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IAEA-SM-284/26

Consolidated Fuel Reprocessing Program

ANALYSIS OF VARIOUS OPTIONS FOR THE BREEDER FUEL CYCLE IN THE UNITED STATES

J. G. Stradley, W. D. Burch, H. R. Yook
Fuel Recycle Division
Oak Ridge National Laboratory*
Oak Ridge, Tennessee

R. E. Lerch
Hanford Engineering Development Laboratory
Richland, Washington

*Operated by Martin Marietta Energy Systems, Inc., for the U.S. Department of Energy.

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Fuel Recycle Division
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ABSTRACT

The U.S. Department of Energy (DOE) has established a program to develop innovative liquid metal reactor (LMR) designs to assist in developing U.S. future reactor strategy. This paper describes studies in progress to examine various fuel cycle strategies that relate to the reactor strategy.

Three potential fuel cycle options that focus on supporting an initial 1300-MWe reactor station have been defined:

1. completion and utilization of the Breeder Reprocessing Engineering Test/Secure Automated Fabrication (BRET/SAF) in the Fuels and Materials Examination Facility (FMEF),
2. a co-located fuel cycle facility, and
3. delayed closure of the fuel cycle for five to ten years.

It appears feasible to increase the capacity of the original BRET design and SAF in the FMEF to accommodate the projected output (up to 35 MTHM/year) from the 1300-MWe liquid-metal concepts under study.

Working with the reactor manufacturers, criteria were developed for a small fuel cycle facility co-located at a utility reactor site. The requirements considered the need to be able to support as little as approximately 400 MWe to as much as 1300 MWe. A scoping design has been completed for a co-located fuel cycle facility with a 35 MTHM/year reprocessing capability. A rough order-of-magnitude capital cost estimate ($300 million) was developed.

Plans developed within the U.S. Consolidated Management Office for an initial reactor project have envisioned that a cost savings could be realized by delaying closure of the fuel cycle as long as supplies of plutonium could be obtained relatively inexpensively. This might prove to be only five to ten years, but even that period might be long enough for the fuel cycle costs to be spread over more than one reactor rather than loaded on the initial project. This concept is being explored as is the question of the future coupling of a light water reactor (LWR) reprocessing industry for plutonium supply to breeder recycle.

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1. INTRODUCTION

As described in poster sessions at this meeting, several U.S. reactor manufacturers are developing innovative LMR conceptual designs. This paper reviews an ongoing study analyzing various options for implementing a supporting LMR fuel cycle. This study, a collaborative effort between the Hanford Engineering Development Laboratory (HEDL) and the Oak Ridge National Laboratory (ORNL), is utilizing the expertise of HEDL and ORNL in fabrication and reprocessing of mixed-oxide breeder reactor fuel.

2. BACKGROUND

The DOE has established a program to develop innovative LMR conceptual designs as part of their civilian reactor program. The program supports the objective of confirming the potential for reducing capital and operating costs, shortening construction schedules, improving reactor safety, and simplifying licensing through innovative development of LMR technology. This program will also identify the supporting research and development appropriate for incorporation in the DOE base program.

While the overall strategy for the U.S. breeder program is being examined and redefined by the DOE, viable options for the fuel cycle must be developed to support this effort. Several scenarios for closing the fuel cycle in the near term are being evaluated with primary emphasis on identifying the comparative costs for each while seeking ways to minimize overall fuel cycle costs. Consideration of the initial fuel supply and its relationship to the back end of the fuel cycle are also being examined.

Three potential fuel cycle options for the innovative LMRs have been identified that focus on near-term needs:

1. utilization of BRET/SAF in FMEF,
2. a co-located fuel cycle facility, and
3. delayed closure of the fuel cycle for five to ten years, predicated on the potential availability of plutonium, until the fuel cycle could be closed to support at least 3000 MWe.

The DOE has supported development programs for both fuel fabrication and reprocessing over the past ten years, and these programs are now sufficiently advanced to fully support closing the fuel cycle when needed. The breeder fuel fabrication program at HEDL has been focused on the SAF line, which is being installed in the FMEF located at the Hanford site near Richland, Washington. The objectives of SAF are to establish and demonstrate automated fabrication of mixed-oxide fuel pins and to ensure a continuing supply of fuel for advanced reactors.

