

The Integrated Fuel Cycle Facility--it could also be called a Nuclear Power Support Park--appears to have the following major features:

- Confinement to one (rather than 15 to 25) site (park) all fission products and transuranics not in fuel assemblies. A single site could provide greater protection to the populace for the maximum credible accident.
- Ramifications of corporate planning could be disruptive to the growth of the industry.
- Substantial potential for improved waste management and effluent control.
- Increased (depending on location) shipping distances for spent and fresh reactor fuel but elimination of transport for most wastes and special nuclear materials.
- Safeguards considerations, radiological impact, costs and timing appear to be at least equal if not improved as compared to allowing Dispersed Fuel Cycle Facilities to be randomly located.
- Support community impact appears relatively small, involving a community of 150,000 to 200,000, including necessary services (referred to as multipliers).
- A significant advantage for IFCF is that a decision for an IFCF is reversible. At any later date decisions can be made to proliferate sites.

Based on the conclusions cited above, the Ad Hoc Study Group recommends that a comprehensive analysis of the IFCF concept be immediately undertaken.

It is the opinion of the Group that an IFCF is technically feasible and desirable. Thus additional study is required only to select an optimum site and to assess the policy, legislative, business and social factors and to develop cost, timing, and technical detail needed for the decision process.

2.0 SUMMARY

To provide isolation of strategic materials and confinement of nuclear wastes, the basic facilities considered in assessing the DFCF and IFCF were mixed plutonium and uranium oxide and HTGR fuel fabrication, fuel reprocessing, high-enrichment isotopic separation and interim waste storage. Reactors, low-enrichment isotopic separation and low-enrichment uranium facilities were excluded. It is expected that the IFCF would attract uranium fuel fabrication and possibly reactors. An assumption was made for the study that the choice of either IFCF or DFCF would not alter the nuclear power generation pattern postulated to exist up to the year 2000.

The Year 2000

In the year 2000, the following picture emerges for U.S. population and the generation of electric power: The population is 285,000,000; half of all energy consumed goes for electric power generation; 60% of this, or 1200 GWe, is nuclear; two-thirds of this nuclear capacity is less than 12 years old, and one-third is less than 5 years old. The reactor mix is 73% LWR, 10% HTGR, and 17% LMFBR. Figure 1 shows the Federal Power Commission's regional distribution of nuclear power production, fuel fabrication and spent fuel reprocessing capacity. The Southeast and Northeast regions lead in the number of reactors, as well as in the nuclear fraction of total regional generation capacity.

About 29,000 MT of fresh fuel per year is produced and about 22,000 MT (19,400 LWR, 700 HTGR, 1900 LMFBR) of irradiated fuel is reprocessed. About 350 MT per year of plutonium is being converted to mixed oxide. Over a million cubic feet of plutonium alpha waste is generated and 9100 MT (equivalent) of high-level waste reach an age of 10 years. Noble gas fission products will be generated at an annual rate of 230 MCi and tritium at an annual rate of 14 MCi.

Fuel Cycle Facilities

The dispersed and integrated fuel cycle facility cases will differ in numbers of plants and locations. Table 1 summarizes a best guess at the numbers and types of facilities in each complex. The IFCF was assumed to

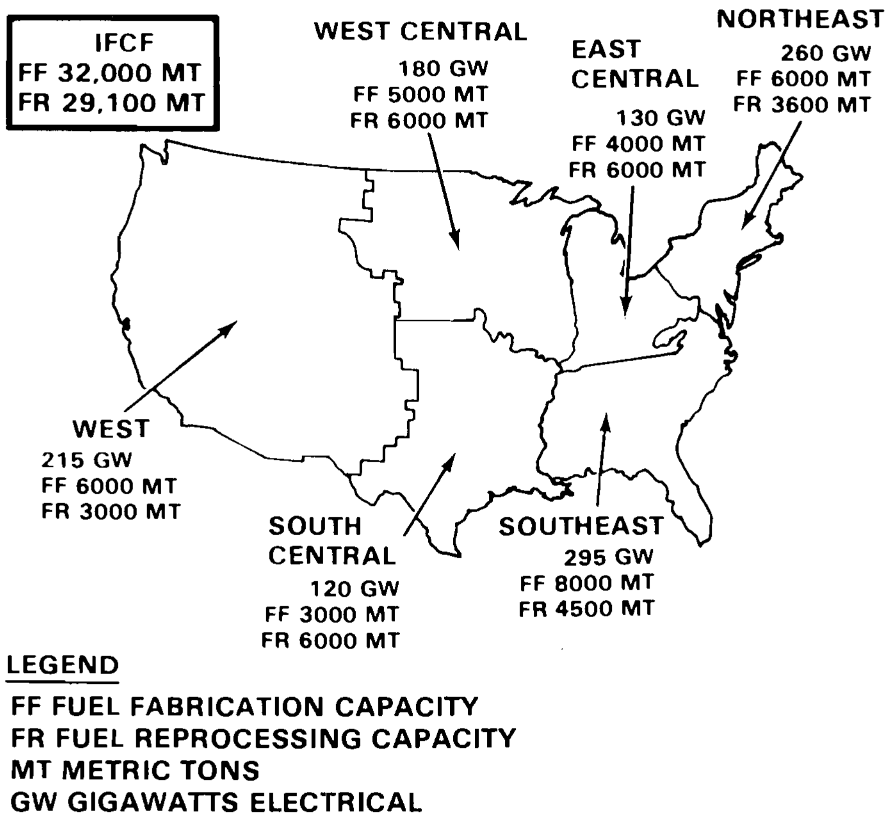


FIGURE 1. Projected Capacities for the Year 2000 for Reactors and Fuel Fabrication and Reprocessing Plants with Respect to FPC National Power Survey Regions

be located at the Hanford site to provide an arid, low population density reference site for evaluating the IFCF concept.

It was estimated that as many as 20 fuel fabrication and fuel reprocessing plants could be involved in the dispersed case, requiring up to 20 sites. However, the consolidation expected for the DFCF case would reduce these to 10 to 15 sites.

Size of IFCF

The idea of concentrating all the post reactor fuel cycle facilities for a 1,200 GWe electrical system at one site creates the image of an immense facility. The relatively small quantities of material actually involved in such a system are hard for most of us to visualize.

Such a site would be only one-half the area of the Hanford site, would have a peak work force of about 10,000, would handle weights of

TABLE 1. Comparison of Projected Facilities for DFCF and IFCF Cases

	Facilities in Year 2000		
	IFCF Case	DFCF Case	
		Waste Mgmt. Site[h]	Dispersed Sites
Reprocessing	5[b] [e]		8[a]
Calcination	5[e]		8
Calcine-To-Glass Conversion Facility	2[e]	2[g]	0[g]
Mixed Oxide and HTGR Fabrication	6[c]		6[c]
UO_2 Fabrication	0-6[c] [d]		6[c]
Spent Fuel Storage	5[f]		8
Alpha Waste Processing	2	2[i]	0[i]
Retrievable Storage γ	1	1	
α	1	1	
Solid Waste Burial (β-γ)	1	1	5
Enrichment (Topping)	1[j]		
TOTAL	1 Site	-- ∿ 10 to 20 Sites --	

a. Comprised of three 6000 MT plants, three 3000 MT plants, and one each at 1500 MT and 600 MT. These are nominal capacities for LWR fuel. HTGR and LMFBR fuels are assumed to be represented at half the nominal rate. The two smaller plants handle LWR fuel only; the other plants handle all types of fuel. If smaller plants (e.g. 1500 MT/yr) are optimum, this value may double.
b. Multifuel 6000 MT plants (weighted for HTGR and LMFBR fuels as in footnote a).
c. Averaging 2670 MT/yr, but ranging from 1500 to 4000 MT/yr in DFCF. If mixed oxide and high-enrichment plants are independent units, the number of plants may double.
d. UO_2 fabrication may be at or off the central site.
e. As many as 8 facilities of this type are conceivable.
f. Could conceivably range from 1 to 8 facilities.
g. Calcine-to-glass conversion facility(ies) could be located at each reprocessing plant.
h. Assumed to be Hanford for the purposes of this study.
i. Alpha waste processing facilities could be located at each reprocessing and fabrication facility.
j. Location of the topping enrichment plant onsite in the IFCF case is optional.

nuclear material similar to those at Hanford, and would probably require a support community of only 150,000 to 200,000 people.

The following text summarizes some of the differences foreseen between IFCF and DFCF complexes.

Transport Impact

The IFCF results in essentially all pure plutonium oxide (400 MT/yr) and all plutonium alpha bearing wastes being limited to onsite movement. Integrating the fuel cycle will eliminate almost 16,000 annual shipments of post reactor radioactive materials, including about 700 shipments of plutonium oxide. However, offsite spent fuel transport will increase by 3.5-fold tonne-miles for an IFCF in western U.S. (Since the quantity of material shipped remains unchanged in this study, the increase in tonne-miles is due to increased shipping distance.) The number of vehicles in transit with spent fuel will increase from about 90 to about 300. However, because much of the additional shipping distance lies in the sparsely populated western U.S., the potential population exposure increases only by a factor of about 2.5. For offsite transport of fresh mixed oxide and high enriched fuel the potential population exposure will be increased by 1.4-fold. Use of military cargo aircraft could reduce the metric ton-miles of truck transport of mixed oxide fresh fuel by a factor of 4.

Safeguards Impact

The IFCF greatly decreases the amount of special nuclear materials in transport that are easily converted to forms usable in explosives. The exact effects of these changes on the real risk of diversion is uncertain. But it is clear that they reduce accessibility of the more attractive nuclear materials (plutonium and enriched uranium) and enhance the capability for pursuit and recovery. On the other hand, having all facilities at one site makes the activities more attractive to subversion. Protective measures to discourage diversion might include: 1) establishing military type controls on transport, 2) using air transport or 3) placing high-energy gamma emitters adjacent to or mixed with the material being transported.

Cost Impact

Cost effects on nuclear power were not evaluated in depth, but no factors were found which indicated a penalty associated with the IFCF. The savings inherent in centralized larger scale facilities, from reduction in waste and plutonium transport and from integrated waste management, including decommissioning, would tend to compensate for increased fuel transport costs and compensation payments for deactivating present facilities.

Waste Management Impact

Waste inventories in other than final form would be minimized and geographically concentrated. Economies of scale and ease of control would be the source of significant benefits, covering many aspects of waste management, especially with regard to implementing policy changes. Decontamination and decommissioning wastes would be significantly reduced in volume and much more easily managed at an IFCF. The number of sites committed long-term for nuclear purposes would be reduced.

Radiological Impact

The IFCF has a unique and key advantage: It limits to one site the permanent (for practical purposes) dedication to contaminated status. The decision, however, is reversible, and at a later time any necessary additional sites can be dedicated.

The IFCF requires increased site area for comparable chronic exposure to large population areas. The increased site area required by the IFCF results in a substantial insurance margin for the very low probability but major accident; however, the multiple facilities do increase the possibility of deleterious interaction.

No significant difference between the IFCF or DFCF is expected in offsite emission effects. Any improvements required to control chronic emissions in the IFCF are forecast to be attainable when they will be needed.

The inherent radiological advantages in the IFCF for offsite population can be realized only in a site which minimizes the possibility of acts of nature leading to the transport of radionuclides to man's environment both during operation and after shutdown.

Nonradiological Impact

Lower impact from construction and from chemicals in gaseous and liquid effluents would slightly favor the IFCF. Water use impact would be essentially the same for either case, but more land would be used for the IFCF. Irreversible environmental effects will be about the same for the IFCF and DFCF; however, the IFCF can probably be located in an area with a lower natural biological productivity than can the DFCFs.

Timing Impact

An argument counter to the IFCF is the delay in getting it into beneficial operation. With the engineering done (GE, NFS, AGNS and possibly Exxon) and site characterization complete (as for AEC reservations), construction periods could be as short as three to five years. (Thus a crash program could conceivably put more IFCF capacity on line in the early eighties than currently planned by industry with a reduction in interim capacity resulting until the IFCF is operational. However, desire for higher capacity plants could cause delays due to additional design-development time.)

Labor Impact

The IFCF creates stability for both construction and operating forces by providing a constant source of employment and variety of job opportunities. The question of concentrated power for labor unions has not been examined.

Technical Skills and Depth

The IFCF clearly produces the incentives for improved technical capability. Professional communities attract professionals. Highly technological centers attract R&D organizations and consultants. Thus increased opportunity for communication and cooperation among technical experts would be expected at the IFCF.

Free Enterprise Effects

In one extreme, land on the IFCF site could be put out for bid (like oil shale land) and industry given almost complete freedom. In the other extreme, all operations could be federally funded (somewhere between the TVA and enrichment operations). Even in the latter case, Federal participation would be less than 10% of the cost of nuclear power.

There seems no doubt that there would be complaints by industry, workers and communities regarding decommissioning existing facilities or cancelling projected plants.

Policy Impact

Although not all inclusive, a number of items were identified as worthy of further investigation. Several broad questions provide a framework for identification and analysis of these policy considerations: What facilities should be included? Which location? What are the implementation considerations? What degree of Federal participation should be considered? These policy considerations range over the areas of economics, transportation, safeguards, labor, geography, environmental impact, and a multitude of others.

Two early matters must be dealt with: (1) Who should have the responsibility for answering the above questions in sufficient depth to allow a decision on whether to proceed with a generic environmental impact statement on the IFCF concept? (2) What are the timing imperatives for an IFCF, and what dispersed facilities should be permitted to be constructed?

Technical Development Impact

The scope of this study was limited to post reactor fuel cycle facilities. The numbers and types of power reactors and their fuel management schemes were not examined. The technical developments suggested below were established on this basis.

The IFCF will afford the opportunity to provide more effective emission control through concentrated R&D efforts. Included are noble gas, iodine, and tritium recovery and possibly a new generation of de-entrainment and filtration devices. Improved detectors will be needed to monitor performance. Natural mechanisms for transport of radioactive materials must be defined for a specific site in either the IFCF or DFCF case.

Transportation R&D will need to be focused on fuel transport with diminished emphasis on plutonium, waste and scrap transport.

The incentives for large plants will increase the need for improved high-capacity equipment, criticality prevention, remotized operations and full automation.

An IFCF will allow a true systems approach to Waste Management. Substantial redirection of current programs is foreseen with emphasis on centralized facilities, increased decontamination and reuse, and reduction in inventories.

Similarly the gross reduction in radionuclides transported offsite and the large inventory onsite will require the safeguards program to provide assured protection of inventories and immediate detection of clandestine movement.

Advantages and Disadvantages

On the whole, advantages of IFCF are seen to outweigh disadvantages. Table 2 lists major points in summary form.

TABLE 2. Advantages and Disadvantages of IFCF

Advantages	Disadvantages
General	
1. Decision can be reversed after commitment to IFCF is made.	
Transport	Transport
1. Removes all radioactive wastes from transport (until ultimate disposal) except those collected at the reactors and those in the form of spent fuel. 2. Makes possible the use of military cargo rail, truck and aircraft for high-security shipment of mixed-oxide fresh fuel.	1. Increases mileage for shipping fresh fuel. 2. Increases mileage for shipping spent fuel. 3. Increases mileage for shipping wastes collected at reactors. (Six commercial β-γ burial grounds already committed).
Safeguards	Safeguards
1. Reduces effort required to protect against diversion of nuclear explosive materials in transit. 2. Reduces consequences of sabotage in transit since only spent fuel elements are shipped in open transit. 3. Lessens diversion possibilities by removing all high-enriched nuclear materials from transport. 4. Facilities would allow concentration of inspection forces and allow for enclosure of the entire area.	1. Concentration of facilities makes them more vulnerable to attack by a foreign power. 2. Sabotage could shut down several facilities because of proximity. 3. Mixed oxide and highly enriched uranium fuels would be shipped greater distance.
Waste Management	Waste Management
1. Economies of scale may reduce quantities of waste generated. 2. Facilitate implementation of improved processing techniques. 3. Single glassification facility would ensure consistent product safety and manageability. 4. Onsite control ensures uniformity in waste management procedures. 5. Smaller inventories of waste held in other than final form at each point of generation.	1. Commercial burial sites for β-γ waste are already committed; their geographical distribution is near-optimum.
Radiological	Radiological
1. Eliminates transportation over public highways of highly radioactive materials between the several process stages. 2. Increases distance between the facilities and the site boundary. 3. Allows sufficient space to build additional facilities as required without dedicating new sites to long-term radiological restrictions.	1. The total quantity of radioactive effluents is discharged to air and water at a single site.
Ecological	
1. Larger exclusion area reduces potential food chain transfers of radionuclides. 2. Larger exclusion area reduces offsite movements of radionuclides.	
Services and Utilities	
1. Large utilization permits better personnel training, better facilities, hence improved services.	
Institutional	Institutional
1. If single ownership were instituted, it could result in better management because of better coordination, better control, and ability to afford better managers. 2. No duplication of facilities.	1. Significant changes in the present institutional arrangements. 2. Increased government regulation will require adjustment of free enterprise system.
Sociological	Sociological
1. Provides stable construction employment for several years, lessening social disruption.	1. Social concern about radioactivity could be increased because of: a. Longer transport of spent and fresh fuel. b. Potential for "common mode" failure within IFCF leading to major releases of radioactive materials.
Labor	Labor
1. National no-strike agreement may reduce stoppages. 2. Potentially better trained labor force. 3. Less labor required. 4. Stable employment for long period of time for both construction and operating personnel. 5. More favorable opportunities for technical and professional personnel to communicate and cooperate.	1. Labor force less readily available. 2. Labor strikes could have more impact on IFCF. 3. Less choice of location for employees.
Capital and Cash Flow	Capital and Cash Flow
1. A required overall funding plan may, when implemented, reduce market impact on capital raising and cash flow problems. 2. Lower capital and operating costs due to economies of scale.	1. Because traditional capital funding and cash flow needs might not prevail, the IFCF might require new and innovative methods for raising capital monies. 2. Higher interest costs on enriched fuel during transportation. 3. Initial capital investment is higher, particularly for a single owner. 4. May have higher transport costs for materials, equipment, and special service personnel.

3.0 DESCRIPTION OF DISPERSED FUEL CYCLE FACILITIES (DFCF) CASE

This section briefly describes the U.S. nuclear fuel cycle system expected in the year 2000 if no significant changes are made in policies or technical programs. The projection is based on continuation and/or extrapolation of policies, programs, and procedures currently authorized or anticipated in the near future. Individual fuel cycle facilities are assumed to be constructed or enlarged (1) on a time schedule which accords with the commercial demand for the services provided by the facilities and (2) at locations judged to be commercially competitive and sufficiently safe to satisfy licensing requirements. The dispersed distribution of facilities projected to result from these timing and siting considerations (Figure 1) is designated the Dispersed Fuel Cycle Facilites (DFCF) case.

3.1 NUCLEAR POWER

In the year 2000, the following picture is projected: the U.S. population is 285,000,000; half of all energy consumed goes for electric power generation; annual electric power consumption is 32,500 kW-hr per capita; total electric generating capacity is 7 kWe per capita or 2000 Gwe for the nation; 60% of this, or 1200 Gwe, is nuclear; two-thirds of the nuclear capacity is less than 12 years old, and one-third is less than 5 years old. Table 3 presents the distribution of these power reactors by FPC National Power Survey Region for an average generating capacity of 1200 MWe per reactor. The Southeast and Northeast regions lead in the number of reactors, as well as in the nuclear fraction of total regional generating capacity. The reactor mix is 73% LWR, 10% HTGR, and 17% LMFBR.

Year 2000 population projections range from 264 million to 324 million.[1-4] This study is based on the Series D projection of 287 million.

Projected power capacity and consumption figures used in this study have been updated in accordance with Reference 5, the high intermediate Case B.

TABLE 3. Projected Year 2000 Geographic Location of Reactor, Fuel Fabrication, Reprocessing Capacity, and Waste Storage Facilities with Respect to FPC National Power Survey Regions

	Number of Plants						
Type of Facility	West	West Central	South Central	East Central	Southeast	Northeast	Total
Reactors[a]	180	150	100	110	240	220	1000
Fuel Fabrication	2	2	2	2	2	2	12[c]
Regional Capacity, MT	6000	5000	3000	4000	8000	6000	32,000
Reprocessing	1	1	1	1	2	2	8[d]
Regional Capacity, MT[b]	3000	6000	6000	6000	4500	3600	29,100
Topping Enrichment	0	0	0	0	1	0	1
Federal Repository	1	0	0	0	0	0	1
Commercial Burial Grounds	2	1	0	1	1	1	6

a. 1200 MWe each

b. HTGR and LMFBR reprocessing capacities are reduced by a factor of 2 compared to LWR

c. If mixed oxide and high enrichment plants are independent units, the total number of plants may be doubled.

d. If smaller plants become optimum, this number could double.

Projections of total generating capacity and nuclear generating capacity are given in Figure 2. The nuclear fraction of the total capacity is projected to be 60 percent in the year 2000.

Figure 2[6] shows the historic and projected growth of annual production of electric energy. The projected nuclear power capacities for 1980, 1985, 1990, and 2000 are 102, 260, 500, and 1200 Gwe, respectively.

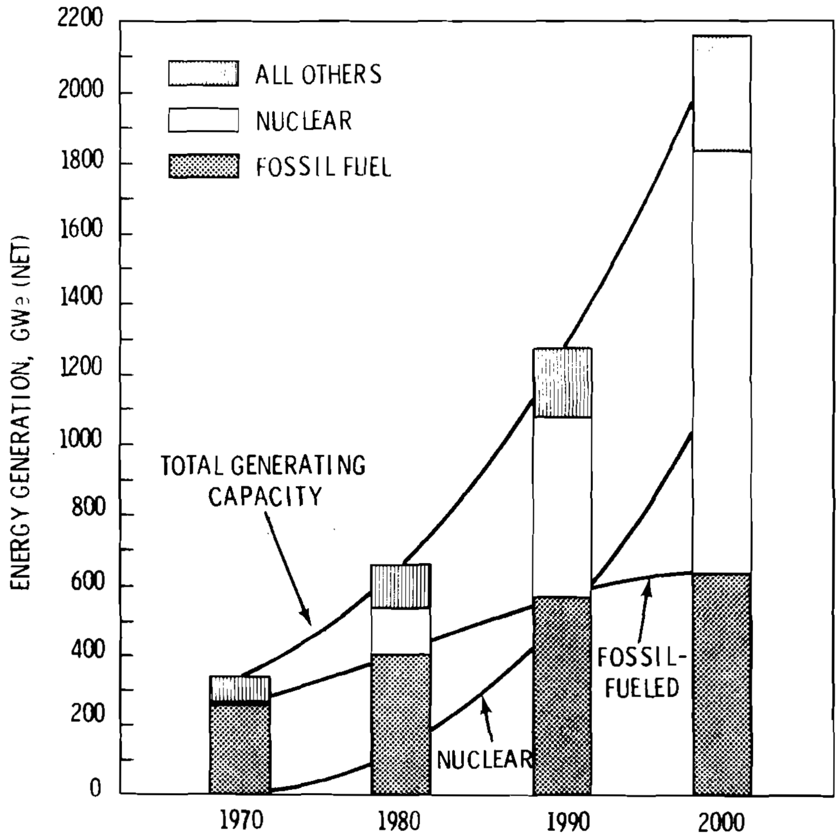
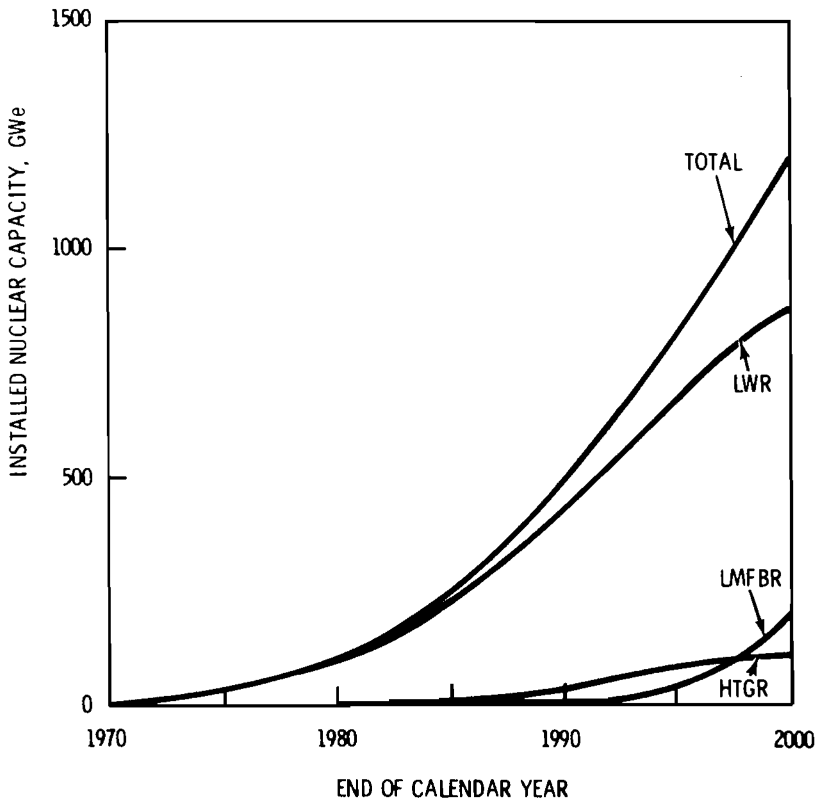


FIGURE 2. Projected Growth of Electrical Generating Capacity in the United States

The installed capacity of each major nuclear reactor type is shown in Figure 3.

FIGURE 3. Installed Capacity of Each Reactor Type



FPC Location of Nuclear Reactor Capacity, GW(net)

Calendar Year	North-east	East Central	South-east	West Central	South Central	West	Total
1970	3.1	0.1	0	1.2	0	1.5	5.9
1975	14	6	12	9	1	5	47
1980	24	9	30	18	6	15	102
1985	57	25	69	41	24	44	260
1990	108	55	123	74	51	89	500
1995	178	88	201	123	82	148	820
2000	260	130	295	180	120	215	1200

3.2 FUEL EXPOSURE AND REPROCESSING LOAD

The geographical distribution of spent fuel discharges is similar to that for reactors in Table 3. The actual reprocessing load for the year 2000 is 22,000 MT (19,400 MT LWR; 700 MT HTGR; 1,900 MT LMFBR). For early PWRs, exposure was typically 10,000 to 15,000 MWd/MT. Most recently discharged cores, such as Connecticut Yankee, San Onofre 1, and Yankee Rowe, have typically experienced 23,000 to 30,000 MWd/MT. Early BWRs discharged in 1962-1968, exhibited values of 8,000 to 14,000, whereas the most recent values are 15,000 to 18,000.

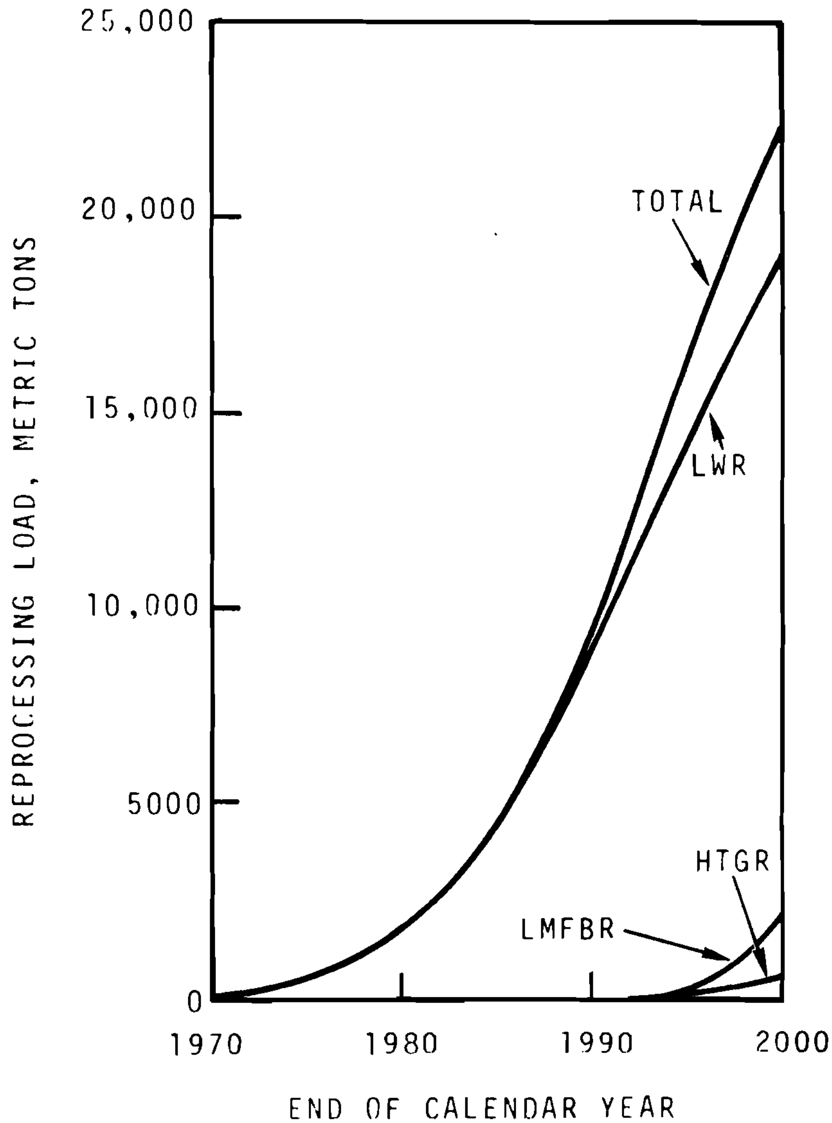
LWR plutonium recycle is assumed to begin in 1977 and to continue beyond the year 2000.

Year 2000 assumptions of fuel exposure[7,8] are an average burnup of approximately 33,000 MWd/MT for LWRs, with or without Pu recycle. The value is based on the Diablo Canyon reference PWR study.[9] For HTGRs, the figure is 93,500 MWd/MT, based on General Atomic data.

LMFBR overall burnup[8] is 32,700 MWd/MT, based on HEDL data. Reference 10 assumed burnups of 31,000 MWd/MT, 68,000 MWd/MT and 39,000 MWd/MT for LWR, HTGR, and LMFBR (core plus blanket), respectively. In all cases the more recent data of Reference 8 were selected for use here. If these burnup figures prove optimistic, the effect will probably be manifest in lower power output, rather than in an increased reprocessing load, core residence times being essentially fixed.

Based on the estimated year 2000 nuclear power generation and the fuel discharge assumptions listed above, Figures 4 and 5[8] present computed reprocessing loads for each reactor type. (The PWR curve represents all LWRs. The calculations were made for a PWR, and it was concluded that BWR data would be similar). Figure 4 presents actual quantities of uranium, plutonium, and thorium in spent fuel for reprocessing, a total of 22,000 MT. This figure shows some fuel with relatively low exposure (from startup cycles) as well as UO_2-PuO_2 and UO_2-ThO_2 scrap recycled from fabrication

FIGURE 4. Actual Annual Reprocessing Load Through the Year 2000[8]

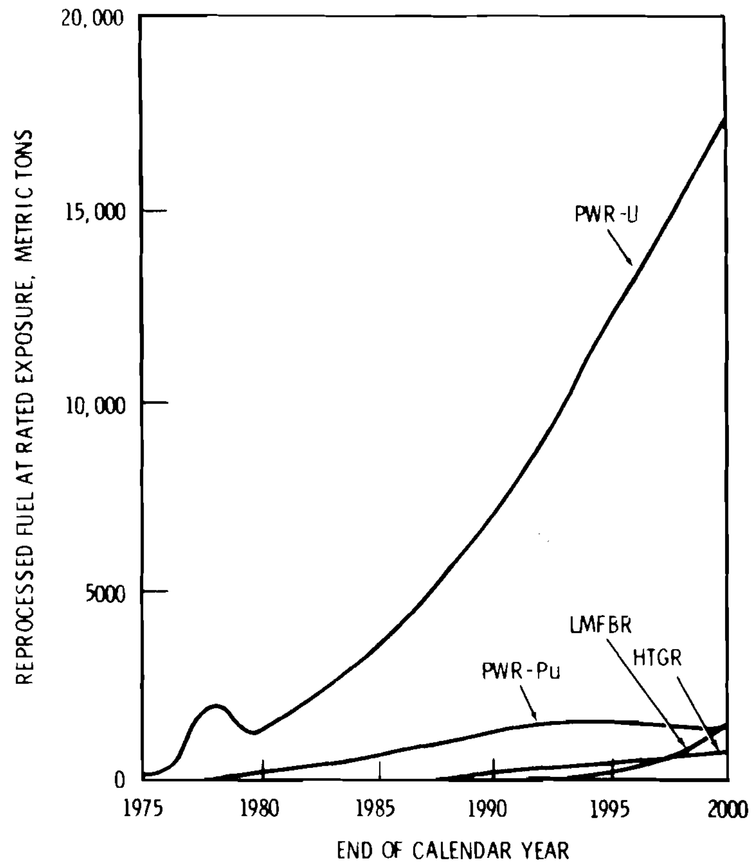


Reprocessing Load Distribution by FPC Region, MT/yr[a]

Calendar Year	North-east	East Central	South-east	West Central	South Central	West	Total US
1975	177	72	144	107	8	59	567
1980	417	152	502	297	106	261	1735
1985	1017	436	1223	713	419	771	4579
1990	2016	1006	2282	1391	939	1664	9298
1995	3503	1736	3966	2409	1618	2889	16,121
2000	5377	2628	6099	3675	2446	4419	24,644

a. HTGR and LMFBR fuels are weighted by a factor of 2, based on the assumption that these fuels are reprocessed in multipurpose reprocessing plants at half the rate of LWR fuels.

FIGURE 5. Reprocessed Fuel at Rated Exposure Through the Year 2000[8]



plants. Figure 5 presents equivalent tons of fuel having the rated steady-state exposures. For comparison, earlier projections[10] of year 2000 fuel discharge were considerably higher at 30,100 MT (18,800 MT for LWR; 2,100 for HTGR; and 9,200 for LMFBR). Figure 5 indications are somewhat lower than the fuel-trac projections,[11] which extend through 1981.

Projected inventories of spent fuel at the reactors were estimated assuming the reprocessing loads of Figure 5 and post-irradiation decay times of 150, 365, and 90 days, for LWR, HTGR, and LMFBR fuels, respectively.[8] The average year 2,000 LWR spent fuel inventory is estimated to be approximately 8,000 MT; for HTGR, 700 MT; for LMFBR, 450 MT.

The three U.S. fuel reprocessing plants in operation or being constructed are described in Table 4.[4] One (NFS) has been in operation since

TABLE 4. Irradiated Fuel Reprocessing Plants Site Data and Demography[4]

Plant and Location	Plant Capacity MTU/day	Site Size, Acres	Population Density People/sq. mi.	Population of Nearby Cities: City	Population	Distance, Miles	Startup
NFS Nuclear Fuel Services, West Valley, N.Y. (N.F.S.)	1[a]	3500	90	Buffalo	463,000	28	1974
				West Valley	<1,500	4	
MFRP Midwest Fuel Recovery Plant, Morris, Ill. (General Elec.)	1	890[b]	150	Morris, Ill.	8,000	8	
				Joliet, Ill.	79,000	15	
				Aurora, Ill.	74,000	27	
BNFP Barnwell Nuclear Fuel Plant, Barnwell, S.C. (Allied-Gulf Nuc. Serv.)	5	1700[c]	35	Barnwell,S.C.	4,500	7.5	1976
				Aiken, S.C.	16,000	26	
				Augusta, Ga.	60,000	33	

a. NFS has applied for a license to operate at 2.5 MTU/day.
b. Adjacent to the Dresden nuclear reactor site of 2,230 acres
c. Adjacent to AEC Savannah River Plant exclusion area

1966, but is shut down indefinitely for modifications and is at least 3 to 5 years away from resuming operation. Another (G.E. MFRP)[a] is expected to commence operation late in 1974. The third (AGNS) is in early construction and scheduled for operation in 1976. The three plants have a combined design capacity sufficient to meet the projected fuel reprocessing requirements of Figure 5 until about 1982. (See also Reference 12).

3.3 FUEL REPROCESSING CAPACITY

The reprocessing load, illustrated in Figure 4, is seen to be accommodated in the year 2000 by eight to twenty reprocessing plants, located as shown in Table 3. Total capacity is 29,100 weighted MT/year. (HTGR and LMFBR loads are weighted by a factor of two.)

a. During the compilation of this report GE declared an extensive delay starting of the Midwest Fuel Recovery Plant.

These projections show sufficient capacity to match requirements, assuming plant construction and expansion occur as planned and as the market requires, without delays from intervention or construction. These last two considerations are arguments for a projection with a relatively small number of reprocessing plants of large capacity.[a] It is generally faster and less expensive to enlarge an existing plant. Larger plants are also more economical to operate.

3.4 FUEL FABRICATION

The projection of fuel fabricated annually through the year 2000 is shown in Figure 6.

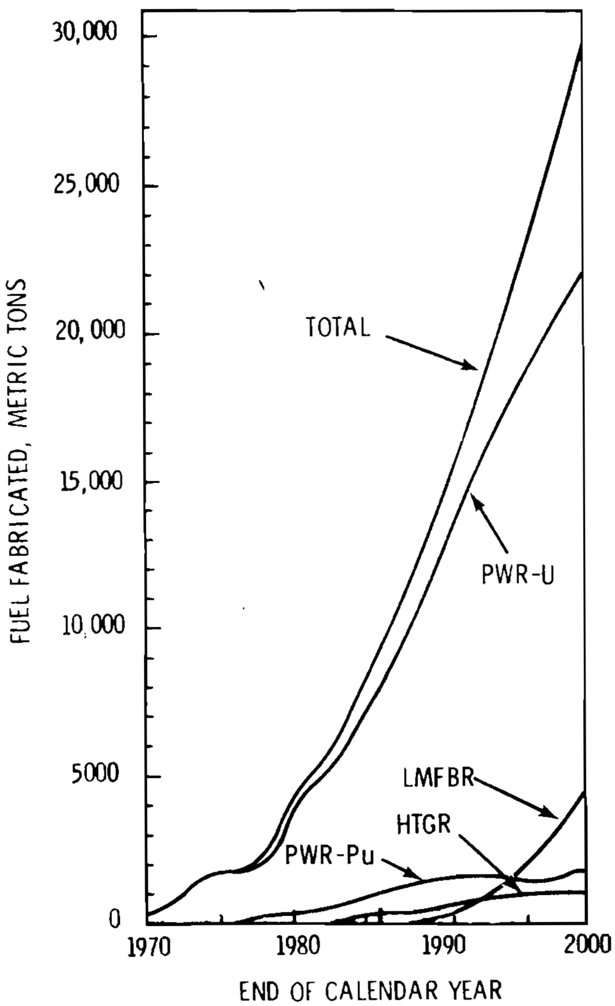
For the year 2000 a total of 29,100 MT of fuel per year is produced at twelve fuel fabrication locations, with capacity averaging 2,700 MT/year each. The geographical location and regional capacity are shown in Table 3. For simplicity, the load in each region is assumed to be divided equally between the two locations within the region. Fuel breakdown by reactor type is 22,100 MT for LWRs, 1,800 MT for Pu recycle in LWRs, 1,000 MT for HTGRs, and 4,200 MT for LMFBRs. At six of the fabrication locations (one per region), only low enriched UO_2 fuel is handled. The other six locations fabricate both UO_2 fuel and mixed oxide fuels. A topping enrichment plant to supply the high enrichment needs of HTGR is accounted for in Table 3.

3.4.1 Forecast of Plant Identity and Location

The most recent projections[8] of fuel fabrication requirements call for 29,100 MT in the year 2000.

a. Prior studies[7] had assumed that it might be technically and economically feasible to construct reprocessing plants with capacities as high as 6000 MT per year. Increasing technical complexity and greatly increased costs now indicate that a greater number of smaller plants might be a more logical estimate.

FIGURE 6. Projection of Fuel Fabricated Annually Through the Year 2000[8]



Fuel Fabrication Loads by FPC Region, metric tons

Calendar Year	North-east	East Central	South-east	West Central	South Central	West	Total US
1970	183	7	0	70	0	92	352
1975	538	221	438	326	24	178	1725
1980	1025	373	1233	729	260	641	4261
1985	1883	806	2264	1321	774	1429	8477
1990	3189	1592	3607	2200	1485	2633	14,706
1995	4697	2337	5317	3235	2179	3877	21,642
2000	6333	3126	7173	4348	2913	5216	29,109

Although fuel fabrication requirements will increase rapidly for many years, opportunities for independent fabricators will continue to be limited. This results from 1) the fact that replacement fuel requirements lag behind those for initial-core fuel and 2) the tendency of reactor purchasers to contract with reactor vendors for fabrication of replacement fuel at the time of reactor purchase. The fuel market for research and other specialized reactors is small and not expected to increase appreciably.[13] For these reasons, the number of year 2000 fuel fabrication plants, will probably not change greatly from the present status. Rather, the capabilities of existing or near-future plants will probably be expanded in an effort to meet the demand.