The breeder reprocessing program at ORNL was initially focused on the design of a facility to recycle fuel from the first four to six breeders, but with the slowdown of the breeder program, various options for closing the fuel cycle on a smaller scale have been considered. The most recent is the BRET, which would utilize the major hot-cell space in the FMEF and in conjunction with the existing SAF line could recycle fuel from the Fast Flux Test Facility (FFTF) and other LMRs.

Plans developed within the U.S. Consolidated Management Office for an initial reactor project have envisioned that cost savings could be realized by delaying closure of the fuel cycle as long as supplies of plutonium could be obtained relatively inexpensively. This might prove to be only five to ten years, but even that period might be long enough for the closure costs to be spread over more than one reactor rather than burdened on the initial plant. This option is being examined although it is recognized that it will be difficult to estimate how much plutonium will be available and at what price.

While the major emphasis of the study is on defining likely fuel cycle scenarios which would allow the initial LMRs to begin, previous studies addressing the future coupling of the LWR reprocessing industry for plutonium supply to breeder reactors and LMR reprocessing are also being updated.

Since the study is ongoing, this paper will review the current status of each option and touch briefly on other aspects developed to date.

3. UTILIZATION OF BRET/SAF

The BRET/SAF complex in FMEF has been described at other meetings,[1,2] so this paper will only review the basic design aspects as necessary to provide background for the assessment which addressed the potential for increasing the throughput to the level necessary to support the fuel cycle needs of the LMRs.

The FMEF, completed in 1984, is currently undergoing acceptance and start-up testing. The SAF line is currently being installed with expected start-up in 1987. A recently completed conceptual design of the BRET[3] defined a fuel reprocessing capability which could be installed in the FMEF. An overall view of FMEF, located in the Hanford 400 Area, is shown in Fig. 1. The FFTF and the Maintenance and Storage Facility are shown in the background. The FMEF Process Building is 76 m (250 ft) long by 46 m (150 ft) wide and extends from 11 m (35 ft) below grade to 30 m (98 ft) above grade at the roof level.

A cutaway view of the six different operating levels of the FMEF is shown in Fig. 2. Fuel pin fabrication in the SAF line (Fig. 3) is located on the top floor of the building, and the fuel assembly fabrication process is located in a portion of the ground floor. BRET would utilize many of the other areas of the building with the primary fuel reprocessing operations located in the large, shielded Main Process Cell (Fig. 4) in the center of the building.