The current status and planned capabilities of the U.S. fuel fabrication industry, along with information or enrichment, R & D, and reprocessing, are given in Reference 13. A simplified listing of fuel fabrication capabilities is given in Table 5.

Companies in competition for fabrication of UO_2 replacement fuel are the four LWR manufacturers plus one independent fabricator, Exxon Nuclear. Until the latter half of 1973, a second independent fuel fabricator (Gulf United Nuclear Fuels) was also competing for reload orders. The fact that there were five different companies offering UO_2 fabrication services in early 1971 illustrates the difficulties encountered by independent fabricators.

AEC work on plutonium recycle has been phased out.[13] Programs sponsored by the utilities, the Edison Electric Institute and the fuel fabricators are continuing and have demonstrated satisfactory performance. At present, Consumers Power Company's Big Rock Point Plant is the only commercial reactor using, on a limited basis, mixed-oxide fuel.[4] Most of the mixed-oxide fuel fabricators are planning to have small numbers of mixed-oxide fuel assemblies inserted into reactors during the coming year. These demonstrations are to pave the way for plutonium recycle on a large scale.

TABLE 5. Domestic Fuel Fabrication Capabilities

Licenses	Plant Location	Fabrication and/or Processing of Fuels Containing			
		Pu	U-233	Carbides	Fabrication of Fuel Elements Containing UO_2
Atomics International	Canoga Park, CA	X		X	
Babcock and Wilcox	Lynchburg, VA	X			X
NUMEC (subs. of B & W)	Apollo, PA				X
	Leechburg, PA	X	X	X	
Combustion Engineering	Windsor, CN	F			X
Exxon Nuclear	Richland, WA	X			X
General Atomic	San Diego, CA			X	
	Youngsville, NC			F	
General Electric	San Jose and Vallecitos, CA	X			
	Wilmington, NC				X
Kerr-McGee	Cimarron, OK	X		X	X
Nuclear Chem. and Metals	Huntsville, TN			X	
Nuclear Fuel Services	Erwin, TN	X	X	X	
Westinghouse	Anderson, SC	F			
	Cheswick, PA	X		X	X
	Columbia, SC				X

X Present Capability
F Future Capability

3.4.2 Assumptions Regarding Plant Size

Year 2000 projections of the size and location of fuel fabrication plants are as uncertain as those related to reprocessing plants. One might project that the 24,640 MT/year weighted load will be satisfied by 16 or 17 plants, each of 2,000 MT capacity, listed as the present plants in Table 5. Some of these plants might fabricate UO_2 only and others provide both UO_2 fuel and mixed-oxide fuel. No mixed-oxide fabrication plants of this size exist today. However, a Westinghouse plant designed to produce 200 MT/year of mixed oxide (3 to 4% Pu) for LWR plutonium recycle is scheduled for operation at Anderson, S.C. in 1977. It is anticipated that the mixed-oxide fabrication industry will be dominated by plants in the 200 to 400 MT/year range through the year 1990.(4) The Westinghouse UO_2 fabrication facility at Columbia, S.C. has a 1,000 MT/year capacity.

For uniformity with other studies, the latest projections(8) of plant capacity and location are used here. These projections, given in Table 6, assume a strong correlation between fuel fabrication load and total capacity of fabrication plants within each FPC Region. The types of fuel fabricated in each region are projected in Table 6. Where an actual number of plants must be assumed, it is projected that there are two equal-capacity plants in each region (a total of 12 plants). For simplicity, half of these are assumed to be UO_2 only; the other half are assumed to provide both UO_2 and mixed oxide fuel in equal quantities. This results in roughly three-fourths of the capacity lying in UO_2 fuel fabrication, in agreement with the fabrication requirements of 22,000 MT UO_2 versus 6,000 MT mixed-oxide LWR-Pu and LMFBR and 1,100 MT HTGR fuel.

3.5 WASTE GENERATION

Fuel cycle wastes generated in the year 2000 are summarized in Figure 7. Accumulated quantities from previous years are also shown, along with numbers of annual shipments of various types of waste. Included are 250 rail shipments of solidified high-level waste and 1150 of alpha waste. The waste classifications followed are generally those of Blomeke et al.(7,8) In several cases, a wide range of possible quantities can be projected,

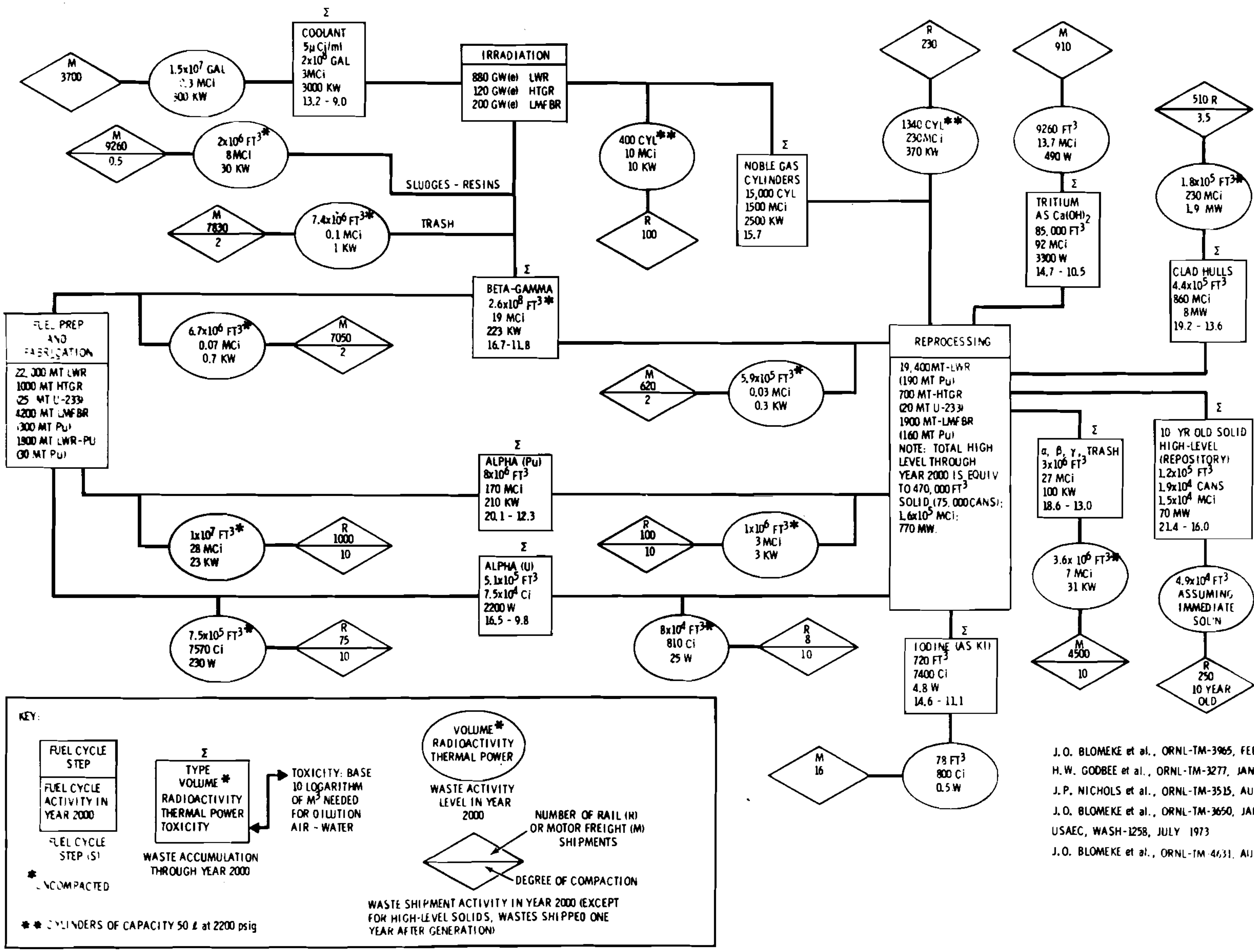
TABLE 6. Projected Capacities and Locations of Fuel Fabrication Plants[8]

Year	Total On-Line Capacity	Region	Fuel Fabrication Capability
1970	300	East Central	LWR-U
	200	Southeast	LWR-U
	100	South Central	LWR-U
	100	West	LWR-U
1980	500	Northeast	LWR-U, Pu
	1000	East Central	LWR-U, Pu
	2500	Southeast	LWR-U, Pu; HTGR
	500	West Central	LWR-U, Pu
	500	South Central	LWR-U, Pu; LMFBR
	1000	West	LWR-U, Pu; HTGR
1990	3100	Northeast	LWR-U, Pu
	2000	East Central	LWR-U, Pu
	5000	Southeast	LWR-U, Pu; HTGR
	2000	West Central	LWR-U, Pu
	1500	South Central	LWR-U, Pu; LMFBR
	2500	West	LWR-U, Pu; HTGR
2000	6000	Northeast	LWR-U, Pu
	4000	East Central	LWR-U, Pu; LMFBR
	8000	Southeast	LWR-U, Pu; HTGR, LMFBR
	5000	West Central	LWR-U, Pu; HTGR
	3000	South Central	LWR-U, Pu; LMFBR
	6000	West	LWR-U, Pu; HTGR; LMFBR

depending on the bases for the projection. To minimize small discrepancies between various assumptions, the results were rounded to one or two significant digits.

For purposes of this study, the handling, storage, and disposal of the accumulated wastes listed in Figure 7 are assumed to be performed as follows. High-level waste is calcined at each reprocessing plant 3 years after fuel dissolution and is shipped to a Calcine Conversion Facility (CCF) 10 years after reprocessing. The CCF is assumed to be located at Hanford. There the calcine is converted to a stable glass/ceramic product of low dispersability. Two parallel conversion facilities (or at least two parallel lines) at the same site are envisioned for reasons of redundancy. The waste is

FIGURE 7. Generation of Wastes by U.S. Nuclear Power Industry in and Through the Year 2000



J.O. BLOMEKE et al., ORNL-TM-3965, FEBRUARY 1974
H.W. GODBEE et al., ORNL-TM-3277, JANUARY 1971
J.P. NICHOLS et al., ORNL-TM-3515, AUGUST 1971
J.O. BLOMEKE et al., ORNL-TM-3650, JANUARY 1972
USAEC, WASH-1258, JULY 1973
J.O. BLOMEKE et al., ORNL-TM-4631, AUGUST 1974

then stored under federal jurisdiction at an associated Retrievable Surface Storage Facility (RSSF). Work is continuing on techniques for ultimate disposal of waste; a specific method may have been selected and demonstrated by pilot-plant by the year 2000. All waste streams other than high-level are held at the point of origin for 1 year, compacted if feasible, and shipped to the federal repository. Alpha waste will be treated (e.g., incineration, acid digestion) and converted to an insoluble final form, probably by two parallel lines or facilities at the repository, for further reduction of volume prior to storage at the same location. It is possible that one or more independent alpha-waste processors will be in operation, probably near fuel fabrication plants. Low-level beta-gamma waste will qualify for disposal in licensed surface burial grounds, six of which are presently in existence, distributed geographically as in Table 3.

The unit bases for waste generation follow in Table 7. Estimates concerning decontamination and decommissioning wastes and treated effluents are not included. All waste streams are assumed to be held 1 year at point of origin, with the exception of high-level waste, for which 10-year holdup is assumed.

The remainder of this section briefly discusses the origin, characteristics, and immediate storage and/or disposal methods for the major types of waste.(7) Longer term storage/disposal is discussed in Section 3.6.

3.5.1 High-Level Waste

High-level waste is defined as "those aqueous wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuels." These wastes contain virtually all nonvolatile fission products, ∿ 0.5 percent of the uranium and plutonium in the spent fuels, ∿ 0.1 percent of the iodine and bromine fission products plus all other actinides formed by transmutation of the uranium and plutonium in the reactors. It is projected that these materials will be calcined and packaged in steel canisters typically 1 ft in diameter by 10 ft in length and shipped by rail to a repository after 10 years' storage at the reprocessing plants.

TABLE 7. Generation of Wastes by United States Nuclear Power Industry Unit Bases

Waste	Unit Bases	Compaction Factor	Volume/ Shipment	Reference
High-Level	2 ft^3/MT - LWR 3 ft^3/MT - LMFBR 6 ft^3/MT - HTGR	-	12 Canisters 75 ft^3	(7)
Clad Hulls	7.4 ft^3/MT - LWR[a] 30.8 ft^3MT - LMFBR[a]	3.5	27 Packages LWR 36 Packages LMFBR 3.53 ft^3/Package	(7)
Alpha-Beta-Gamma (>µCi/kg and require shielding and remote handling)	10,000 ft^3/MT of Plutonium or U-233 processed (0.025g of Pu or U per ft^3).[a]	10[c]	75 ft^3	(7)
Alpha	10,000 ft^3, 20,000 ft^3, and 4,000 ft^3/MT of Plutonium or U-233 processed in Fuel Preparation, Fabrication, and Reprocessing Plants, respectively. (0.25 g of Pu or U per ft^3).[a]	10[c]	1000 ft^3	(7)
Beta-Gamma (Fuel Preparation. Fabrication, and Reprocessing)	4,000, 8,000 and 1600 ft^3 per MT of Pu or U-233 Processed at Fuel Preparation, Fabrication, and Reprocessing Plants, respectively.[a,b] 100 ft^3/MT for UO_2[a].	2[c]	475 ft^3	
Beta-Gamma reactors	300 ft^3/MT Trash - LWR[a] 200 ft^3/MT Trash - LMFBR[a] 100 ft^3/MT Resins and Sludges from LWRs[a]	2 Trash 0.5 Resins and Sludges[c]	475 ft^3	(2)
Iodine (as KI)	0.01g of I/MWD (th) 99.9% of Iodine Recovered at Reprocessing Plant	-	---	(7)
Noble Gases	0.037 Cylinder/MT - BWR 9.3×10^{-3} Cylinder/MT - PWR 0.06 Cylinder/MT - Reprocessing 5700 kg/MT	-	6 Cylinders (50 liter gas cylinders at 2200 psig)	(7)
Tritium (reprocessing $Ca(OH)_2$)	0.02--.03 Ci of H-3/MWD (th), 700-1200 Ci/MT, 0.5 ft^3 $Ca(OH)_2$/MT	-	10.2 ft^3 of $Ca(OH)_2$	(7,8)
Tritium (Reactors, as coolant)	800 gal tritiated water - (5µCi/mℓ)/MT, result of bleeding about 20,000 gal/yr from a 1000-MW LWR	-	4000 gal	(7)

a. Uncompacted volumes
b. Unit bases for fuel fabrication, preparation, and reprocessing are a factor of 10 less than those presented in ORNL-TM-3965. No allowance for volume reduction was made in ORNL-TM-3965.
c. Compacted volume associated with 55-gallon steel drums (assumes solidification of resins-sludges increases volume by factor of two).

3.5.2 Cladding Wastes

Cladding wastes are residual Zircaloy and stainless steel cladding and structural components of the fuel assemblies that remain after the fuel cores have been dissolved. Although their radioactivity arises mainly from neutron-induced isotopes, the hulls are similar to high-level waste in that approximately 0.05 percent of the actinides and fission products (and several percent of fission-product tritium in the case of Zircaloy cladding) may be associated with the cladding wastes. The compacted cladding, after 1-year storage at the reprocessing plant, is shipped by rail to a repository.

Alpha-Beta-Gamma Wastes

Alpha-beta-gamma wastes are defined as solid materials, other than high-level and cladding wastes, which contain long-lived alpha activities greater than 10 μCi/kg and have gamma radiation levels sufficient to require biological shielding and remote handling. They arise at fuel reprocessing plants and consist of an assortment of materials similar to alpha wastes. It is assumed that 0.025 percent of the fission products in the spent fuels is present.

Alpha Waste

"Alpha" wastes are presently defined as solid materials that contain plutonium or other long-lived alpha emitters in concentrations greater than the upper range of concentration of radium in the earth's crust. Wastes containing less alpha activity are regarded as disposable in burial grounds, whereas alpha wastes must be stored in special repositories. Alpha wastes arise principally at fuel preparation and fabrication plants, and to a lesser extent at fuel reprocessing plants. They consist of solid materials of paper, cloth, wood, plastic, glass, and metal, as well as salts and sludges from treatment of liquid waste streams and of filters from cleanup of off-gas. It is projected that alpha wastes will be shipped by rail and accumulated at a repository 1 year following their generation.

Beta-Gamma Wastes

These diverse solid wastes, common to all facilities handling radioactive materials, range from radionuclide concentrates generated in decontamination of plant effluent streams to almost every conceivable type of contaminated solid refuse from plant operations. Since they do not contain long-lived alpha activity, they are disposable in surface burial grounds.

Figure 7 indicates year 2000 quantities related to waste generation, accumulation, and transportation. Generation quantities are given in terms of volume, radioactivity, and thermal power. Accumulation includes these measures and measures of toxicity. Transportation is given in terms of shipments by rail (R) or motor freight (M), assuming a certain degree of compaction.

Iodine

Iodine is a semivolatile fission product which, because of its biological significance, requires special attention to ensure adequate safety. R & D work shows promise of removing at least 99.9 percent of it from the other fuel constituents by volatilization at the head-end of the process. For this study it was assumed that 99.9 percent of the iodine was recovered in a pure form at the reprocessing plants, converted to KI, and stored for 1 year before shipment by truck to a repository or disposal site. The quantity involved, in curies, and in cubic feet, is extremely small in comparison with other waste streams.

Noble Gases

Noble-gas fission products consist of stable and short-lived isotopes of krypton and xenon. Less than 1% of these gases are released to the atmosphere at power plants. The rest remains within the fuel delivered to the reprocessing plants. Only ^{85}Kr (10.8 year half-life) remains in the irradiated fuel after 150 days decay. Although offsite radiation exposures have been small, processes are available or under development for recovery of these gases from plant off-gas streams. It is projected that the mixed gases will be collected under 2200 psig pressure in 50-liter gas cylinders, stored for 1 year at the reprocessing plant, and shipped by rail to a remote site for long-term storage.

Tritium

Tritium wastes are generated at power stations and fuel reprocessing plants. Tritium in LWRs arises principally from neutron reactions with lithium and boron that may be present in primary coolants. It is projected that new power stations will recycle the coolant until the tritium reaches a prescribed concentration. This concentration will be maintained by adding fresh water and bleeding off tritiated water. This waste containing tritiated water can be stored in tanks at the power stations for 1 year then shipped by truck to disposal sites.

Tritium produced in fission appears in wastes from fuel reprocessing. A few percent may be associated with the cladding, but most is present with the core materials and is eventually released as water vapor to the atmosphere. Future plants having head-end operations like "voloxidation" should be able to separate and recover the tritium in a relatively small volume. This concentrate could be converted into a stable solid form, such as $Ca(OH)_2$, packaged, and shipped by truck for storage or disposal.

Tritium may act differently in LMFBRs than in other reactor types. As much as 95 percent may diffuse through the stainless steel cladding during reactor operation and appear as sodium tritide sludge in primary-coolant cold traps. Processes for recovery and packaging of the tritium from LMFBR fuels could be installed at power stations rather than at fuel reprocessing plants (but if the FRP handles more than just LMFBR waste, then tritium recovery is still required at the FRP).

3.6 WASTE STORAGE/DISPOSAL

A. Projected Waste Inventories

The projected year 2000 accumulations of various types of waste are given in Figure 7, in terms of curies, volume, and thermal generation.

Basically the year 2000 storage/disposal requirements consist of the following accumulated inventories of compacted wastes: 19,000 canisters (1 ft diameter by 10 ft long) of solidified high-level waste, a total of 1.2×10^5 ft^3; 4.4×10^5 ft^3 of cladding hulls; 85,000 ft^3 of tritium as

$Ca(OH)_2$; 720 ft^3 of iodine as KI; 15,000 cylinders (50 ℓ each, under 2200 psig) of noble gas; 2.6 x 10^8 ft^3 of beta-gamma waste; 3.6 x 10^6 ft^3 of alpha-beta-gamma waste; 8 x 10^6 ft^3 of alpha (Pu) waste; 5.1 x 10^5 ft^3 of alpha (U) waste; 2 x 10^8 gal of tritium-contaminated reactor coolant. Since the high-level waste may be held at the reprocessing plant for 10 years, only the pre-1990 high-level waste is included in Figure 7. An additional quantity is assumed to be stored at the reprocessors. Part of this will be in liquid form. If only the liquid from the three most recent years of reprocessing is unsolidified, then the liquid high-level storage consists of approximately 6 x 10^6 gal. The solidified high-level waste stored at the reprocessors would be 30,200 canisters.

The other waste streams are assumed to be held at the point of origin for one year. Thus the year 2000 storage at the point of waste origin would be approximately the year 2000 generation quantity shown for each stream in Figure 7.

4.0 DESCRIPTION OF INTEGRATED FUEL CYCLE FACILITIES (IFCF) CASE

This section describes a possible system configuration of U.S. nuclear fuel cycle facilities for the year 2000. The configuration embodies a large, integrated fabrication/processing/storage park termed the Integrated Fuel Cycle Facilities (IFCF) case. The facilities assumed for the DFCF, described in Section 3, and the IFCF case are compared in Table 8.

For the IFCF case, the basic demands upon the nuclear fuel cycle system are unchanged. That is to say, the projected nuclear generating capacity and the reactor mix, characteristics, and regional distribution are unchanged. This implies that the total and regional requirements for fuel fabrication and reprocessing are unchanged in quantity and reactor type.

Numerous options exist regarding the types of facilities to be located at the IFCF site. Some of these options are discussed throughout this report. The primary assumption for the present IFCF study is that policies and regulations will have been formulated and enforced, constraining fuel fabrication plants (mixed oxide, HTGR fuel, and possibly UO_2), all reprocessing plants, waste disposal facilities, and the topping enrichment plant to be located at one integrated site. For purposes of the present study, the IFCF site was taken to be the Hanford reservation in the state of Washington. Also, to provide a basis for comparison of IFCF locations, the transporation requirements were examined for the Southeast FPC region. Twelve fabrication plants are assumed, the same in number and capacity as those for the DFCF case. Five multifuel reprocessing plants, each of 6000 weighted MT capacity, are assumed for this study; but it is conceivable that as many as eight such facilities will be in operation. Each reprocessing plant includes a calcination facility. Two glass plants (CCFs) are included; however, it is possible that a CCF could be located at each reprocessing plant, resulting in a total of five to eight CCFs. Two facilities for processing alpha waste (e.g., incineration, acid digestion, etc.) are envisioned. Burial of beta-gamma waste occurs only at the integrated site. In addition, the IFCF could conveniently include facilities for technical support personnel and other indirect functions.

TABLE 8. Projected Facilities for DFCF and IFCF Cases

	Facilities in Year 2000		
	IFCF Case	DFCF Case	
		Waste Mgmt. Site[h]	Dispersed Sites
Reprocessing	5[b] [e]		8[a]
Calcination	5[e]		8
Calcine-To-Glass Conversion Facility	2[e]	2[g]	0[g]
Mixed Oxide and HTGR Fabrication	6[c]		6[c]
UO_2 Fabrication	0-6[c] [d]		6[c]
Spent Fuel Storage	5[f]		8
Alpha Waste Processing	2	2[i]	0[i]
Retrievable Storage γ	1	1	
α	1	1	
Solid Waste Burial (β-γ)	1	1	5
Enrichment (Topping)	1[j]		1
TOTAL	1 site	-- ∿ 10 to 20 Sites --	

a. Comprised of three 6000 MT plants, three 3000 MT plants, and one each at 1500 MT and 600 MT. These are nominal capacities for LWR fuel. HTGR and LMFBR fuels are assumed to be represented at half the nominal rate. The two smaller plants handle LWR fuel only; the other plants handle all types of fuel. If smaller plants (e.g., 1500 MT/yr) are optimum, this value may be doubled.
b. Multifuel 6000 MT plants (weighted for HTGR and LMFBR fuels as in footnote a).
c. Averaging 2670 MT/yr, but ranging from 1500 to 4000 MT/yr in DFCF. If mixed oxide and high enrichment plants are independent units, the number of plants may be doubled.
d. UO_2 fabrication may be at or off the central site.
e. As many as 8 facilities of this type are conceivable.
f. Could conceivably range from 1 to 8 facilities.
g. Calcine-to-glass conversion facility(ies) could be located at each reprocessing plant.
h. Assumed to be Hanford for the purposes of this study.
i. Alpha waste processing facilities could be located at each reprocessing and fabrication facility.
j. Location of the topping enrichment plant onsite in the IFCF case is optional.

5.0 COMPARISON OF DISPERSED AND INTEGRATED CASES

The following subsections discuss how various parameters influence the dispersed and integrated concepts. Some of the parameters considered are transportation, safeguards, radiological considerations, and safety.

5.1 TRANSPORTATION

From Table 8 and the text of Sections 3 and 4, the transportation requirements of the IFCF and DFCF cases for the year 2000 can be determined for sites located in the Northwest (IFCF-NW) and Southeast (IFCF-SE) FPC power regions. A summary comparison is given in Table 9.

5.1.1 Special Nuclear Materials

In the year 2000, for the DFCF approximately 360 MT of plutonium as PuO_2 powder will be shipped by truck from reprocessors to fuel fabricators in 720 shipments of 0.5 MT each. At any time, an average of 2.0 such loads (1.0 MT) will be on the road. This figure may be optimistic because the reprocessing and fabrication plants were assumed to be located so precisely by FPC Region, effecting a favorably low average shipping distance.

In addition, 25 MT of ^{233}U will be shipped by truck for HTGR fuel fabrication in the DFCF case. This will involve 50 shipments, with an average of 0.14 loaded vehicles (0.07 MT) on the road at any time. Shipping of 93% enriched ^{235}U and 40% enriched ^{235}U for HTGRs is projected to involve, respectively, 52 and 12 MT/year, 70 and 24 shipments/year, and 0.4 and 0.06 loaded trucks in transit. Offsite shipments of PuO_2, 93% $^{235}UF_6$, 40% $^{235}UO_2$, and HTGR-UO_2 drop to zero for the IFCF-NW and IFCF-SE systems.

5.1.2 Spent Fuel

Assumed shipment modes for spent fuel, fresh fuel, and Pu and HTGR-^{233}U are given in Table 10.[8] The 3.1 MT rail cask of ORNL design is similar to an IF-300 shipping cask carrying an average of 3.3 MT of LWR fuel (3.2 MT for PWRs and 3.4 MT for BWRs). The LMFBR spent fuel cask was assumed to carry 18 assemblies of either core plus axial blanket or radial blanket,

TABLE 9. Comparison of Transportation Requirements in the Year 2000 for DFCF and IFCF Cases

Case	DFCF	IFCF	
		IFCF NW	IFCF SE
Fresh Fuel[a]			
Number of shipments	9,601	9,601	9,601
Metric tonne-miles	1.2×10^7	5.7×10^7	2.5×10^7
Vehicles in transit	26.3	145	67
Mass heavy metal in transit, tons	80	440	200
Spent Fuel			
Number of shipments	15,987	15,987	15,987
Metric tonne-miles	1.0×10^7	4.6×10^7	2.2×10^7
Vehicles in transit	88	307	164
Radioactivity in transit, MCi	659	2,258	1,170
93% $^{235}UF_6$[b]			
Number of shipments	70	0	0
Vehicles in transit	0.4	0	0
Mass U in transit, tons	0.3	0	0
Plutonium Oxide[c]			
Number of shipments	722	0	0
Vehicles in transit	2.0	0	0
Mass Pu in transit, tons	1.0	0	0
HTGR-Uranium Oxide[d]			
Number of shipments	50	0	0
Vehicles in transit	0.14	0	0
Mass U in transit, tons	0.07	0	0
40% ^{235}U Oxide[e]			
Number of shipments	23	0	0
Vehicles in transit	0.06	0	0
Mass U in transit	0.03	0	0
High-Level Solidified Waste[f]			
Number of shipments	252	0	0
Vehicles in transit	5.0	0	0
Radioactivity in transit, MCi	56	0	0
Alpha Solid Wastes[g]			
Number of shipments	1,144	0	0
Vehicles in transit	25.1	0	0
Mass actinides in transit, tons	0.06	0	0
All other Wastes			
Number of shipments	35,126	21,800	21,800

a. UO_2 plants located at integrated site.

b. Isotopic composition is 1.0% ^{234}U, 93.1% ^{235}U, 0.2% ^{236}U, 5.7% ^{238}U.

c. Isotopic composition is 1.0% ^{238}Pu, 59% ^{239}Pu, 24% ^{240}Pu, 12% ^{241}Pu, 4% ^{242}Pu.

d. Isotopic composition is 0.041% ^{232}U, 59.6% ^{233}U, 26.3% ^{234}U, 8% ^{235}U, 6.1% ^{236}U.

e. Isotopic composition is 1.4% ^{234}U, 40.7% ^{235}U, 43.9% ^{236}U, 14% ^{238}U.

f. High-level waste is shipped ten years after it is generated in reprocessing.

g. Wastes are shipped one year after generation.

TABLE 10. Summary of Shipment Modes for Fuels, Plutonium, HTGR-^{233}U and ^{235}U for Year 2000

	Reactor Type			
	LWR-U	LWR-Pu	HTGR	LMFBR
Spent Fuels				
Fuel per shipment, tons				
Truck	0.44	0.44	-	-
Rail	3.1	3.1	0.6	2
Pu or HTGR-U per shipment, kg				
Truck	4.1	14	-	-
Rail	29	96	35	158
Radioactivity per shipment, MCi				
Truck	1.9	2.4	-	-
Rail	14	17	2.7	20
Thermal power per shipment, kW				
Truck	9	16	-	-
Rail	62	110	13	80
Fresh Fuels[a]				
Fuel per shipment, tons	5.5	5.5	1	1
Pu or HTGR-U per shipment, kg	-	274	93[b]	71

Pu, HTGR-U, and 40%-Enriched ^{235}U Oxides[a]	
Load per shipment, tons Pu or U	0.5
UF_6 (93% ^{235}U)[a]	
Load per shipment, tons U	0.75

a. Truck shipments are assumed.

b. Includes 93 and 40% ^{235}U.

about 2 MT of fuel in either case, although it is possible that only six assemblies (0.68 MT of fuel) will be carried.[9,14] Spent fuel shipments will total 8600 by truck and 7000 by rail. At any time, an average of 88 shipments will be in transit for the DFCF case, 307 for IFCF-NW, or 164 for IFCF-SE. In the IFCF systems, the longer shipping distances for spent fuel result in increased metric tonne-miles and numbers of vehicles in transit, even though the numbers of shipments and quantities of material are unchanged. Spent fuel metric tonne-miles and shipments in transit grow by factors of approximately 4 and 2, respectively, for IFCF-NW and IFCF-SE. (If this factor of 4 for the IFCF-NW system is adjusted by the ratio of route-averaged roadside population densities compared with the DFCF case, the 4:1 ratio reduces to less than 3:1. This is because a large fraction of the additional shipping distance lies in the sparsely populated Western FPC Region. This ratio of 3:1 is a simple measure of relative risk, in terms of MT x miles shipped x people/square mile.)

5.1.3 Fresh Fuel

A total of 29,000 MT will be transported by truck to reactors in approximately 10,000 shipments. Of the total, LWR-Pu fuel shipments will be 330, HTGR shipments 1000, and LMFBR shipments 4200. At any time, there are projected to be an average of 26 such shipments in transit for the DFCF case, 145 for IFCF-NW, or 67 for IFCF-SE. Thus fresh fuel metric tonne-miles and shipments in transit increase by factors of approximately 5 and 2 1/2, respectively, for IFCF-NW and IFCF-SE systems. If the IFCF UO_2 fabrication plants are dispersed rather than integrated, these ratios are approximately halved.

The possibility has been raised of transporting mixed-oxide fresh fuel from the IFCF-NW site to eastern LMFBRs by military cargo aircraft over most of the route. This scheme raises significant safeguards questions.(15) In addition, questions are raised as to the availability of military aircraft, bases and personnel, effects on national security, transport safety of such shipments, availability of appropriate shipping containers, and military-civilian transport interfaces at both ends of the air transport route.

A quick estimate of the aircraft requirements and the principal effects on shipping distances showed the most promising aircraft to be the Lockheed C5A and the military version of the Boeing 747. Payloads are in the range of 75-100 tons, compared with 40 tons for the military version of the Boeing 707 and approximately 15 tons for the B52 bomber. For purposes of this study, a 75-ton payload was assumed, containing approximately 8 MT of mixed oxide fresh fuel. This compares with a truck-transported payload containing from 1 to 3 MT of mixed oxide fresh fuel. The projected quantity of mixed oxide fresh fuel shipped in the year 2000 is 5980 MT.

Three options were examined: (1) truck shipments from Hanford to LMFBRs; (2) truck shipments to a (presently nonoperational) military airfield near Moses Lake, Washington, followed by military air transport to an optimally located eastern military airfield (taken to be in eastern Kentucky), followed by truck transport to the LMFBRs; (3) the same as (2), but incorporating air shipment to 5 nonwestern military airfields, 1 centrally located in each FPC region. These airfields were taken to be located in central New York state, central Ohio, central Georgia, south-central Oklahoma, and Northeastern Iowa. For the second and third options, truck shipments were assumed from Hanford to western FPC region LMFBRs.

Shipments were studied by dividing the country and the quantity of mixed oxide fuel by FPC regions, so that proper weighting was given to the geographical distribution of LMFBRs. The calculations and results are summarized in Table 11. The total metric tonne-miles (air plus truck) of transport varies only slightly among the three schemes, with option 2 having the highest number. The effect of the use of military aircraft is to shift the composition of the metric tonne-miles from 100% truck in option 1 to 31% truck in option 2 and 23% truck in option 3. The number of metric tonne-miles of truck transport cannot be reduced by more than a factor of 4 without proliferating the number of military bases involved.

TABLE 11. Comparison of Options for Transporting Mixed Oxide Fresh Fuel

	Metric Tons Transported Annually/Shipping Distance		
	Option 1	Option 2	Option 3
	No Air Transport	Truck/Air/Truck 1 Central Eastern Airfield	Truck/Air/Truck 5 (non-West) Regional Airfields
MT-miles, Truck	9.2×10^6 (100%)	3.4×10^6 (31%)	2.2×10^6 (23%)
MT-miles, Air	0	7.6×10^6 (69%)	7.5×10^6 (77%)
MT-miles, Total	9.2×10^6	11.0×10^6	9.7×10^6

Under option 1, the annual number of truck shipments is 4600. The number of such 1 metric-tonne shipments in transit is approximately 75. Under option 2, the annual number of air shipments is 575, or approximately 2 per day. Assuming 1 round trip per day, and allowing for maintenance and backup, the equivalent exclusive use of three aircraft is indicated.

5.1.4 Waste Streams

The projected quantities of fuel cycle wastes (less ore tailings) to be transported in the year 2000 are summarized in Table 12. The numbers of shipments are given in the case of the DFCF system. For the IFCF systems, the number of shipments of wastes collected at reactors (or at dispersed UO_2 fuel fab plants) is the same as that in the DFCF case. The number of offsite shipments of all other wastes is zero. (See also Table 9.) Thus the numbers of shipments and the numbers of vehicles in transit for high-level, α-β-γ, iodine, cladding hulls, and α waste streams are zero for IFCF-NW and IFCF-SE systems.

TABLE 12. Waste Transport Projected for the Year 2000

Waste Type	Approximate Quantity	Transport	Shipments DFCF
High Level	3020 Canisters	Rail	250
Cladding Hulls	0.18×10^6 ft^3	Rail	510
α-β-γ	3.6×10^6 ft^3	Truck	4900
α-Pu	11×10^6 ft^3	Rail	1160
α-U	0.83×10^6 ft^3	Rail	83
β-γ	17.5×10^6 ft^3	Truck	24,760
Iodine	78 ft^3	Truck	16
Noble Gases	1740 cylinders	Rail	330
Tritium			
Reprocessors	9260 ft^3	Truck	910
Reactors	2×10^6 ft^3	Truck	3700

For some waste streams, the number of vehicles in transit and the shipment-miles differ between IFCF-NW and IFCF-SE systems, although in all cases the number of shipments is unchanged. For example, the total shipment-miles of nonreactor β-γ wastes is 25% higher for IFCF-NW than for IFCF-SE, in the case of dispersed UO_2 fuel fab plants. The number of shipment-miles of wastes collected at reactors (β-γ trash, sludges, and resins, tritium-contaminated coolant and part of the noble gases) for IFCF-NW is roughly twice that for IFCF-SE.

Although the reactor-collected wastes are relatively low in activity, they represent 21,800 annual shipments (56% of all waste shipments in the DFCF case). For this reason, present policies regarding dispersed β-γ burial grounds should be continued. The six existing commercial burial grounds, combined with AEC burial grounds, constitute a network which is quite uniformly distributed geographically.

5.2 SAFEGUARDS

Introduction and Background

Until recently, nuclear materials safeguards have been concerned with the diversion of sufficient fissionable material to manufacture a nuclear explosive. As a result, systems design parameters have included the amount, form, and kind of material. Similar design parameters have been developed for safeguarding radiotoxic materials from dispersal by acts of sabotage.

Highly strategic materials, such as plutonium and high-enriched uranium, and very attractive material forms such as pure compounds have received strongest protective measures. Materials of low-strategic value, such as thorium and low-enriched uranium, and unattractive material forms, such as waste, scrap, or spent fuels, have received the least protection. The amount of material of safeguards importance was closely related to the critical mass.

In the future the concept of strategic value, which is the inherent value of the material as a nuclear explosive, may change due to technological advances. Currently, low-enriched ^{235}U is considered to have little inherent strategic value because of the immense capabilities required to enrich it sufficiently to be a nuclear explosive. With the advent of technologies which would allow small-scale, clandestine enrichment, this form of grading will change.

The other grading factor currently applied is that of attractiveness or convertibility. This is defined as the ease with which a given form of material can be converted to a form suitable for making a nuclear explosive. The convertibility of the material form defines the time and capability a successful diverter would need to convert a given chemical form to a form useful for making a nuclear device, e.g., a pure metal. The attractiveness of any material will increase as other forms become less accessible. Currently, spent fuel and certain wastes and scrap forms are considered to have convertibilities which preclude their use by an individual (or a small group) diverter. By contrast, PuO_2, UO_2, UF_6 and other pure compounds are considered to be highly convertible. Mixed oxide fuels, PuO_2 - UO_2, are also considered to be quite convertible even though a preliminary separation step would be required to isolate the plutonium from the uranium matrix.

Plutonium oxide can be converted to plutonium metal by direct reduction of the oxide using calcium metal and iodine booster to provide the heat needed for a reasonable yield. To obtain 16 kilograms of plutonium metal requires on the order of 18 kg of plutonium as oxide. This could be done with a rather crude pressure vessel and heating equipment readily available in commerce.

To realize the same 16 kg of plutonium metal starting with mixed oxide fuel elements requires, in addition to direct oxide reduction, several operating steps that involve different equipment and processing capabilities. About 500 kg of mixed oxide fuel pellets (3 1/2 percent plutonium) would be required. The fuel elements would have to be disassembled, the mixed oxide pellets dissolved in a dissolver that is critically safe, the plutonium then partitioned from the uranium, using processes such as solvent extraction or ion exchange, and the aqueous plutonium stream then concentrated for either direct calcination to oxide or a combination precipitation-calcination to oxide. However, a simpler process such as fractional precipitation might give a material rich enough in plutonium for a crude weapon or a convincing threat.

All aqueous processing would have to be done in critically safe geometries or in small enough batches to prevent a criticality event. This requires degrees of processing sophistication that are not required to obtain metal from oxide, time to carry out the processing, and space for locating the processing capability. While metal can be obtained using mixed oxide fuel elements as the feed material, it is not nearly so easy to achieve as it would be starting with plutonium oxide. The purity of metal produced from plutonium oxide from a fuels reprocessing plant would undoubtedly be much better than that obtained from mixed oxide fuel elements because of the fewer processing steps required in crude equipment. Purity would influence the effectiveness of a clandestine explosive.

The time required to produce metal from mixed oxide fuel elements would be on the most optimistic projection three to five times greater than the time required starting with plutonium oxide.

The total mass of material diverted to yield 16 kg of plutonium metal would be much greater for mixed oxide fuels than for plutonium dioxide (about three metric tons of fuel element bundles as compared to less than one-half metric ton of plutonium dioxide in birdcage containers). The individual item mass differential is nearly the same as the total mass differential.

Preventive Measures

Preventive measures in future years are expected to be applied to all locations (including transit) where significant quantities and attractive forms of "safeguarded" materials are present.

1. Facility Measures

At facilities where quantities and forms call for a high degree of safeguards, the following preventive measures are envisioned: (a) Double or triple barriers to prevent unauthorized entry to materials or vital areas, as well as sensing units and alarms to indicate attempts at penetration. The barriers would also operate to prevent unauthorized removal of materials. (b) Monitoring of all personnel and vehicles entering and leaving vital areas. This may include both search and the use of sensors. (c) Maximized containment of all key materials by use of vaults, high-security storage areas, and highly resistant containers. This would be to prevent unauthorized removal as well as to protect against "in situ" nuclear explosions or dispersal by acts of sabotage. (d) Redundant communications with law enforcement bodies in the event of attack. (e) Personnel clearances and security checks of personnel who have access to vital areas and attractive forms of materials.