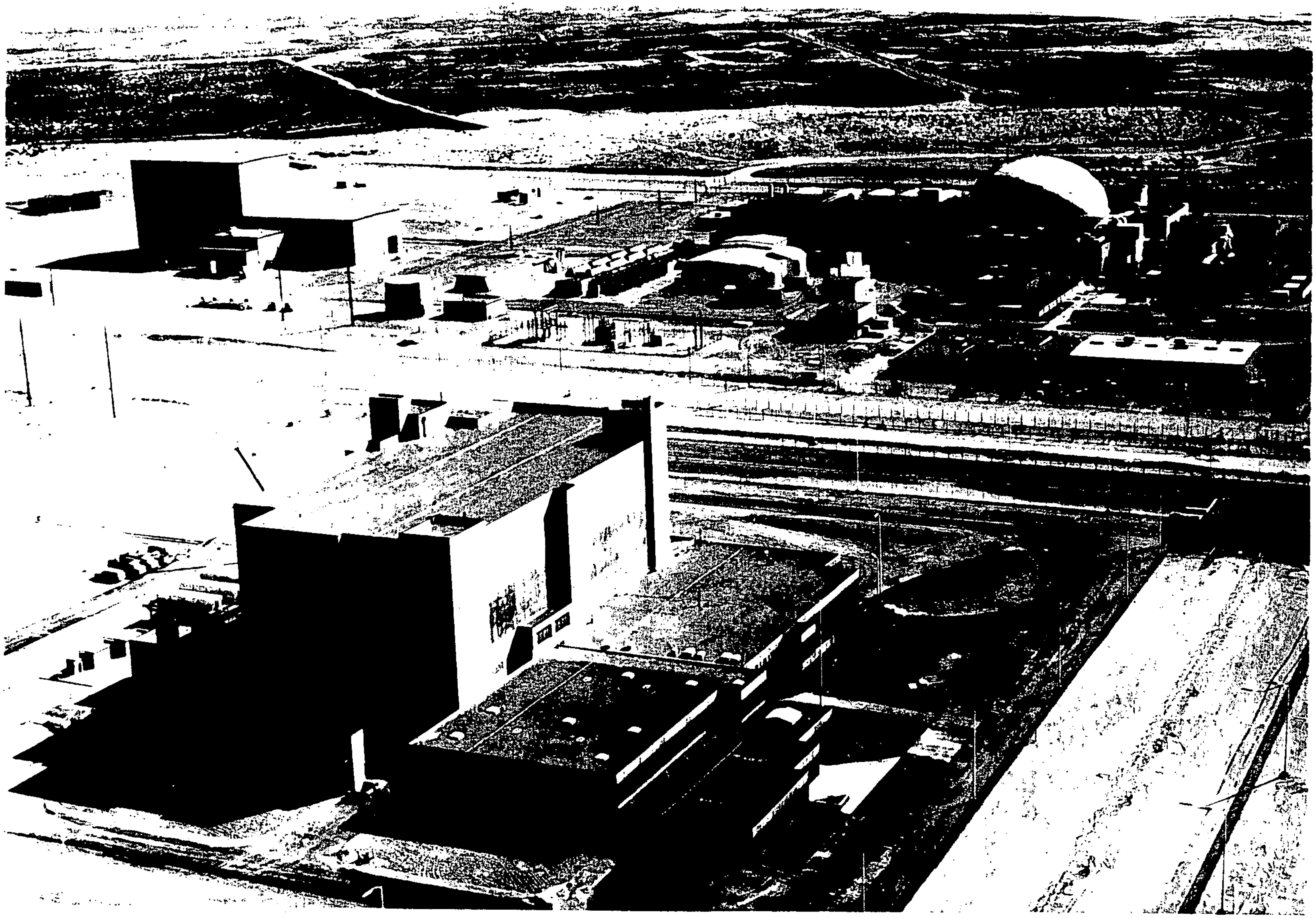

Fig. 1. The Fuels and Materials Examination Facility (FMEF) at the Hanford site near Richland, Washington.

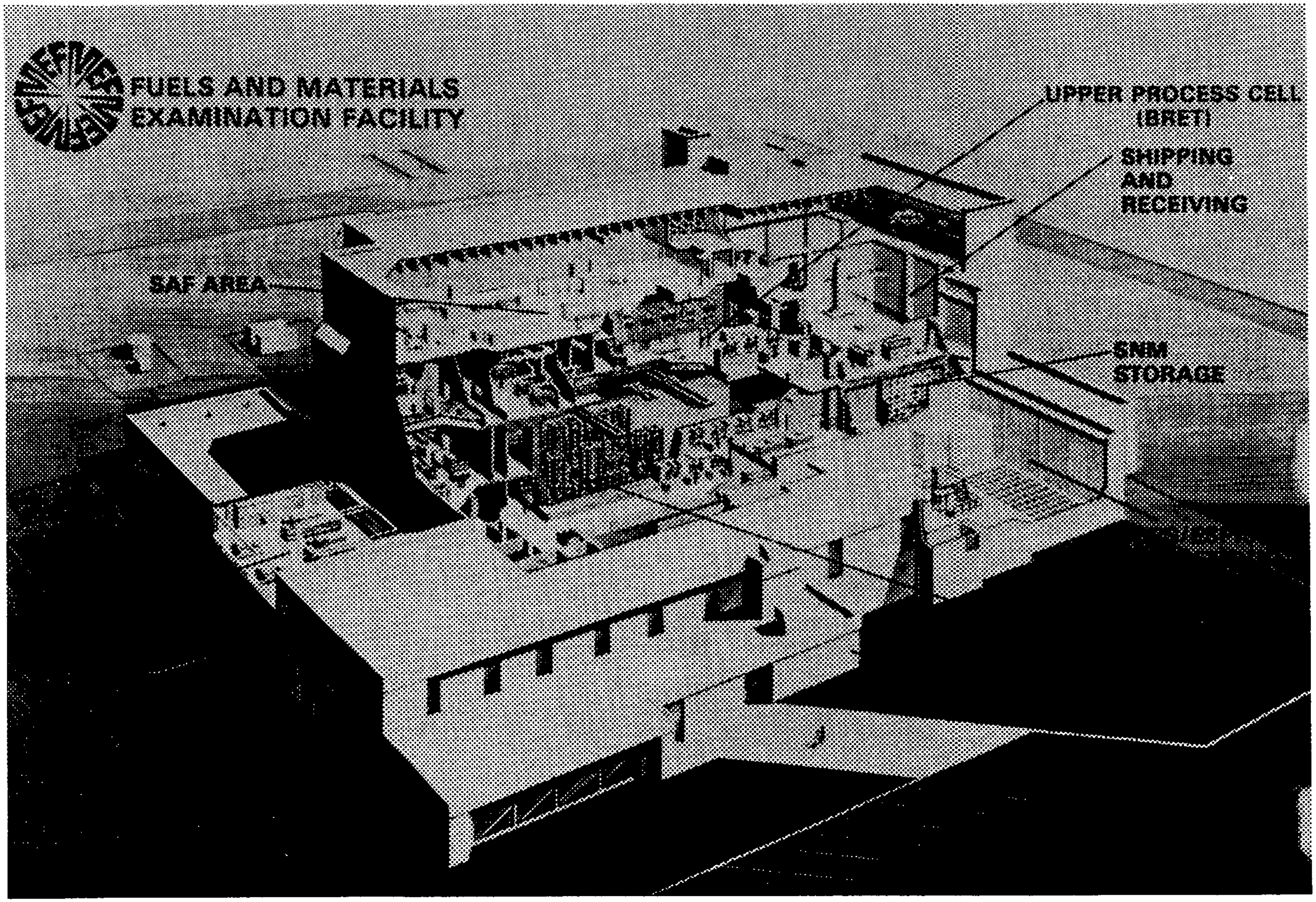

Fig. 2. Cutaway view of the FMEF.