2. Protection in Transit

For significant shipments, the following measures are envisioned: (a) Transport in high-security vans or trains which are both difficult to move and to penetrate if attacked, (b) Continuous communication links between carrier and authorities, both voice communication and special continuous transmitter, (c) Special shipping containers for toxic materials which would protect against dispersal by sabotage, (d) Use of armed guards, escort cars, etc., in addition to special carriers. The entire system may be placed under military escort or control.

It is also possible that special protective measures could include transport in military land vehicles or military aircraft. However, this latter approach presents a higher risk of dispersal in the event of an aircraft accident. Another inherent disadvantage in air transport is the possible diversion of a shipment to a foreign location in event of hijacking or a diversion by the pilot(s). This could be carried out by one person and could lead to an international incident.

Another concept currently under discussion is that of deliberately contaminating the nuclear materials with a hard gamma emitter (e.g., cobalt) to discourage diversion and to assist in locating the material in the event of diversion.

Assurance Measures

Current policy decisions indicate a heavy emphasis on obtaining positive and quantitative assurance that safeguards measures will be, are, and have been effective. This includes assurance that proposed measures will be effective before granting a license, assurance that in-place measures are satisfactory, and independent public assurance that measures taken by material holders have been effective. This emphasis implies close inspection and evaluation by an authoritative public representative. It also implies measurement technology which is capable of, at least, periodically indicating that the materials of concern are indeed present and accounted for.

Siting Considerations

Under current policy decisions, the number, size, and location of nuclear facilities is dictated by factors other than safeguards, e.g., health, safety and economics. Only when the location would definitely hinder the capability of safeguarding the material would siting be a safeguards concern. However, it is expected that the remoteness desirable for safety reasons would also be valuable in reducing the possible consequences of sabotage.

Comparison of Fuel Cycle Concepts

For purposes of comparing fuel cycle concepts, the scope of safeguards is taken to include the following:

- Diversion of nuclear materials which could be used as nuclear and/or radiological weapons;
- Acts of sabotage aimed at
  1. halting nuclear production,
  2. the dispersal of radiotoxic materials,
  3. the creation of an in situ nuclear excursion.

Features associated with each of the two cases--integrated sites and dispersed sites--are given in Table 13. As shown in Table 13, the main safeguards advantages which accrue to the integrated site are:

- Reduction in the level of effort required to protect against the diversion of nuclear explosive materials in transit since only fresh and spent fuels are shipped.

- Reduction in the consequences of sabotage in transit since only fuel elements are shipped in open transit--no high-level radioactive wastes are shipped other than in the form of spent fuels.
- Concentration of the bulk handling facilities would allow concentration of inspection forces and allow for enclosure of the entire area inside a personnel barrier--e.g., a fenced and patrolled restricted area.

The main disadvantages of an integrated site stem from the concentration of facilities at a single area. This concentration makes such facilities more vulnerable to direct attack by a foreign power. There is also a possibility that the results of acts of sabotage could shut down several facilities because of their close proximity.

One important aspect of diversionary safeguards not properly compared in Table 13 is the risk of diversion by "key insiders." For diversion by trusted insiders, there is little advantage of one concept over another. The integrated site concept has one advantage in that the outer barrier would presumably be manned by a guard force which is independent of the companies using the integrated site. Other than this difference, the risk of diversion by inside forces is about the same for either case, except in transportation because two complete links of transportation are eliminated by an IFCF.

While air transport would reduce substantially the number of surface miles of transport, it would create the minimum number of key insiders needed to create the maximum threat.

For the threat of diversion posed by outside forces, the integrated site concept has several distinct advantages. These include the enhancement of protective measures as well as the detection of loss or an abnormal event. The proximity of bulk processing facilities would allow concentration of inspector and guard forces. The cost of protective measures for nuclear materials in offsite transit would reduce to that of protecting fresh fuel shipments to reactors. All shipments of bulk forms of pure PuO_2, enriched UO_2 or UF_6, and $^{233}UO_2$ would take place within the nuclear park. Here transit distances would be short and presumably protection costs lower than for cross-country transit.

TABLE 13. Comparison Matrix for Siting Impact on Safeguards

	Consideration	Dispersed Sites		Integrated Sites	
		On-Site	Off-Site	On-Site	Off-Site
1.	Attractive nuclear explosive materials	Pure forms of Pu, ^{235}U, ^{233}U	All forms in transit	Pure forms of Pu ^{235}U, ^{233}U	Spent and fresh fuel in transit
2.	Radiotoxic materials	All toxic materials	All toxic materials in transit	All toxic materials	Spent fuels and fresh Pu and ^{233}U fuel in transit, no waste in transit
3.	Vulnerability to sabotage	All facilities vulnerable - but no interaction between facilities	All forms in transit	All facilities vulnerable - plus interaction from close proximity	Spent fuel and fresh Pu and ^{233}U fuel in transit, no waste in transit
4.	Vulnerability to foreign attack	Dispersed target	--	Concentrated target for foreign attack	--
5.	Benefits and problems	Main benefit of dispersed sites is in regard to foreign attack and to interactive effect in case of sabotage. Main disadvantages are the spreading of protective forces and the increased risk of all materials in transit.		Main benefits are a reduction in the risks encountered in transit since all attractive forms are in closed or onsite transit only. It also would allow concentration of protective forces and also concentration of barriers. Disadvantages stem mostly from concentration of target in case of foreign attack and interaction effect of sabotage.	

The integrated site concept would also enhance several aspects of detection. It would ease the problem of detecting unauthorized entry. Presumably, guard forces, barriers, alarm systems, etc., could be concentrated to give a double layer of protection. Secondly, inventory checks on materials in onsite transit could be completed more rapidly. This would be particularly important in reducing time delays for material in onsite transit and for resolving any material transfer discrepancies. The concentration and close coupling of operations would facilitate inspection activities aimed at measuring compliance and in actually verifying material quantities.

The IFCF may also have some advantage to international safeguards. If the U.S. facilities which are placed under international safeguards were located at an integrated facility, it would likely reduce international inspection cost due to the proximity of the facilities under IAEA inspection.

5.3 WASTE MANAGEMENT IMPACT

To a first approximation, the quantities of waste generated in the IFCF case are somewhat reduced but would be in the same range as those for the DFCF case. Increases in reprocessing plant size and improved technology could reduce the quantity of waste generated.

The IFCF system offers attractive possibilities for waste management. Calcined high-level waste can be almost immediately transferred onsite to the glass plant repository. Because of onsite shipping and improved handling techniques, other nonreactor waste streams would probably be held only for very short periods at the point of origin (compared with a probable 1-year holdup in the DFCF case), followed by transfer to the onsite repository.

All of these practices have the effect of greatly reducing the inventories of wastes in other than final or improved forms, at reprocessing and fabrication plants. (In the year 2000, with 1-year holdup at the point of origin, such inventories would otherwise constitute more than 10% of the accumulated [since 1973] volume and radioactivity of most waste streams.) This effect is in addition to the benefit of having all waste in one geographic location, if not in one storage facility.

A major waste management impact lies in the area of decontamination and decommissioning (D & D). The quantity of such wastes would be reduced by virtue of economies of scale and greater control over plant design. The closer control over design could also facilitate simpler D & D operations. Transportation of D & D waste would be minimized. The IFCF would also provide a sufficient base load to allow a more economical, centralized D & D operation.

With the dispersed plants, each operator of reprocessing or fuel fabrication plants must develop processes for scrap recovery, waste reduction, temporary waste storage and waste transport. With the IFCF concept both industrial participation and technical expertise could be more effectively directed toward waste management problems.

A number of common support facilities could be used at an IFCF, simultaneously reducing the overall capital investment and operating costs and increasing the reliability. In the dispersed case, many services are required to be redundant such as electric power (and emergency generators), water systems and other equipment for fire protection. Most significant would probably be effluent treatment, particularly gas effluents. Were a sand filter required for ultimate cleanup, one such system would certainly be more economically constructed. Thus with the opportunity in an IFCF of channelling all gaseous effluents into a single system, the ideal of "zero-release" becomes more readily achievable.

Figure 8 illustrates possible material flow and/or treatment options for waste management at an IFCF site. The waste management advantages resulting from an IFCF are many and varied. In general, the placement of multiple fuels processing and multiple fuels fabrication facilities at one site allows the consolidation of specific waste types for treatment in

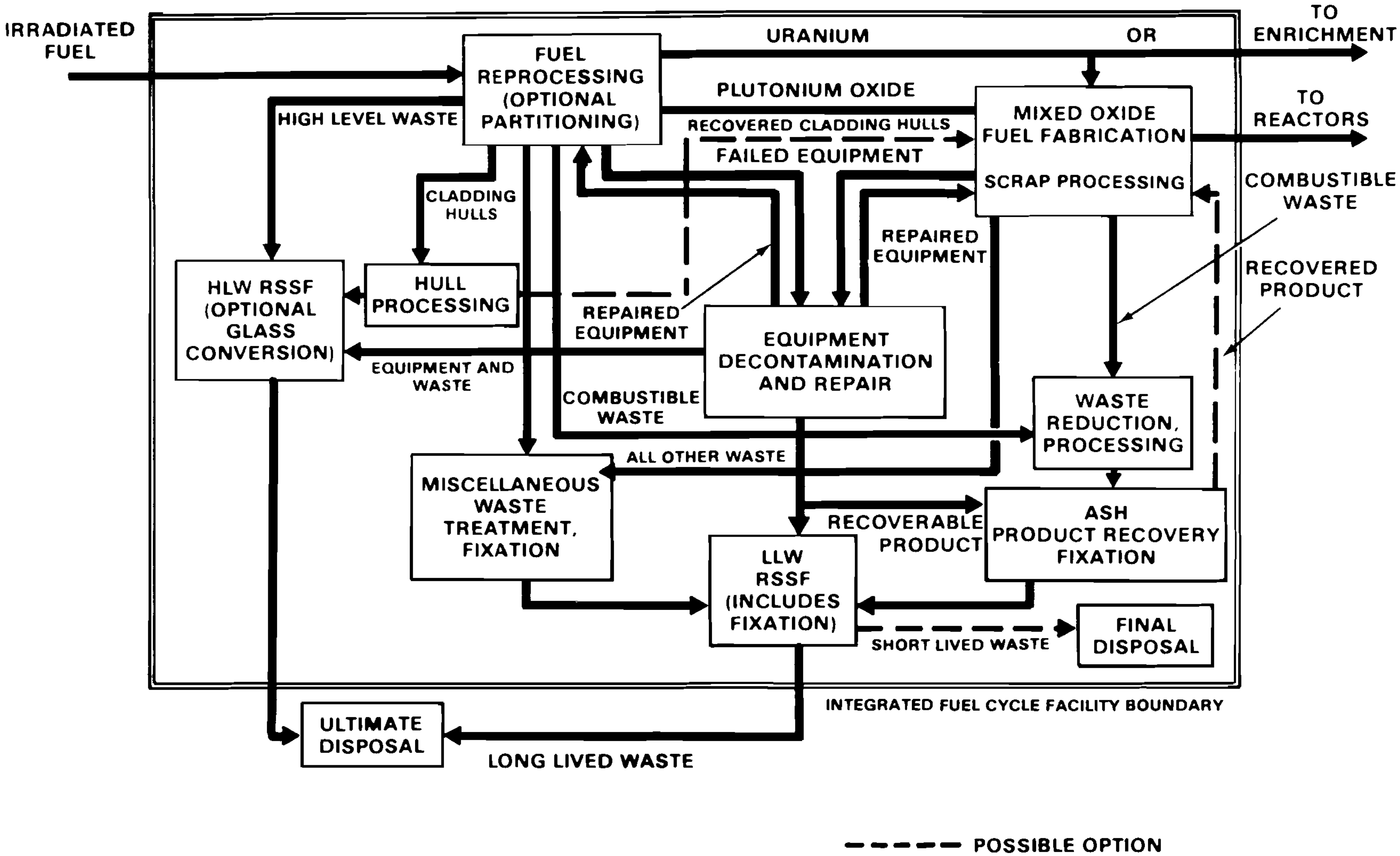


FIGURE 8. Waste Management at Integrated Fuel Cycle Facility

central (common) facilities. This includes, but is not limited to, a central 1) glass plant for high-level waste, 2) hulls processing plant, 3) equipment decontamination facility, 4) equipment repair and/or salvage facility, 5) oxidation facility (incinerator), 6) equipment (metal) treatment (consolidation) facility, 7) actinide salvage facility, 8) aqueous waste from fuels fabrication scrap processing facility, 9) miscellaneous (other than high level, including actinide) waste immobilization facility, and 10) decommissioning facilities.

Many of these activities would not be realisticially feasible in the dispersed case. If they were carried out under the dispersed case, they would result in more contaminated facilities and equipment than they would in centralized facilities. The base load for a central facility would be large at an earlier date, thereby providing the need for technology and facilities. As a result, the ultimate treatment of the wastes to place them in disposal or long-term storage would be realized at a much earlier date.

Decommissioning

Included in the planning for any nuclear facility should be plans for decommissioning the plants at the end of their useful life. Since the ultimate repository for nuclear industry wastes may not be at the IFCF, the objective of a program for decommissioning should be to leave the land in as near the natural condition as possible. The land should be placed, therefore, in a reusable condition with no special precautions necessary.

With these objectives in mind, the following guidelines for physical condition and radiation levels are useful. The site or plant location within the IFCF should require no surveillance after a definite period, say 50 years. There should be no pathway to man via food chains open for radioactive and nonradioactive wastes from any potential use of the site. During the 50 years there should be protection of casual public from any residual radiation.

The IFCF allows for an overall decommissioning plan that could use the other facilities of the site to maximum advantage for decommissionining. Facilities still operating could process equipment or contaminated structural materials or soils that came from a decommissioned plant. This requires that planning to be decommissionable should come into the initial phases of the IFCF development. The inventory of radioactive materials and site description developed in the site selection procedure will provide the guidelines for return of the decommissioned site as nearly to its original state as possible. The decommissioning plan would be identified in the environmental impact statement prepared for the single site. The continued use of the plants operating within the IFCF to decommission defunct plants should greatly simplify the environmental impact analysis for the IFCF compared to the DFCF case.

Design for decommissioning should be developed based on the process capabilities to be installed at the IFCF. For example, capability and capacity in fuel processing, reactor and structural materials recycle, and waste management plants could be used for processing contaminated components. Detailed requirements for decommissioning would identify additional support facilities, or special processes might be installed at these ongoing operations to accomplish the decommissioning and disposal.

Depending upon the details developed in a plan for decommissioning an operating plant, special methods or materials of construction might be required. Massive structures that remain after all operating components are dismantled may be decontaminated sufficiently to be considered nonhazardous. These massive structures can themselves be converted to engineered repositories for other structural components or slightly contaminated soil from the plant vicinity. The structures could be considered as engineered storage of these materials to permit decay of radioactivity for the expected lifetime of their physical integrity. However, a shorter, clearly defined period (50 or 100 years) would be better from the environmental safety standpoint.

5.4 RADIOLOGICAL CONSIDERATIONS

The following discussion addresses, in a generic sense, the routine release rates of radionuclides from uranium enrichment facilities, fuel fabrication plants, reprocessing plants and interim waste storage facilities associated with an integrated fuel cycle facility (IFCF). The radiation doses resulting from such releases are summarized briefly, but details of the dose calculations are not presented. Depending upon the actual site characteristics, the radiological impact could be different than derived here for the generic site, but in all probability the net impact would not be significantly greater because of the conservative assumptions employed. Principal attention is directed to the estimated radiation doses received by man. Experience at operating nuclear facilities has shown that, barring unusual circumstances, regulation of radiation doses received by man to levels consistent with currently accepted guidelines will ensure that the doses to other biota are inconsequential.

Primary radiological safety advantages of siting all of the fuel reprocessing, waste management and interim storage facilities at an IFCF include 1) elimination of transportation over public highways of certain highly radioactive materials between the several process stages, 2) the increased distance between the facilities and the site boundary, and 3) sufficient space to build additional facilities as required without dedicating new sites to long-term radiological restrictions.

The major disadvantage is that the total quantity of radioactive effluents is discharged to air and water at a single site. There would not seem to be insurmountable problems with the combined releases to the atmosphere since the facilities would be separated from each other and from the general public.

The radiological impact of releases of radioiodine and noble gases to the atmosphere from fuel reprocessing plants is difficult to quantify without detailed calculations of the contribution from each source to the total dose. The population dose was approximated by assuming all of the releases occurred at some one point, an effective average distance from the boundary. On this basis, it was estimated that the total-body population dose from all sources combined could be restricted to no more than 20 to 30 man-rem/yr. With an iodine removal DF (in the effluent treatment processes) of approximately 10^3 the population thyroid dose could be held to about 2000 man-thyroid-rem/yr.

The maximum individual dose would probably be, to an infant consuming milk from a cow pastured at the Exclusion Zone Boundary (EZB) location with the highest atmospheric dilution factor (20 km SE). This dose would be about 26 mrem/yr with an iodine DF of 10^3. Even though this dose may be acceptable as a design guide, it would be prudent to plan for a DF of 10^4 so that the individual dose could be reduced to 2.6 mrem and the population dose could be reduced to 200 man-thyroid-rem. On the other hand, decreasing the EZB distance in the SE direction from 20 km to 10 km would nearly double the doses associated with the gaseous effluents released at the fuels reprocessing plant.

These population doses at the IFCF would be about 20% to 30% of those received if the fuel reprocessing facilities were dispersed. However, the major contributor to the population doses (barring accidental releases) would result from the transportation of irradiated fuel and solid wastes from power reactors to the reprocessing and waste storage sites. These doses amount to about 3000 man-rem/yr to the general population and 5000 man-rem/yr to transport workers under the dispersed concept. These doses would be about 3 times as high under the IFCF because of the increased transportation distances.

The only savings in general population transportation dose under the IFCF concept would be the shipments between the fuel fabrication and reprocessing facilities and the waste burial or storage sites. These latter doses would account for about 300 man-rem in the year 2000 under the DFCF concept.

In either case, the radiation doses received by the population would be small compared to the dose received from natural background radiation, which amounts to about 100 to 200 mrem/yr in the U.S., depending upon the location. For example, the approximately 3×10^5 persons in the vicinity of the IFCF in the year 2000 would receive an integrated population dose of about 4×10^4 man-rem/yr from natural background.

The contribution to employee exposures attributable to effluents discharged by adjacent facilities is not expected to increase the occupational exposure significantly above that received at separated facilities.

The IFCF, located at a single site, would reduce the radiological impact by providing a larger site boundary distance and by reducing the need for transportation of radioactive and other hazardous materials, e.g., Pu, through the public domain. On the other hand, the radiation doses received by the few individuals living near the site boundary could be somewhat higher at an IFCF than at dispersed facilities because of the greater quantities of radionuclides released to the environment from a relatively compact group of facilities.

5.4.1 Control of Radioactive Effluents

All industrial plants handling radionuclides have radioactive waste (radwaste) systems that treat the waste streams containing radionuclides. These systems are referred to as the liquid, gas or solid radwaste systems in accordance with the physical form of the waste streams being treated. The purpose of the radwaste systems is to minimize release of radionuclides to the environment and the consequent radiation dose to the general public.

The radwaste systems can be designed for all degrees of treatment from essentially zero up to very sophisticated systems which result in virtually no release of radionuclides to the environment. The costs for operating these systems also have a broad range from a low value for minimal treatment up to high values for sophisticated treatment.

The AEC has a general policy that the radiation dose received by the general public shall be "as low as practicable," which is defined as "as low as is practicably achievable taking into account the state of technology and the economics of improvement in benefits to the public health and safety and in utilization of atomic energy in the public interest."[(2)] This has been translated into design guides, in proposed Appendix I to 10 CFR 50, which defines the term "as low as practicable" in relation to radiation doses that the general public might receive as a result of radionuclide releases from nuclear power plants. Such design guides have not been proposed for facilities other than Light Water Reactor (LWR) power plants, but when issued they will probably be based upon a control philosophy similar to that used for the LWRs. For reprocessing plants this may be a very severe limitation since the very nature of the process is to release the fission products from the fuel.

The radiation dose received by the general public, as a result of radionuclide release from a plant, depends primarily on the design of the radwaste systems; the distance between the plant and the nearest members of the general public, and the pathways for radionuclide travel to the public. Of particular importance is the thyroid dose to infants consuming milk containing radioiodine from the air-grass-cow-milk pathway. The reprocessing plants siting document ORNL-4451[9] states that plants of capacity of greater than 6 to 10 metric tons/day of LWR fuel will have to have more efficient iodine removal equipment than that demonstrated in present technology. If LMFBR fuels, cooled 90 days, were to be processed, the iodine removal efficiency would have to be improved two orders of magnitude over present technology. It may be that these fuels will have to be cooled the same length of time as the LWR fuels (150 days).