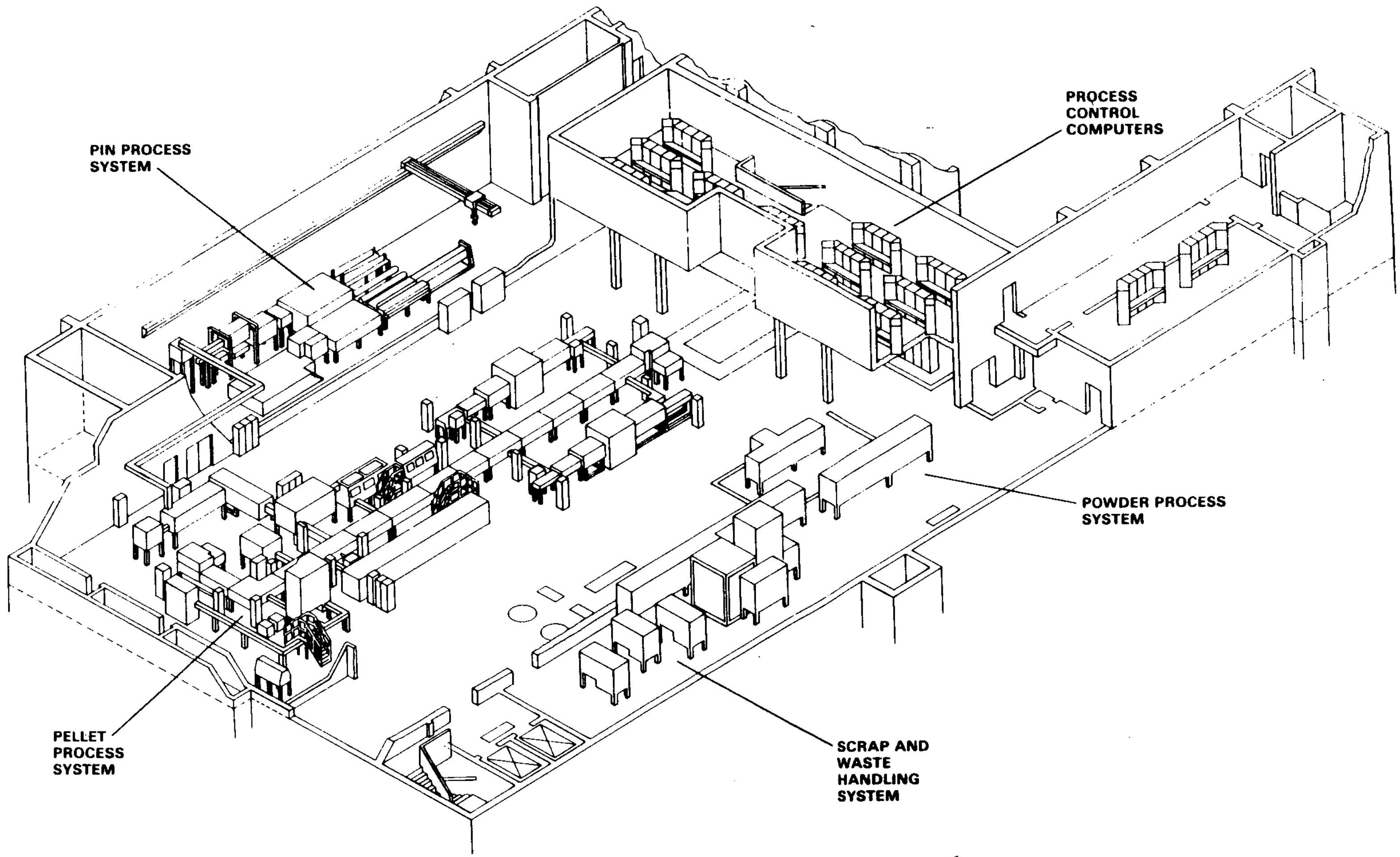

Fig. 3. Secure Automated Fabrication (SAF) process equipment arrangement.

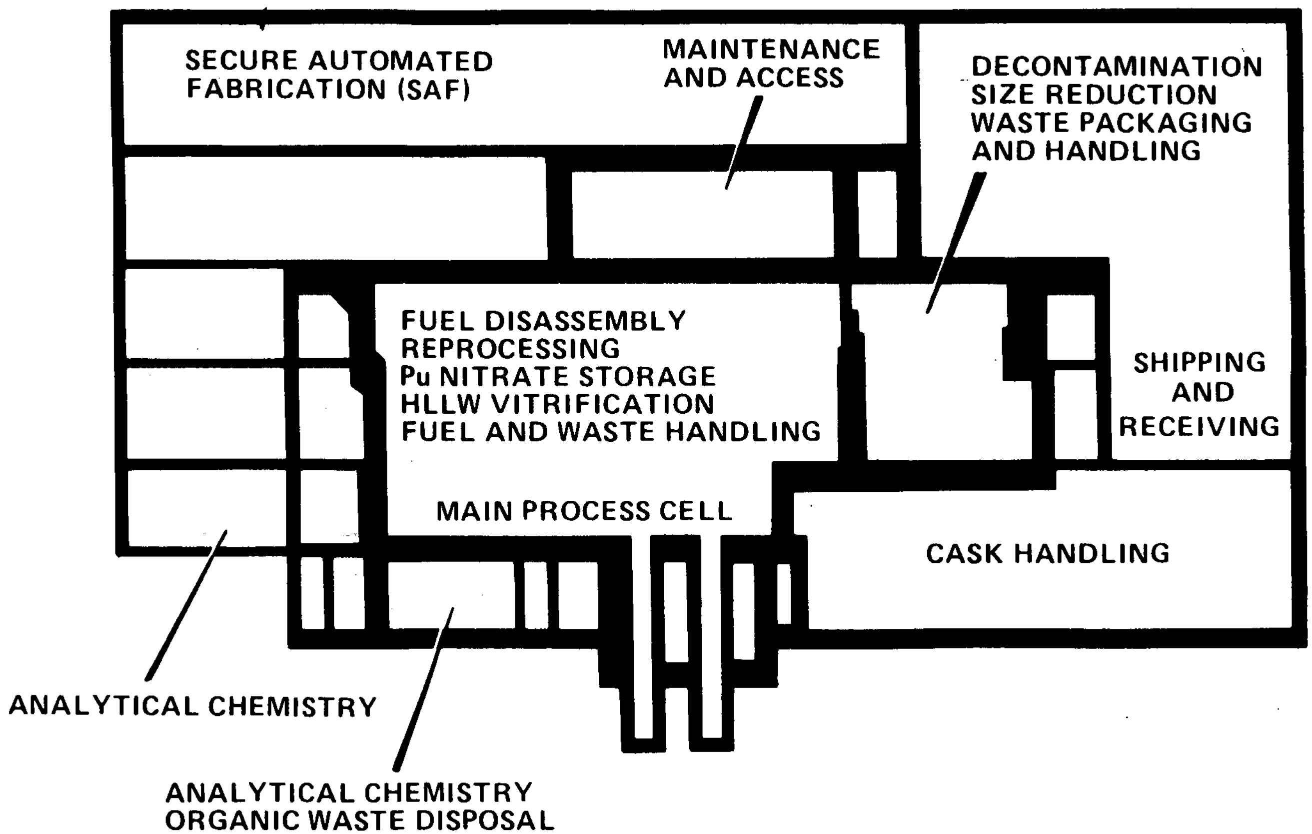

Fig. 4. Cross section of the proposed BRET facility.

The design and construction and associated cost data (actual and estimated) were compiled for FMEF, SAF, and BRET to serve as building blocks in developing new designs and their associated costs. The capital costs, in 1984 dollars, included definitive design, procurement, construction, and in the case of equipment fabrication, installation costs.

The originally proposed BRET/SAF complex was designed to have the capability to

1. reprocess FFTF and Clinch River Breeder Reactor Project (CRBRP) core and blanket assemblies at a throughput up to 15 MTHM/year (100 kg HM/d and 150 d/year), and

2. fabricate FFTF or future reactor fuel assemblies up to 6 MT mixed oxide (MOX) per year, equivalent to 36,000 fuel pins per year.

The following criteria were used to assess the capability of the FMEF/BRET/SAF being expanded to support the innovative LMR concepts.

The FMEF/BRET/SAF would be capable of

1. reprocessing both core and blanket LMR assemblies at a throughput of 35 MTHM/year (200 kg HM/d and 175 d/year), and

2. fabricating 8.5 MT MOX/year, equivalent to 33,000 fuel pins or 130 driver fuel assemblies; blanket fuel assemblies would be provided from other sources.

Employing these criteria, each major function (e.g., reprocessing, fabrication, etc.) of the FMEF/BRET/SAF complex was evaluated to establish the required equipment changes, facility modifications, and the resultant costs. The results indicated that the FMEF/BRET/SAF complex could be upgraded to serve as the fuel cycle facility to support the LMR concepts. No changes to the basic reprocessing processes were identified, but some equipment would be larger and some facility modification would be required. In SAF, no major process or equipment changes were found to be necessary to handle the slightly greater MOX throughput. In-cell handling of fuel, waste material, and equipment for maintenance will require some facility modifications, which are currently under review. Since the LMRs would likely be located at some site other than Hanford, a brief assessment was made of shipping casks needs (fuel and waste). Three casks would probably be adequate to support the number of fuel and blanket assemblies to be transported each year. However, approximately 100 canisters of vitrified high-level waste would be generated so additional casks would be needed, but the specific quantity is dependent upon the number of canisters to be carried in each cask. The costs associated with providing this increased capacity appear to be nominal, only 5 to 15% above the original BRET costs if done initially.

4. CO-LOCATED FUEL CYCLE FACILITY

Working with the reactor manufacturers doing the innovative LMR design studies, criteria were developed for small co-located facilities to close the fuel cycle at a utility LMR site. Then treating each major function area as a building block, a scoping-type design study was performed to concept and cost facilities that would satisfy these criteria. The fuel cycle facilities would be

1. co-located with the LMR site;
2. support an LMR generating capacity of 1300 MWe;
3. capable of reprocessing 35 MTHM/year (140 kg HM/d at 250 d/year);
4. fabricate 8.5 MT MOX/year, equivalent to 33,000 fuel pins or 150 driver fuel assemblies per year; blanket fuel assemblies would be provided from other sources; and
5. capable of processing associated wastes for shipment.

The following assumptions were made:

1. The fuel cycle facility may interface directly with a reactor service building.
2. Major utilities and services would be provided by the LMR site facilities. Only emergency utilities will be included in the fuel cycle costs.
3. General administrative services such as shipping, receiving, warehousing, laundry, etc. would be provided by the LMR site.
4. Dedicated onsite surface transporters would handle top- or bottom-loading casks to transfer spent fuel assemblies between the reactors and the fuel cycle facility.
5. High-level waste would be transferred onsite in top-loading casks handled by dedicated onsite surface transporters; waste would be shipped offsite by truck or rail in shipping casks.

A facility has been scoped which satisfies these criteria and assumptions. As shown in Fig. 5, overall it is about 57 m (185 ft) wide by 81 m (265 ft) long by 63 m (206 ft) high. It was designed to allow an orderly flow of the spent fuel and blanket assemblies in, and waste and new fuel assemblies out, while striving to keep the overall facility as small as possible. This was achieved as shown in the plan view (Fig. 6) and section (Fig. 7).