Each of the several types of nuclear facilities expected to be located within an IFCF will routinely release radioactive gases, liquids, and/or solids to the environment under the "low as practicable" philosophy. In a general way, the total impact of the facilities is the sum of the impacts caused by each facility. However, the individuals receiving the highest doses will not necessarily be identical for each geographically separated facility, and the doses to the maximum individual will not necessarily be completely additive, especially in the instance of gaseous effluents.

Several mathematical models developed for calculating radiation doses to man and other biota from radioactive materials released to the environs have been reported in detail in the literature. Some of these models were specifically designed to treat accidental or acute releases,[16,17] although they can be applied with modifications to chronic releases.[18,19] Other models were designed to calculate radiation doses in a large region of the United States from chronic releases.[20,21] Applications of these models to the estimation of radiological impact of nuclear facilities for inclusion in the environmental reports required by the National Environmental Policy Act (NEPA) have also been discussed in the literature.[22,23]

In the discussion that follows it is assumed that the fuels reprocessing plants and the high-level waste management facilities are located in the approximate center of a site similar in size and meteorology to Hanford. The site boundary (SB) distance for these facilities is then about 20 km in the direction of the prevailing wind. The other facilities such as the fuel fabrication plants with lesser potential for radiological impact would then be located about midway between the waste management facilities and the SB at an average distance of about 10 km from the latter.

5.4.2 Enrichment Topping Plant

It is estimated that an enrichment topping plant with a capacity of about 11,500 MT separative work units (SWU) will be required in the year 2000 or perhaps sooner. Regardless of the siting concept considered, the same plant will be required and, therefore, its impact on the environment will be the same.

The radioactive releases to the environs from a plant of about this size have been estimated[24] to be 0.2 Ci/yr of uranium in gases and 1.8 Ci/yr of uranium in liquids. The release of these quantities of uranium to the environs should result in insignificant radiation exposures regardless of the site being considered.

5.4.3 Fuel Fabrication Facilities

Fuel fabrication facilities will be required for uranium and plutonium LWR fuels as well as for LMFBR and HTGR fuel.

In the uranium plant, uranium is received as either the hexafluoride or oxide powder. It is converted to the oxide, formed into pellets, sintered, etc., and then placed in zirconium tubes. The tubes are sealed and then assembled into finished assemblies. The plant ventilation system employs adequate safeguards to prevent the release of significant amounts of particulate matter.

The plutonium fabrication plant has several additional steps in the process. The plutonium may have to be converted to an oxide, blended with uranium oxide and then formed into pellets. The pellets, after further treatment, are then placed in tubes and welded closed. Up to this point all operations have taken place in glove boxes because of the highly radiotoxic nature of plutonium. The remainder of the process parallels the uranium assembly line steps. The releases from the plutonium fabrication plant are held to very low levels by extensive air filtration equipment, so that both plants should not require large controlled access or low population zones surrounding them.

The potential environmental impact of a mixed oxide fuel fabrication plant was addressed in document BNWL-1697.[25] Figures 5 and 8 of that report illustrate the 50-year dose commitment to bone and lung of a Standard Man inhaling plutonium continuously released throughout a 50-year life of the facility. The doses were calculated for the maximum sector (highest air concentrations) versus distance from the facility and for two release heights, ground level and 100 meters, and the results were normalized to a chronic release rate of 1 μg of Pu per year. The highest dose commitments were associated with a ground-level release, which would be more typical for a fuel fabrication plant than a 100-meter release.

The annual average atmosphere dilution factors given in Figure 2 of BNWL-1697 for the maximum sector are somewhat higher than those estimated for the Hanford project in the direction of the prevailing wind. The factors given in those figures are 9×10^{-7} $\text{sec}\cdot\text{m}^{-3}$ at 10 km and 4×10^{-7} at 20 km from a ground-level release point. Similar values for the Hanford project are 5.5×10^{-7} and $2.7 \times 10^{-7} \times 10^{-7}$ $\text{sec}\cdot\text{m}^{3}$ at 10 and 20 km respectively. Therefore, the doses per unit release to be estimated for a typical fuels fabrication plant located at Hanford would be about 2/3 of those listed in the reference document at comparable distances downwind.

The release for a typical 1000 metric ton per year (MT/yr) fabrication plant might be about 50 μg/yr.[26] The total capacity estimated for the IFCF exclusive of LWR-U fuels is about 15,000 MT/yr, and therefore a release rate of up to 750 μg Pu/year is possible from these facilities.

Assuming a ground-level release (Figures 5 and 7 of BNWL-1697) and using the curve for the new ICRP Task Group Lung Model,[27] a release rate of 750 μg/yr would lead to 50-year dose commitments of 30 mrem to the bone and 0.6 mrem to the lung at an Exclusion Zone Boundary (EZB) of 10 km from the plant for the IFCF. The dose per year of operation was not calculated and would vary with time since startup, being higher in later years. "Average" doses per year of operation could be taken to be about 0.6 mrem to bone and 0.01 mrem to lung at a distance of 10 km. Such doses do not seem to be in disagreement with the intent of the "as low as practicable" philosophy. They are also about the same order of magnitude as the dose an individual could receive at an EZB 1 to 2 km from the typical 1000 MT/yr mixed oxide plant releasing 50 μg/yr of Pu.

The radiological impact of a uranium fuel plant would be very much less than that of a mixed oxide plant, so much less that the impact of chemical rather than radioactive releases to the environment would be of more concern.

5.4.4 Fuel Reprocessing Plants

When the irradiated fuel from the power reactors is dissolved in the reprocessing plants, the radionuclides in the fuel are released and enter either the reprocessing liquid streams or the gas atmospheres in the reprocessing equipment. These gaseous and liquid streams are then treated to remove the radionuclides for storage or reuse. The inventory of radioactive material at a reprocessing plant consists of fuel waiting to be processed and the wastes from fuel previously processed. Listed below is the inventory of radioactive material at a typical reprocessing plant versus the type of fuel being processed assuming the wastes are stored onsite for up to 5 years before solidification and a total of 10 years prior to shipment to a Federal repository:

Plant Type	LWR	HTGR	LMFBR
Plant Throughput	1500 Tonnes/yr	260 Tonnes/yr	1500 Tonnes/yr
Amount of Radioactive Material Stored Onsite	1.7×10^{10} Ci	4.8×10^{9} Ci	2.6×10^{10} Ci

Siting of reprocessing plants and associated waste management facilities was discussed in ORNL-4451.[9] At the time that document was prepared, the proposed Appendix I guideline and associated philosophy had not yet been prepared. As a result the authors assumed that control of routine releases of radionuclides could be based upon the air concentrations listed in 10 CFR 20. It may be assumed that a significant reduction below these latter air concentrations and resultant radiation doses will be required by a future definition of "as low as practicable" for fuel reprocessing plants dictating more sophisticated radwaste treatment systems.

The Barnwell fuel reprocessing plant has a minimum EZB distance of ~2350 meters. The capacity of this plant is 1500 tonnes/yr of LWR fuels. Radionuclides will not normally be released with liquid effluents. Estimated release rates to the atmosphere, taken from the Barnwell Environmental Report,[28] are listed in Table 14.

At present no removal systems for noble gases are commercially available and none appear to be needed at Barnwell. The doses estimated from the releases listed are summarized in Table 15.

The doses listed in Table 15 were estimated for an EZB distance of 2350 meters and an annual average atmospheric dilution factor of 1.5×10^{-8} sec m^{-3}.[a] Assuming that the IFCF site were located at Hanford with an EZB of 20 km for the reprocessing plants, the atmospheric dispersion factor would be 6×10^{-9} sec m^{-3} for an elevated release, or about 40% of that at the Barnwell site boundary. Therefore, the doses would be about 40% of those estimated for Barnwell per unit release rate.

a. Units are actually Ci/m^3 air per Ci/sec released.

TABLE 14. Estimated Radionuclide Release Rates from the Barnwell Fuels Reprocessing Plant[28]

Nuclide	Ci/Yr
^{3}H	5.8×10^{5}
^{85}Kr	1.4×10^{7}
^{90}Sr	2.8×10^{-1}
^{129}I	4.7×10^{-2}
^{131}I	3.8×10^{-1}
^{134}Cs	6.0×10^{-1}
^{137}Cs	3.8×10^{-1}
^{238}Pu	4.1×10^{-3}
$^{239, 240}Pu$	1.0×10^{-3}
^{241}Pu	1.7×10^{-1}
^{241}Am	1.0×10^{-3}
^{242}Cm	1.2×10^{-1}
^{244}Cm	1.2×10^{-2}

TABLE 15. Annual Radiation Doses Associated with Gaseous Effluents from the Barnwell Plant

Exposure Pathway	Organ	Nuclide	Individual mrem	Population man-rem
External	Skin	^{85}Kr	6.3	180
External	Total Body	^{85}Kr	0.074	2.1
Inhalation and Transpiration	Total Body	^{3}H	0.44	13
Deposition on Crops	Total Body	^{134}Cs ^{137}Cs	0.018[a] 0.006[a]	0.52 0.17
Milk-Infant	Thyroid	^{129}I	3.4	99
Milk-Infant	Thyroid	^{131}I	1.9	55
Deposition on Crops	Bone	^{90}Sr	0.044[a] 1.0[b]	1.3 30[b]
Inhalation of Soluble Forms	Bone	Pu, Am, Cm	0.17[c] 8.6[b]	4.8[c] 240[b]

a. Calculation is based on fallout-contaminated food and assumes equilibrium (after several half-lives) with 2/3 of the food being uncontaminated.
b. 50-year dose commitment from 1-year's release.
c. Average dose over a 50-year period.

In addition, the population dose in the vicinity of the facility must be adjusted for the relative distribution of people versus atmospheric dispersion. An estimate of this adjustment indicated that the product of the two distributions (people and $\overline{\chi}/Q'$) for the Hanford vicinity in the year 2000 would be about 4.06×10^{-4} man·sec·m^3 compared to 4.36×10^{-4} man·sec·m^3 which corresponds to the population doses in Table 15. The ratio of these two values of 93%, and thus no correction need be applied for the population dose estimates per curie released.

The capacity of the fuel reprocessing facilities of the IFCF must be sufficient to process approximately 17,000 MT/yr of LWR-U, 2,000 MT/yr of LWR-Pu, 1850 MT/yr of LMFBR fuel and 710 MT/yr of HTGR fuel.

Radiation doses to individuals and the population can be estimated for the IFCF by correcting the doses in Table 15 for the difference in throughput (in terms of curies per year in the fuel reprocessed), for removal of 99% of the ^3H and ^{85}Kr in the IFCF, and the difference in the atmospheric dispersion of the two sites. The results for the Maximum Individual are given in Table 16.

Except for the thyroid dose from radioiodine, the doses listed in Table 16 are all well within probable numerical guidelines for the "as low as practicable" philosophy, when applied to reprocessing plants.

The current LWR guidelines for thyroid doses specify 15 mrem/yr but allow some flexibility in terms of environmental monitoring after startup to determine the actual concentrations and dose. If this same flexibility is allowed for reprocessing plants, then the thyroid dose of 26 mrem/yr may be acceptable as a design guide. It would, however, be prudent to plan for improved iodine removal systems for installation prior to the year 2000. It should be possible before then to gain a factor of 10 in the iodine decontamination factor without undue expense. Such improvements might also allow for cooling of LMFBR fuels for less than the 150 days postulated when calculating the doses in Table 16.

TABLE 16. Estimated Annual Radiation Doses from Gaseous Effluents Released from the IFCF Reprocessing Facilities in the Year 2000[a]

		Individual at Site Boundary (mrem)				
Organ	Nuclides	LWR-U[b]	LWR-Pu[b]	LMFBR[b]	HTGR[c]	Total
Skin	^{85}Kr	0.58	0.045	0.40	0.13	1.12
Total Body	^{3}H	0.028	4.5×10^{-3}	4.8×10^{-3}	6.9×10^{-3}	0.044
	^{85}Kr	7.4×10^{-3}	4.8×10^{-4}	5.7×10^{-4}	1.5×10^{-3}	0.010
	^{134}Cs	0.086	8.8×10^{-3}	1.2×10^{-3}	9.8×10^{-3}	0.11
	^{137}Cs	0.022	2.7×10^{-3}	2.8×10^{-3}	2.6×10^{-3}	0.030
	Total					0.19
Thyroid	^{129}I	14.6	2.20	1.66	8×10^{-9}	18
	^{131}I	4.65	1.35	1.92[d]	9.8×10^{-3}	7.9
	Total					26.
Bone	^{90}Sr	0.16	0.012	0.011	0.027	0.22
	Pu,Am,Cm	0.38	0.98	0.26	0.036[c]	1.64[e]
Throughput, Metric Tons per Year		17,000	2,000	1,850	711	21,561

a. Tritium and noble gases were assigned release fractions of 10^{-2}. Release fractions for other radionuclides were derived from the Barnwell Environmental Report as follows: ^{131}I, 2×10^{-4}; ^{129}I, 8×10^{-4}; Cs, Am and Cm, 2×10^{-9}; and Pu, 6×10^{-10}. (The release fraction is that fraction of the radionuclide eventually released from the "cooled" fuel to the atmosphere.)
b. Cooled for 150 days.
c. Cooled for 365 days.
d. If LMFBR fuel were cooled only 90 days, then this thyroid dose would be 220 mrem.
e. Average dose over a 50-year period.

The annual doses to the total population within 50 miles of the IFCF corresponding to the individual dose values listed in Table 16 were estimated to be 13 man-rem to the total-body, 1,900 man-rem to the thyroid, and 120 man-rem (average over 50 years) per year of release to the bone.

Again, with the possible exception of the thyroid, these population doses should not be unacceptable to either the licensing or regulatory agency or the general public. These doses are all very small when compared to the natural background radiation to which these same persons are exposed.

Both the individual and population doses from the IFCF are about the same order of magnitude as would be expected for each of the separate sites were the reprocessing plants dispersed. However, the overall total population dose would be greater with the dispersed concept, primarily due to the smaller SB distances involved.

The accumulation of long-lived radionuclides, such as ^{129}I and the actinides, in the immediate vicinity of either the single IFCF site or the several DFCF sites should not be a serious problem. The postulated releases of the actinides are relatively insignificant. The long-term accumulation of ^{129}I will, of course, be less offsite at the IFCF because of the longer EZB distance involved. Soldat[29] has discussed the implications of long-term accumulation of ^{129}I in the soil and has estimated that soil-plant uptake would add only 1% to 2% per year of soil accumulation to the radiation doses received from consumption of milk and vegetables contaminated by direct foliar deposition. In other words, after about 50 to 70 years of soil accumulation the resultant annual radiation doses from ^{129}I would be about twice those received during the first year via direct foliar deposition. Long-term dedication of several contaminated sites or expensive restoration procedures would be required under the DFCF concept. Under the IFCF, however, only one site, which could be retained indefinitely, is involved.

5.4.5 Waste Management Facilities

Waste management facilities were discussed in ORNL-4451, where it was concluded that with proper design and siting any environmental radiological impact of such facilities would be minimal. Interim storage of high level liquid wastes does not normally result in release of radioactive materials to the surface waters. Acceptably small releases of radionuclides to the atmosphere will occur routinely, and accidental leaks could release liquid material to the ground. Careful design and judicious siting of the high-level liquid waste storage facilities must be accomplished. Siting of these facilities within an IFCF where the distance to the nearest population is relatively large would normally result in lowered radiation doses to the offsite population.

Solidification of liquid wastes after a brief (3 to 5 yr) storage period will be done at the site of the reprocessing plant. It may be desirable to remove certain fission products and actinides from these wastes prior to solidification. The fission products ^{90}Sr and ^{137}Cs may be removed to reduce the heat generation rate within the solids, and the actinides may be removed to reduce the extremely long time that the solid product remains highly radiotoxic.

Neither these removal processes nor the solidification itself should impose an unacceptable environmental impact provided that the proper design and siting as mentioned previously have been followed. The separated fission products would need to be encapsulated and placed in a cooled storage facility until such time that their heat rate has decreased significantly or alternately until some beneficial use could be found for them. The separated actinides could possibly be fabricated into suitable form for charging into an "actinide burner" for transmutation and fission. Properly encapsulated solidified wastes could be stored at an interim Retrievable Surface Storage Facility (RSSF) for several years prior to shipment to an ultimate disposal site. The radiological impact associated with the solidification of the high-level liquid wastes was included in the foregoing evaluation of the fuels reprocessing plants.

Evaluation of the several concepts proposed for a Retrievable Surface Storage Facility is currently under way by the AEC and its contractors.[12,30-33] Such a facility could provide interim storage of solidified wastes from all U.S. power reactors accumulated to the year 2000 until such time as they can be transferred to the ultimate disposal site. Only minor radiological impact is predicted for the RSSF concepts evaluated to date.

It is envisioned[15] that standard cylinders containing noble gas fission products will be retrievably stored in a Noble Gas Storage Facility (NGSF). The facility would be designed for safe operation and recovery under emergency conditions and would be modular to allow for expansion. The heat removal system (natural convection cooling by air) would assure acceptable surface temperatures for the gas containers to help maintain container integrity. Other options include underwater storage, forced air cooling, and underground storage. Injection of noble gases into porous underground formations has also been discussed.[34] The facility would be comprised of areas for receiving, handling, and inspecting cylinders received from fuel reprocessors and for transferring and storing the cylinders. An AEC reservation is a logical location for the NGSF, perhaps near the RSSF for high-level waste.

Table 17 summarizes the estimates of the radiation dose resulting from the shipments of fuel and waste between the reactors, the fuel fabrication plants, and the fuel reprocessing plants. An estimate of the product of tonne-miles and population distribution for each concept indicated that this factor was two to three times as large for irradiated fuel under the IFCF as under the DFCF. Therefore, the doses listed in Table 17 for the DFCF were multiplied by 2.5 to obtain the comparable values for the IFCF. Table 17 also summarizes the estimated doses for shipments from reprocessors under the DFCF concept which would be eliminated if the IFCF concept were employed. The data in Table 17 are based on References 24 and 32, adjusted to reflect transport of materials other than uranium. It can be seen that the doses eliminated under the IFCF concept (Table 17) are a small fraction of the total transportation doses.

TABLE 17. Estimated Annual Radiation Dose to the Population from Transportation of Radioactive Materials in the Year 2000.[24,32]

Shipment/Mode	Radiation Dose, Man-rem: DFCF Transport Workers	DFCF General Population	IFCF Transport Workers	IFCF General Population
Unirradiated fuel FP to reactor/truck	460	115	920[a]	160[b]
Irradiated fuel Reactor to reprocessor rail/barge/truck	3600	1300	12,600[c]	3200[d]
Solid wastes reactor to storage or burial Truck	1300	1350	4500[c]	3400[d]
Reprocessing Plants to Repository/Rail				
High-Level	25	140	-----	-----
Low-Level	19	110	-----	-----
MO_2 Facility to Burial or Repository			-----	-----
Low-Level Wastes/Truck	17	32	-----	-----
Total Dose	5,400	3000	18,000	6800

a. Assuming shipments increase 2.0-fold in units of tonne-mile compared to the DFCF concept.
b. Assuming population dose increases only 1.4-fold because of the lower population density compared to the DFCF concept.
c. Assuming shipments increase 3.5-fold in units of tonne-mile compared to the DFCF concept.
d. Assuming population dose increases by only 2.5-fold because of lower population density compared to the DFCF concept.
e. The doses from rail shipment would be slightly less than those via truck.

5.5 NONRADIOLOGICAL CONSIDERATIONS

Included within this section is information related to ecological, environmental, and service and utilities considerations of IFCFs and DFCFs. The major ecological differences between IFCFs and DFCFs appear to be in the decreased number of monitoring and reporting programs in the case of the IFCF. The topping enrichment plant so overpowers the remaining facilities that, from environmental and services and utilities standpoints, the IFCF would be only slightly favored.

5.5.1 Ecological Considerations

The irreversible effects upon the environment would be about the same in either the IFCF or the DFCF. However, it would seem possible to locate the IFCF in an area with a lower natural biological productivity than in the case of the DFCFs.

The principal ecological differences when considering the IFCF and DFCF are associated with the number of ecological monitoring and research programs required and the number of environmental reports required to safeguard against introducing radionuclides into the ecological system.