The reprocessing equipment was laid out in two cells (Fig. 8) employing the equipment rack and center-aisle maintenance concepts (Fig. 9) utilized in earlier Consolidated Fuel Reprocessing Program (CFRP) design studies. The fuel assemblies will be received, cleaned, and stored in a water pool. A laser disassembly system will remove the end fittings and shroud prior to being sheared in a whole-element shear. The sheared fuel will be transferred to a

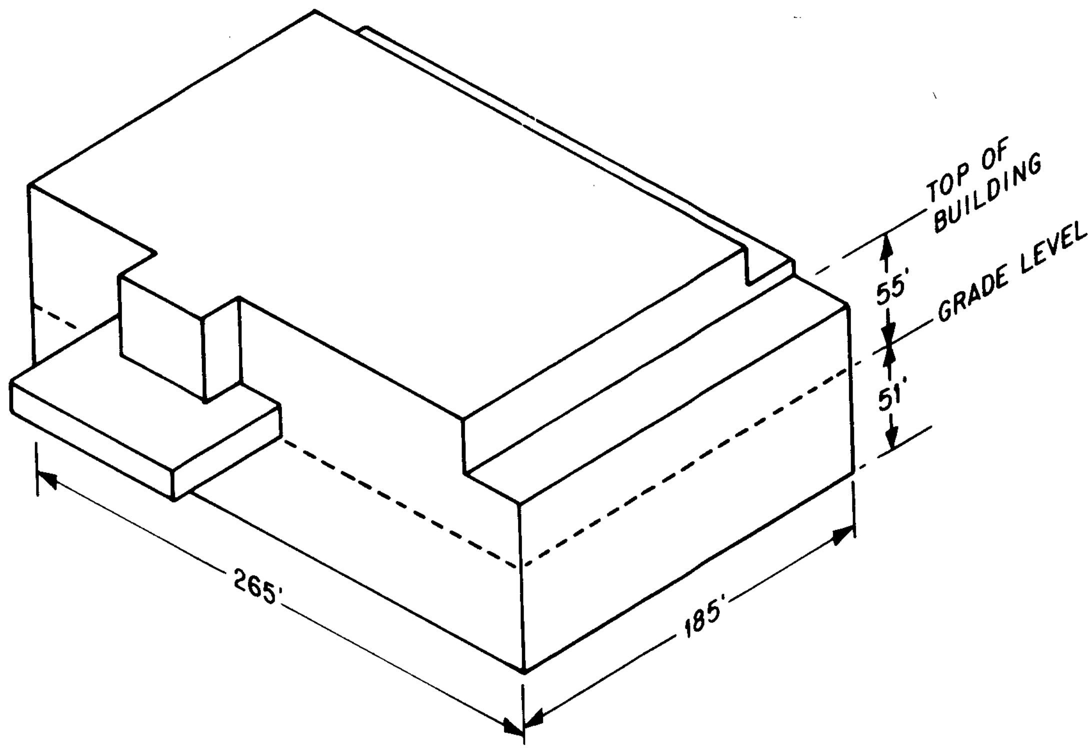

Fig. 5. Fuel cycle facility total structure.