Some of the desired ecological attributes of an integrated nuclear fuel cycle facility are indicated below:

- Remote from resident human populations
- Low biological productivity
- Low species diversity
- Food chains that characteristically do not lead to man
- Deep soil layers over ground water for waste burial
- Low precipitation to restrict soil water percolation to ground water
- Waste burial and storage sites remote from surface waters
- Background of ecological studies
- Land area exclusively dedicated to nuclear facilities

The National Environmental Policy Act seeks to provide for the protection of the earth's environment through the preparation and publication of environmental reports. These reports seek to assess both the short-range and the potential environmental impact of construction and operation of nuclear facilities on local and regional ecological systems. An integrated nuclear fuel cycle facility would probably require a single environmental report while each DFCF site would require a separate report.

The nuclear fuel cycle produces potentially biologically harmful radioactive substances that, when released into surrounding air and surface waters, can be expected to participate in bio-geochemical cycling processes of ecological systems and in food chain transfers that in instances can lead to people. As a safeguard against introduction of harmful amounts of man-induced radionuclides to people through food, air, and water pathways, radiological monitoring programs are routinely established. Also, ecological monitoring programs seek to evaluate the impact of acute and chronic ionizing radiation, increased water temperatures, and the release of chemical effluents upon ecologically important plant and animal populations and upon habitats identified as essential to the continued existence of rare, endangered, or esthetically important flora and fauna.

An integrated facility would require a single comphrehensive ecological monitoring program while the DFCF case would require multiple programs.

5.5.2 Environmental Considerations

The nonradiological impacts considered for the integrated and dispersed facilities include the land and water used, the heat dissipated, and the chemicals discharged to the air and water environment. Information presented in this section is based upon data obtained from Reference 24 and adjusted to the processing capacities projected for the year 2000.

The primary source of environmental impact is related to the effluents discharged from the coal-fired power stations generating the electrical energy consumed in the topping enrichment plant. Enrichment facilities approaching the size considered in this study are presently in operation without an adverse impact upon the environment.

Land Use

A program of new facility construction will be necessary at the integrated site or at new dispersed sites due to the continuously increasing processing requirements. During construction the environmental effects will primarily be the production of noise and dust and the denudation of those portions of the site where buildings will be located. The environmental impact of the construction program will be no more severe than construction programs of the same magnitude undertaken in the past.

The total commitment of land in the case of the DFCF is estimated to be about 60,000 acres on a temporary basis. In the case of the IFCF, the land commitment is estimated to be upwards of 150,000 acres (about one-half the area of the Hanford reservation). The larger areal requirement for the IFCF is needed because of the number of facilities located at a single site and the close proximity of the facilities. The resulting greater facility density causes an increase in the total quantity of material released at the IFCF site, requiring an extension of the site boundaries to conform to existing release limits.

Water Use

Water requirements for the integrated and dispersed cases are essentially the same, with each case needing about 3×10^9 gallons per day (4600 cfs) for once-through cooling. Of this amount the topping enrichment plant will utilize 99% of the water used in the IFCF and about 96% of the DFCF total requirements. Consumptive water usage is on the order of 40×10^6 gallons per day (60 cfs).

Assuming once-through cooling, the major water demand is made by fossil fuel and/or nuclear power plants supplying the large amounts of electrical energy used by the enrichment facilities. The large quantities of cooling water used by the enrichment facility power plants is discharged to surface water bodies and will not result in significant impact to the environment. About 30 million gallons of water per day are required by the reprocessing plants. Topping enrichment plant requirements were based upon production of 11,500 metric ton SWU, which can be compared to the current national production level of 10,500 MT SWU.

Thermal Discharge

About 75% of the 45 x 10^9 Btu/hr (13 GW) of heat dissipated into the environment by both cases being considered is associated with the topping enrichment process. The fossil fuel and/or nuclear power plants supplying the electrical energy to the enrichment facilities contribute greater than 90% of the thermal load imposed by the enrichment facilities.

Operation of cooling towers used to dissipate the waste heat from the gaseous diffusion complex is expected to result in occasional atmospheric misting and fogging at the plant site. The thermal impact is not sufficiently large in either case to produce adverse environmental effects.

Effluents

The estimated environmental impact of facility effluents is presented for the IFCF and DFCF cases in Table 18.

The primary source of environmental impact is related to the gaseous and particulate effluents from the coal-fired power stations generating the electrical energy consumed in the gaseous diffusion plant.

Small quantities of airborne fluoride are generated at the diffusion plants. Measurements in unrestricted areas at existing plants indicate concentrations below the range for which deleterious effects have been observed. In addition, oxides of nitrogen and sulfur are released at the diffusion plants. Conservative estimates of the offsite concentrations of these contaminants yield levels which are below EPA standards. Furthermore, the total quantity of these effluents is insignificant in comparison with the combustion products generated by the supporting electric power plants.

A number of chemical species are present in the liquid effluent stream from the diffusion plant. Calcium, chloride, sodium, and sulfate ions are major constituents of this stream. With water treatment to reduce chromium concentrations and with sufficient dilution within the receiving river, all

TABLE 18. Estimated Effluents Discharged by the IFCF and DFCF in the Year 2000

Effluents - Chemical	Effluents, metric ton per year Fuel Fabrication	Reprocessing	Enrichment	Total
Gases[(a)]				
SOx	28,000	7,000	426,000	461,000
NOx	7,000	9,000	112,000	128,000
Hydrocarbons	75	25	1,100	1,200
CO	180	50	2,800	3,030
Particulates	7,000	2,000	112,000	121,000
F^-	5	130	50	185
Liquids				
$SO_4^=$	-	480	540	1,020
NO_3	27,600	1,100	300	29,000
F^-	4,900	-	-	4,900
Ca^{++}	-	-	540	540
Cl^-	-	240	810	1,050
Na^+	-	6,400	800	7,200
NH_3	12,000	-	-	12,000
Fe	-	-	40	40
Solids	31,200	-	-	31,200

a. Estimated effluents based upon combustion of equivalent coal for power generation. Most gaseous effluents are produced in power generation.

incremental concentrations resulting from the discharge will be reduced to a small fraction of the recommended permissible water quality standards in each of the cases considered.

The UO_2 fuel fabrication flow sheet assumed for this study converts natural UF_6 into natural UO_2 at the uranium fuel plant. Essentially all of the fluoride that enters the plant ends up as calcium fluoride (CaF_2), which is generally buried onsite.

5.5.3 Services and Utilities Needs

The service and utility requirements for a single IFCF would probably be smaller than the aggregate of similar capacity DFCFs, though neither is great apart from the electrical requirements of an enrichment facility. Water use requirements are estimated at 50 to 75 cfs for a single IFCF; a topping enrichment plant could require a similar amount of water. Most of the water would be released through cooling towers and would approximate the release from the cooling towers of several large nuclear reactor power plants.

The electrical requirements for a single IFCF are about 250 MWe. A new gaseous diffusion plant for enriching LWR fuel with a 13 x 10^6 SWU annual capacity requiring $\sim$3000 MWe. The former figure can readily be provided by most electrical utilities over the time span for buildup of a single IFCF. The latter figure (or a lesser amount which may be required by a topping enrichment plant) would require special arrangements with the servicing electrical utilities.

Natural gas requirements could reach one to four trillion cubic feet per year for fuel fabrication, depending on how much UO_2 fuel is fabricated at a single IFCF in addition to mixed oxide fuel fabrication.

Other fossil fuel requirements (coal or fuel oil) for generation of process steam are modest. Process steam could be obtained from reactor plants located on an IFCF.

Other typical service and utility requirements for the various fuel cycle facilities include:

- Inert gases
- Highways
- Railroads
- Equipment
- Architect-engineers
- Construction organizations
- Chemical suppliers

Most such items are readily available at any locations in the country although the cost will be higher if a local supply is not available.

Some services, such as those of specialty equipment fabrications and architect-engineers, are generally independent of sites. The services are performed primarily at the home site of the service organization, and the product is shipped to the point of use. In that case, the difference between an IFCF and DFCFs is primarily one of cost.

In summary, the availability of utilities and services is expected to be about the same for DFCFs and an IFCF, assuming that the sites are selected such that an adequate supply of physical requirements such as water is available. The primary difference between DFCFs and an IFCF probably will be a smaller cost for IFCFs because of the smaller requirements, the economies of scale, and the elimination of multiple supply and use locations.

5.6 FREE ENTERPRISE EFFECTS

A decision to build one or two IFCFs rather than DFCFs will influence institutional, social, labor, and economic aspects of our present way of doing business. This section explores some of the possible impacts.

5.6.1 Institutional Effects

Major institutional problems may be created by a single IFCF; these problems may be decreased somewhat by having a second IFCF. For the purpose of highlighting the problem areas, two general institutional arrangements are considered:

1. All facilities at a given site could be owned and operated by a single entity. The entity could be the Federal government, a single corporation, or a combine of corporations sharing ownership.
2. Major plants within the IFCF could be owned and operated by separate entrepreneurs.

The IFCF could be owned by the Federal government and could sell services on a cost-reimbursed basis like the present enrichment plants. A single corporation ownership would encounter antitrust problems. The IFCF could be operated by a single enterprise in which ownership is held by a number of companies. It could be regulated like a public utility with governmental review of selling prices and costs. Antitrust problems might be present under this arrangement, too. In any case, all of these approaches conflict with the free enterprise approach to industrial development which has characterized the nuclear industry to date. Thus major institutional problems can be expected from these approaches.

In the second arrangement, major facilities would be owned and operated by separate entrepreneurs. The major problems with this approach lie in determining who builds which plants and when. At present an entrepreneur decides where it is most strategic to build a plant (i.e., where the market is thought to be, where long-term customers are located, etc.). The entrepeneur builds the plant large enough to handle initial projected loads in keeping with competing demands for capital. This approach generally results in several plants being built in the same time frame at scattered locations (e.g., NFS, Midwest, and Barnwell). Will this same approach be used when all entrepreneurs have to build at one (or two) locations?

Economic advantages of transportation will no longer exist. Advantages derived from propinquity to long-time customers and other company components may disappear. Building two smaller plants simultaneously at a single location where one larger one permits significant economic gains (see Section 4) may be considered too wasteful.

One approach might be to select (by an undefined process) an order for each entrepreneur to build at an IFCF. Apart from the selection process there are major unknowns in this approach. Will the first entrepreneur be prevented from adding to its plant as demand increases? What provisions may be required as the earlier plants become less competitive than later plants?

The foregoing are some of the potential problems which may arise; discussions with potential entrepreneurs could surface additional problems and/or produce acceptable solutions to some already identified.

It is clear, however, that modification to the present way of doing business will be required if entrepreneurs are limited to one or two IFCFs. At this time it is believed that this will cause major problems of an institutional nature.

5.6.2 Sociological Effects

Two sociological effects which should be considered in evaluating IFCFs include:

1. Public acceptance of IFCFs;
2. Construction effects of IFCFs on nearby communities: long-term effects on local employment, business, and taxation.

Public acceptance of IFCFs will probably relate to the radiological aspects of the various alternatives open to the public. Two aspects of concern are likely to center around diversion of plutonium and fission products for clandestine purposes, and the likelihood of accidental release of radioactive materials.

Integrated fuel cycle facilities appear to have the following potential advantages and disadvantages in relation to these two concerns:

Advantages of IFCF	Disadvantages of IFCF
Potential for centralized, larger operations to result in better personnel training, more sophisticated guard systems, and better monitoring. Less potential for diversion.	Longer transportation of spent and new fuel to and from reactors.
Potential for accidental release of radioactive materials to affect smaller populations because of remote siting.	Potential for "common mode" failure within IFCF leading to major releases of radioactive materials.
Likelihood of overall improved reliability due to fewer plants and equipment items that can fail. Better backup systems can be provided at the same cost.	
No offsite transportation of solid alpha and high-level wastes.	

Although this is not a comprehensive list of pros and cons for IFCFs, it is our opinion that IFCFs are likely to be of less concern to the general public than DFCFs. This is not to say that DFCFs are unacceptable to the public. However, the reduction in public concern about plutonium and fission products releases probably would be larger than the increase in public concern about fuel transportation. Distance appears to be an important factor in the public concern about the matter; i.e., concern is often an inverse function of distance from the trouble. Further, many hazardous materials are transported now, and the public accepts the fact.

The disruptions of life patterns due to construction and operation of IFCFs probably could be less than for DFCFs because there would be one or two disruptions instead of several and because there would be a continuing construction activity over many years at the IFCF.

If a single IFCF were built in an orderly manner such that there would be a relatively constant construction force varying between about 4000 and

5000 workers, the disruption would consist primarily of (1) the displacement of residents from the land needed for the IFCF, (2) the initial buildup of the construction force and the accompanying need to increase housing, municipal services, and retail establishments, and (3) the final reduction of the construction force after all facilities had been built. This entire process could require as much as 20 years, resulting in a long period of relatively stable construction employment during which time the additional municipal, housing, and commercial facilities would be paid. The construction work forces for each of two IFCFs are not unlike that required for a large reactor construction project.

In contrast, the DFCF concept would result in numerous disruptions scattered across the nation. Each disruption would have about the same buildup and decline of construction forces, but instead of a long period of relatively constant employment, there would be a short construction peak over about a 4 or 5-year period. The local effects could be much larger because of insufficient time to pay for additional facilities needed for the construction workers.

Long-term local employment and business effects result from employment of operating personnel. Generally, the effect is desirable because fuel cycle facilities provide permanent jobs for long periods of time. In the case of a single IFCF, employment would build up to about 10,000 operating personnel, or about half that number for two IFCFs, by the year 2000. No conclusion can be made as to whether an IFCF is more favorable than a DFCF because the benefits depend primarily on the employment conditions in the region. As an example, an IFCF located at a site with full employment would result in less benefit than would several facilities located at sites with significant unemployment.

The property tax base for a county or even a state receiving an IFCF could be enormously increased. Some means of sharing this large amount of income with other political subdivisions might be necessary.

It is concluded that neither the construction nor operating work force should overtax communities such as those adjacent to Hanford.

5.6.3 Labor Effects

Four general types of labor are related to operation of fuel cycle facilities:

1. Construction,
2. Technical and managerial operating personnel,
3. Nontechnical operating personnel, and
4. Employees of service industries.

The general effect of an IFCF or DFCFs on these types of labor will depend primarily on the location of the facilities. Construction in a region with high unemployment will decrease the unemployment and will reduce the number of persons who must move to the site to provide the necessary employees. On the other hand, construction in a region with full employment will require obtaining essentially all additional employees from other locations.

The primary differences between DFCFs and an IFCF for construction labor are: (1) less total labor is required for an IFCF and (2) the local labor problems probably are less for the IFCF than for the DFCFs. This latter situation results from the relatively continuous construction program at an IFCF. If the IFCF facilities are built at a relatively uniform rate, the construction and related service industry employees should remain relatively constant for the relatively long period while all facilities are being built. This contrasts with the large buildups and then reductions in construction labor forces over a relatively short time at each of the DFCFs.

The general effect on technical, managerial, and nontechnical operating personnel and related service employees generally will be about the same for either DFCFs or an IFCF. In general, most of these persons will have to move to the general vicinity of the facilities unless they are built in a region with large unemployment among persons with the desired capabilities. They would have no choice as to the region of the country that they must live in if an IFCF facility is built. They would have a broad choice if DFCFs are built.

An advantage of an IFCF for technical people is the presence of a large number of persons with similar education and work activities. This would provide greater opportunity for professional contacts and development.

5.6.4 Capital and Cash Flow Effects

As a general rule, the capital and operating costs for industrial facilities decrease as the size is increased and the number of facilities is reduced. This results from the economies of scale by use of larger facilities and more efficient use of personnel.

On the other hand, when the number of facilities is reduced, the transportation costs for raw materials and products increase because of the longer distances from supply sources to the processing facilities and from the facilities to the locations where the products are used.

The general relationships between plant capacity and costs are as follows for reprocessing and fuel fabrication plants:

Plant Size	Relative Unit Cost of Activity	
(Tonnes/day)	Reprocessing	Fabrication
1	1.0	1.0
2	0.65	0.81
4	0.41	0.67
8	0.26	0.58
10	0.24	0.55

Transportation costs, on the other hand, generally are directly proportional to the distance traveled. However, because they generally represent less than 20% of the total fuel reprocessing and fabrication costs, the increase in transportation costs is not expected to exceed the decrease in other costs when an IFCF is substituted for DFCFs.

An important part of the transportation cost is the interest cost on enriched uranium. Longer transportation distances result in higher interest costs because the uranium has to be produced earlier.

One of the primary causes of lower costs for a centralized facility is the ability to use better equipment and more highly trained personnel. In many cases, as the capacity is increased, it is advantageous to convert from manual to automated operations. As a result, there are lower personnel costs and more uniform products. Human error is reduced, and facilities generally have a higher operating efficiency because machinery can operate continuously. As an example, a single large rail yard might have automated classification equipment, whereas such equipment could not be justified for eight separate smaller yards.

An IFCF would be expected to have a different cash flow schedule than those for DFCFs. The total cash flow during the first 20 years probably would be lower than for the DFCF because of the lower average unit costs. However, the initial expenditure would be higher because of the larger plant facilities and land requirements. Whereas the first DFCF reprocessing plant might have a capacity of 600 MT/year, the first IFCF reprocessing plant would have a capacity of 6000 MT/year, and would cost about 2.25 times as much. Similarly, the initial land and supporting facility costs probably would be considerably higher for the IFCF.

In summary, a limitation to one or two IFCFs is expected to produce a lower total fuel cycle cost than a large number of DFCFs. A larger initial expenditure would be needed to initiate the IFCF, but the lower fuel cycle costs should still make this larger expenditure attractive.

5.6.5 Timing

The schedule difficulties which are currently being experienced with the DFCF reprocessing plants have resulted in a serious spent fuel storage problem. The IFCF schedules must give priority attention to this storage problem. It is feasible, with only a minor cost and overall schedule impact, to build the spent fuel storage basin initially and complete the contiguous reprocessing plant in a secondary construction phase. While this approach offers some storage relief, normal basin storage at a reprocessing plant usually is sized at less than one year's production. Oversized basins perhaps suitable for the later joint use of two or more large reprocessing plants could provide the solution. Large IFCF central basins would require subsequent secondary handling of the fuel which would create higher operating costs. Some temporary initial storage may also be possible in existing Hanford facilities.

A preliminary examination of construction scheduling is shown in Figure 9. Site preparation and transportation facilities are essential to the total construction effort and can be started very rapidly. Priority is then given to spent fuel storage basins. The fuel storage structures are large covered concrete basins usually about 3 fuel lengths deep (about 50 ft), require about 5 ft^2 per tonne of fuel and would require railroad or road connections, cask unloading facilities and basin water clean up auxiliaries. In an area such as Hanford, where the geology is well understood, it should be feasible to receive fuel three years after initiation of the IFCF project.

If does not appear likely that the first reprocessing plant could be in production in less than 5 years. To approach a 5-year schedule, engineering would have to be well under way when the IFCF effort is initiated.

Once the IFCF has a fuel reprocessing plant in production, the need for the rest of the IFCF complex begins to develop. It is feasible to store several years of fuel hulls, store $Pu(NO_3)_4$ on site, ship UF_6 offsite and store calcined waste in the same fuel basins which are being emptied as spent fuel reprocessing proceeds. The UO_2 fuel fabrication, waste fixation fuel reprocessing and retrievable waste storage facilities could come on line many years after the first reprocessing plant starts up.

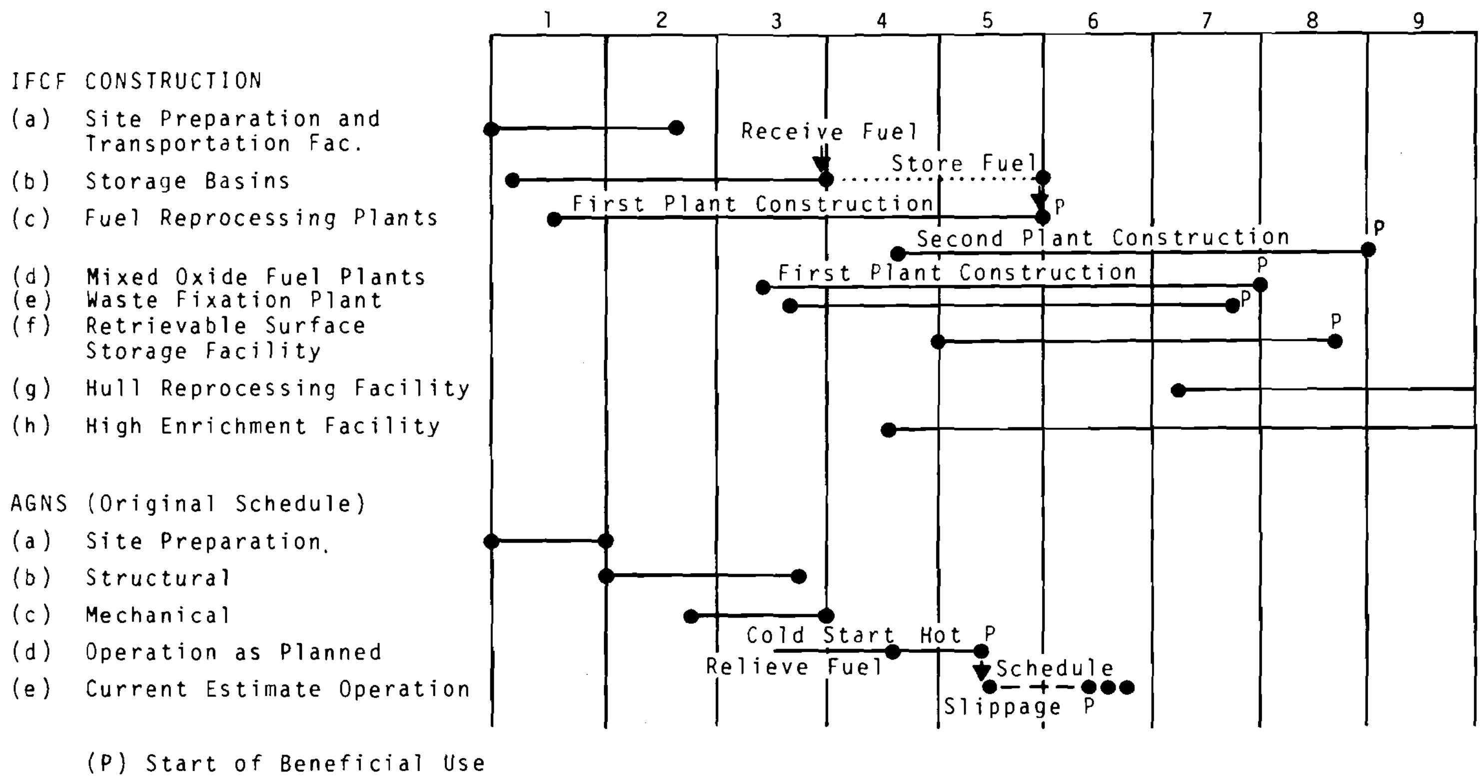


FIGURE 9. IFCF Construction Schedule Comparison

To meet the spent fuel deliveries to the IFCF anticipated in 2000, several very large reprocessing plants are envisioned. These plants would require large construction efforts, each on the average needing 2000 to 2500 construction workers at the peak of construction. To meet the demand for spent fuel reprocessing, more than one plant would be under construction at any one time. Also other facilities such as waste fixation and mixed oxide fuel fabrication will require sizable construction crews. A continuing construction work force of 4000 to 5000 workers would be required through the year 2000.

The purposes of comparison, the original construction schedule for the AGNS plant is also shown on Figure 9. It is noted that the AGNS schedule anticipated receipt of spent fuel in a little less than 3 years after the start of construction with reprocessing capability about on year later. A schedule slippage of a year and one half has been officially recognized. The Midwest Fuel Reprocessing Plant had an original schedule similar to that of AGNS and was over three years behind scheduled startup when General Electric announced major process changes would be required for plant operation. The IFCF schedule proposed anticipates fuel storage capability by some 18 months less time than the current AGNS schedule and production capability in 6 months less time.

IFCF/DFCF Comparisons

The AGNS schedule as now currently adjusted should provide some relief to the spent fuel storage problem within the next 18 months. The first IFCF spent fuel storage will not be available for three years after start of construction. There does appear to be an initial period for the IFCF when some loss of fuel storage and fuel reprocessing capability exists. This initial situation should, however, be corrected by the early eighties. The site studies, licensing and public relations for the IFCF should be greatly simplified, and much of the lost time associated with the multiplicity of problems at each DFCF site would be recovered. The concentration of craft and professional skills at the IFCF should make further contributions to improved schedule performance.

6.0 POLICY IMPACT

This section identifies a number of items considered worthy of investigation. Few conclusions are presented regarding AEC policy formulation.

Several terms appearing in this section may have very specific meanings when used in official regulatory documents. Examples are the words, "policy," "restriction," "regulation," "legislation," and "control." However, as used in this section, these words are considered to have such meanings as would be commonly understood by the average technical person. It is hoped that the use of such terms in this less precise manner will not cause misunderstanding.

Five broad questions provide a framework for analyses of IFCF policy considerations:

1. What facilities should be included?
2. What are the advantages?
3. What are the disadvantages?
4. What are the site considerations?
5. What are the implementation considerations?

Two matters must be dealt with early: which branch of the Commission should have responsibility for answering the above questions in sufficient depth to allow a decision on whether and how to proceed with a generic environmental statement on the concept? (The impact statement should answer all questions in depth and should point to a decision.) What are the timing imperatives for requiring new facilities to be located at an IFCF (e.g., as soon as possible, in time to accommodate LMFBR commercialization, holdup of announced plants until the IFCF is confirmed or rejected)?

A detailed structure for the five questions is presented in the following paragraphs.

Several types of facilities are basic to the IFCF concept: spent fuel processing, fuel fabrication, waste management, and high enrichment.

However, several options exist for fuel fabrication and waste management facilities. Plants fabricating only LWR-UO_2 fuel could be either located at the IFCF site or dispersed throughout the nation. (In any event, the plants fabricating LWR-mixed oxide, HTGR, and LMFBR fuel would be located onsite.) Waste management facilities would include the RSSF for high-level waste and, most likely, storage for α waste, cladding hulls, iodine, noble gases, reprocessing plant tritium, and α-β-γ waste. Storage of β-γ wastes, including reactor tritium, generated offsite could be accomplished at dispersed commercial burial grounds already in existence or at IFCF burial grounds. Considerations of ultimate disposal could enter into selection of the IFCF site, or the location could be determined independently of such considerations.

Other facilities may be located at the IFCF. Possibilities include development facilities for technical support of onsite operations, satellite operations (manufacture of neutron sources, plutonium devices), centralized storage for inventories of materials not in-process, and possibly reactors.

The advantages and disadvantages of the IFCF are discussed in other sections of this report. Implementation of the IFCF would necessitate policy changes to capitalize on the advantages and to minimize effects of the disadvantages. Implications of the advantages include the following: (1) elimination of transportation of strategic materials except as fresh or spent fuel; (2) reduced restrictions on transfers of materials between facilities (offsite shipping regulations would not affect onsite transfers between reprocessing and fabrication plants); (3) faster response to diversion, through coordination with government agencies; and (4) easier monitoring of material movements and of onsite inventories.

Implications of the disadvantages include the following: (1) Local effects of releases of all effluents could be greater because of the proliferation of facilities at one location. (2) Economic penalty is possible because of restrictions on private industry in the choice of geographic location. (3) Labor strikes could have a magnified effect, with all facilities at one site, and could thus reduce the fuel supply reliability.

(4) To minimize transportation of materials between sites, balanced production among the IFCF facilities would be required. Controls would be needed which might tend to reduce the incentive for innovation because the customers would in effect be captive. (5) To minimize transportation, utilities would be captive customers of particular sites.

Many questions could be asked regarding selection of the IFCF site. How many sites should there be and who should select them? If more than one site, should a minimum and a maximum be set on the total nuclear generating capacity served? Should the site be restricted to service of a specific region? Should utilities be limited to dealing with a particular site? Should the land be federally owned? If federally owned, should special consideration be given to use of AEC sites? What, if any, should be the special safeguards siting requirements for IFCF (e.g., remote location; placement of certain facilities underground; provisions for accommodating additional facilities in the future)? What are the constraints dictated by safety considerations (maximum size in terms of reactor MW accommodated, restrictions on individual locations of activities with respect to each other)?

Implementing the IFCF involves numerous policy decisions. The federal government could own all, some, or none of the facilities. Some of the facilities could be operated by the federal government (e.g., waste management, guard force). Common facilities, such as roads and utilities, could be furnished by the federal government, by Roane-Anderson arrangement, or by private industry. Federal grants may be necessary to stimulate the IFCF concept, as well as "grandfather" clauses to protect committed private facilities. Mandatory subscription to centralized services (guards, transport, monitoring, stacks) may be necessary. Government funding and reimbursement for activities performed (land acquisition, construction, waste management) would have to be determined. The method of selection of the participants would have to be established (e.g., first come, first served; invitation; no restrictions; restrictions based on maintaining a balance between processing and fabrication capacity). Special legislation may be required, e.g., to limit plant locations.

Special regulatory requirements almost certainly include the following: a general environmental impact statement on the IFCF concept, including site selection; environmental statements for individual sites, including the total safeguards plan; and provision for rate equalization for spent fuel in and fresh fuel out in order to compensate for limitations imposed on the location and number of sites providing fuel cycle services. (There may be an economic penalty associated with the restrictions of the IFCF concept.)

Other agencies (Federal, state, local) may be involved in helping the AEC analyze the IFCF concept. How does the AEC obtain the participation of these groups and at what stage?

7.0 ALTERNATIVES

The IFCF approach is only one of many possible ways of altering the DFCF case. Radical redirections from present national plans are possible, such as developing alternative nuclear and/or nonnuclear power generators (or at least changing the reactor mix) in order to reduce the problems of emissions, accidental release, safeguards, and waste disposal in the associated fuel cycles. Less extensive changes, each of which attacks only part of the list of problems, include 1) sharply reducing the volume of waste generated through implementation of new process procedures and controls, 2) eliminating fuel reprocessing through storage of spent fuel 3) eliminating liquid reprocessing of spent fuel (solid processes only), 4) operating facilities on a "zero-release" basis with substantially increased recycle of waste, and 5) relocation of fuel cycle facilities. The IFCF approach primarily represents the last class of changes but includes potential for reducing wastes.

Other examples which include relocation options are nuclear energy centers and plutonium parks.

Features of a nuclear energy center include a large installed electric power plant capacity, perhaps in the range of 10 to 40 GWe, plus facilities for fuel reprocessing and fabrication, plutonium recycle and fabrication, waste handling and utilization, and provision of necessary environmental protection. The plants could be of different types, e.g., light water and breeder reactors, and the centers could include various energy intensive industries. Based upon the projected United States' need for 1200 GWe by the year 2000, there could be between 30 and 120 such energy centers located throughout the country. This approach is contrasted with the IFCF concept, which would require a like number of sites for the power generating reactors but would contain all supporting fuel cycle facilities within a single, isolated site.

Plutonium parks would contain all plutonium handling facilities including a mix of plutonium burning and breeding reactors, plutonium fuel fabrication, reprocessing, and waste handling. Uranium burning reactors would be located externally to the plutonium park. As in the case of the energy centers, a number of locations for the fuel cycle support facilities would be required as compared to a single IFCF site. Roughly one third of the fuel fabricated in the year 2000 is expected to be plutonium enriched. Thus it would be estimated that 10 to 40 plutonium parks would be needed if each contained 10 to 40 GWe.

In the context of this study, that is, improving waste management, neither plutonium parks nor nuclear energy centers reduce the number of sites containing fuel cycle facilities compared to the base IFCF concept.

8.0 RESEARCH AND DEVELOPMENT CONSIDERATIONS

Technical developments required for the IFCF are directed principally to the areas of waste management, emission controls, ecological programs, radiological transport and pathways, and reprocessing plant equipment.

The generated volume of uncompacted alpha waste is estimated at some 10^7 ft^3 in the year 2000 alone. Although compaction would reduce this volume by a factor of about three, it is important that the research and development work in areas other than compaction be bolstered and accelerated, to further reduce the volume and to remove some of the contained radioactivity.

Table 19 presents an estimate of the volume and plutonium weight fractions for several major categories of alpha waste which would be generated if fuel fabrication and scrap recovery plants were operated at the present state-of-the-art until the year 2000. It further assumes full plutonium recycle and maximum plutonium loadings and that a counting capability would be developed to the point that nonsuspect waste could be certified for nonretrievable storage.

TABLE 19. Generation of Retrievable Stored Alpha Waste to Year 2000 with Present State-of-the Art Technology

Category		Volume Fraction, percent	Plutonium Weight Fraction, percent
1.	Cement Sludge	10-15	15-25
2.	Uncompacted Gloveboxes and Long-Lived Equipment	15-20	5-10
3.	Uncompacted Short-Lived Equipment and Tools	5-10	10-15
4.	Process Solids	2-3	15-25
5.	HEPA Filters	5-10	5-10
6.	Compacted Operating and Housekeeping Materials	40-50	20-30

Various research and development programs and their potential impact on volume and radioactivity reductions are shown in Table 20. The fruition of this work might result in volume reductions of from 55 to 85% and a removal of plutonium of from 40 to 80%. Thus, as a result of compaction and direct treatment of these wastes, an overall volume reduction by a factor of about 15 and a reduction in radioactivity by a factor of about 2 might be achieved. This would be substantial.

TABLE 20. Potential Alpha Wastes Volume and Plutonium Reductions

Category	Potential Volume Reduction, percent	Potential Plutonium Weight Reduction, percent
1. Cement Sludge Feed Material	80-90	up to 90
2. Uncompacted Gloveboxes and Long-Lived Equipment	60-90	up to 60
3. Uncompacted Short-Lived Equipment and Tools	60-80	40-50
4. Process Solids	60-70	50-60
5. HEPA filters - Air Treatment	80-95	60-80
6. Compacted Operating and Housekeeping Materials	60-90	50-60

Radioiodine release to the environment presently appears to be the limiting effluent from the standpoint of radiation dose. Release fractions of about 8×10^{-4} for ^{129}I and 1.5×10^{-4} for ^{131}I are presented in the Barnwell Environmental Report.[(28)] Using these same release fractions for radioiodine at the reference IFCF results in infant thyroid doses of approximately 30 mrem/yr at the site boundary.

To achieve a dose value more compatible with the intent of the ALAP concept, improvements in iodine removal systems are required to reduce the quantity discharged to the atmosphere. Removal systems which produce decontamination factors (DFs) on the order of 1000 will be required to accomplish the necessary reduction. Consistent DFs of 1000 are not routinely achieved using existing state-of-the-art techniques, and, depending upon the time frame, programs to develop the necessary systems might require additional emphasis.

Ecological research programs have not kept pace with the need for nuclear energy. Table 21 shows some of the ecological research and development programs needed for nuclear facilities. As can be seen in the table, the research needs are diverse and the number of programs required in the dispersed facility case will be many times the integrated facility case.

TABLE 21. Ecological Research and Development Programs

		Integrated Facility	Dispersed Facilities
1.	Primary productivity (plants)	One	One at each site
2.	Secondary productivity (animals)	One	One at each site
3.	Species diversity	One	One at each site
4.	Radionuclide transfer	One	One at each site
5.	Radiation effects on biota	One	One at each site
6.	Meteorology and climatology	One	One at each site
7.	Ground water and surface water	One	One at each site
8.	Soil properties and seismic studies	One	One at each site
9.	Radwaste burial procedure	One	One at each site
10.	Revegetation of buried waste sites	One	One at each site
11.	Unplanned release of contaminants	As needed	As needed
12.	Transportation accidents	As needed	As needed
13.	University participation	One to several	Several

In general, defining information for the environmental behavior of radionuclides released from an IFCF is about the same as that required for the DFCF. Differences which occur will generally be due to characteristics of the specific site rather than the particular concepts or quantity of nuclides released. Needed are laboratory and field confirmations of presently assumed physical characteristics used to predict the environmental behavior and resultant radiation doses. In addition, research and development programs related to biological behavior of certain radionuclides would assist in estimating doses. Examples of some of these programs would include:

- Long-term (several years) studies of the behavior of ^{129}I deposited in the environs.
- Studies on the incorporation of long-lived nuclides in organic compounds in animals and occupationally exposed persons.
- Studies aimed at the importance of assuming uniform distribution or hot spot distribution of plutonium and ^{129}I in the thyroid.

Except for experimental verification of LMFBR and HTGR reprocessing flow sheets, which is common to both the IFCF and DFCFs, the major problem area appears to be in scale-up of existing process equipment to the larger capacities. The largest commercial reprocessing plant presently being considered has a capacity of 1500 MT/yr, which is on the order of one-fourth the capacity expected at the larger plants. Such scale-up could result in criticality problems, especially when processing fuels containing higher plutonium concentrations. Also, the effect of larger equipment sizes upon processing efficiency will have to be determined.

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APPENDIX

Letter and Terms of Reference
for Ad Hoc Study Group
from F. K. Pittman

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON, D.C. 20545

February 1, 1974

Dr. A. M. Platt
Battelle Memorial Institute
Pacific Northwest Laboratory
Post Office Box 999
Richland, Washington 99352

Dear Mr. Platt:

Commissioner Larson has asked me to convene a group of eight or ten experts to advise on certain problems with regard to: (1) the chemical processing of spent fuel from, and (2) the fabrication of plutonium bearing fuels for commercial nuclear power reactors.

This is to request that you serve as a member of this group.

Dr. Larson is particularly interested in: (1) the possibility of elimination of plutonium and other similar long-lived radionuclides from the high-level waste stream from spent fuel processing; (2) the reduction of the amount of plutonium and similar materials in waste generated by fuel fabrication; and (3) the reduction of the volume of non-radioactive combustible and non-combustible materials in the radioactive waste from both spent fuel processing and fuel fabrication plants.

Since WMT is making a comprehensive study of all waste and decontamination problems arising from the nuclear power industry, I have included certain other areas in the enclosed proposed terms of reference for the advisory group considerations.

Our present plans call for an initial two-day meeting here in Germantown on February 20 and 21, to be followed, if necessary, by one, or possibly two, additional one-day meetings shortly thereafter either in Washington or at one of the AEC installations. You will be informed shortly of time and place for the initial meeting. We expect that following such meetings, a report would be submitted to Dr. Larson and the group disbanded.

I will act as chairman, and Virgil Trice of my Division will serve as secretary to the group.

If you have any questions or comments on the enclosed terms of reference, please contact me by phone at (301) 973-4285, no later than February 7, 1974.

To assist you in preparing for the meeting, I have enclosed flow sheets and certain other data from recent industrial applications for license.

We hope to keep attendance to a workable level, but if you feel a need for technical backup in some of the areas to be covered, please let me know as soon as possible so that proper arrangements can be made.

Your willingness to assist us in this study will be greatly appreciated.

Sincerely,

Frank K. Pittman

Frank K. Pittman, Director
Division of Waste Management
and Transportation

Enclosures:
1. Terms of Reference
2. Selected References from
   License Applications

Terms of reference for Ad Hoc Study Group on Spent Fuel Processing and Plutonium Fuel Fabrication:

Postulate a Commission policy objective of designing, constructing and operating spent fuel processing and fuel fabrication plants in such a way that:

1. Radioactive material entering these plants will either:

   A. Be contained in process equipment which is designed with the objective that all radioactive material introduced into the equipment may be easily removed therefrom.

   B. Decay to a stable state.

   C. Be released to the environment in liquid or gaseous effluents below the levels allowed by Part 20.

   D. Be packaged in manageably sized, transportable containers with appropriate provisions for cooling, shielding and containment.

2. Using best available technology, processes, plant design and operation will provide for:

   A. Rapid recycle of recoverable radioactive scrap and off-specification radioactive product.

   B. Lowest practical volume and amount of radioactive waste.

   C. Smallest practical inclusion of non-radioactive, non-volatile material to radioactive waste.

   D. Segregation of radioactive waste with respect to:

      i. radioactive characteristics (half life, radiotoxicity, type of radioactivity, etc.)

      ii. chemical and physical characteristics (combustibility, solubility, volatility, chemical and physical form, presence of inerts, presence of chemically reactive constituents, etc.)

   E. Smallest practical inventories of radioactive material (product, scrap and waste).

   F. High degree of protection against plant sabotage and diversion of radioactive product and waste.

G. Lowest practical radioactive contamination of building, equipment and land.

H. Disassembly, and packaging of contaminated buildings and equipment.

I. Decontamination of contaminated land for subsequent unrestricted use.

The objective of the group's deliberations will be to:

1. Identify the extent to which plants in use or proposed either:

   A. Meet the postulated objectives;

   B. Can be modified to meet the objectives (estimate problems and cost of such modification).

2. Identify any changes in technology needed to meet the postulated objectives.

3. Outline, in a general way, the scope, cost and schedule of a development program to adopt such technology.

4. Evaluate the relative advantages and disadvantages of meeting the postulated objectives, considering such factors as:

   A. Development costs.

   B. Incremental capital and operating costs.

   C. Schedule of growth of nuclear power.

   D. Public health and safety.

   E. Environmental impact.

   F. Public acceptance of nuclear power.

5. Evaluate advantages and disadvantages of potential options for management of:

   A. In-process inventories of all radioactive material.

   B. Inventories of product and scrap.

   C. Inventories of waste.

   taking into account the problems of environmental protection, public health and safety, and diversion.

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