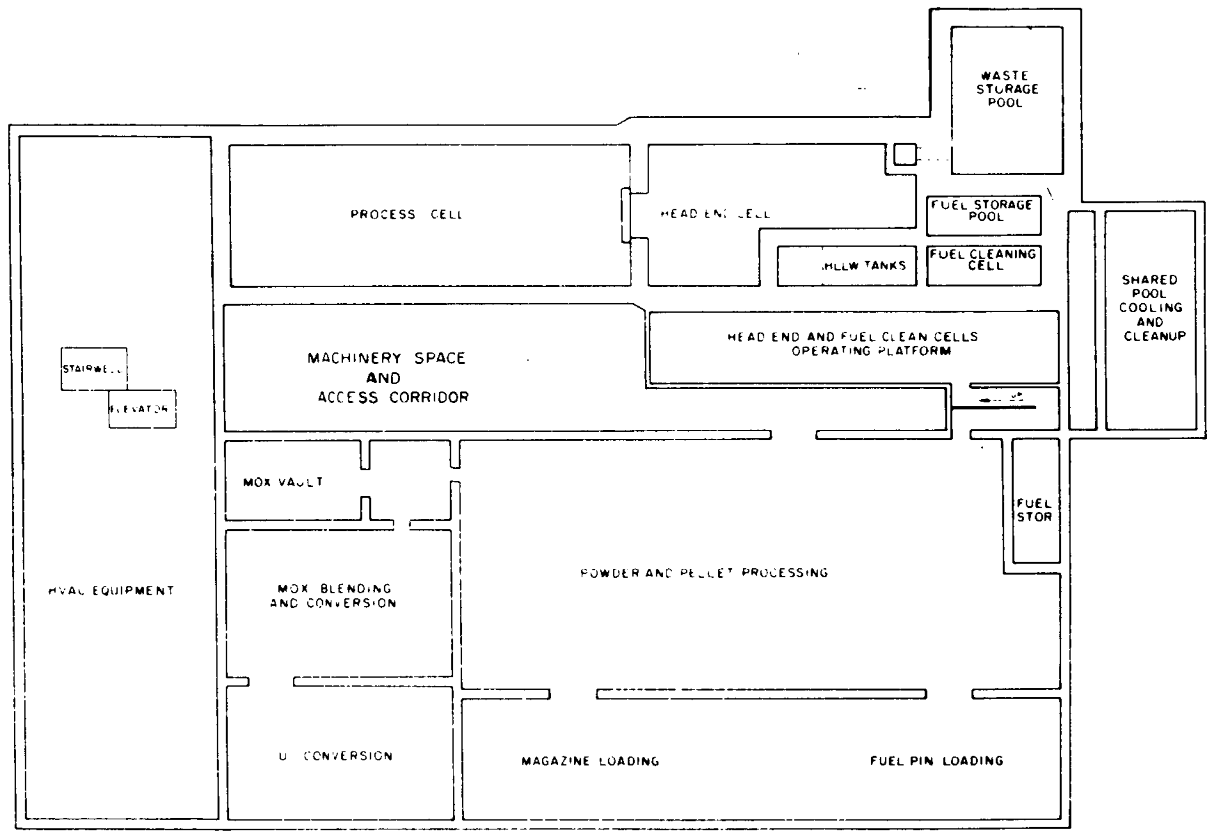

Fig. 6. Co-located fuel cycle facility (plan at 0-ft level).

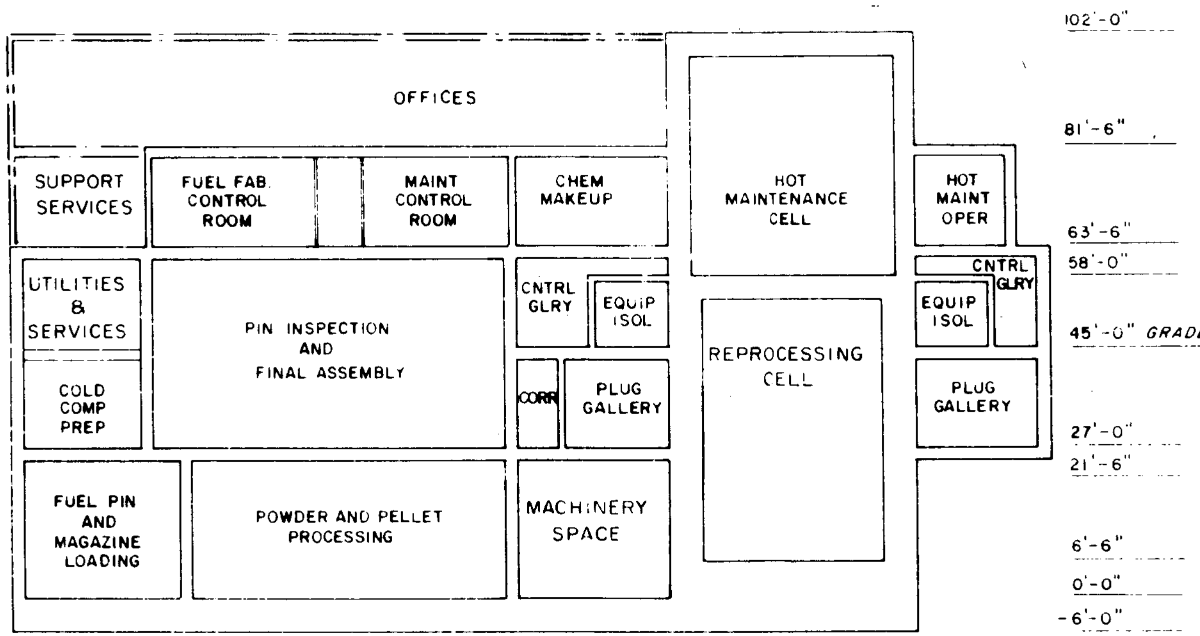

Fig. 7. Co-located fuel cycle facility section.

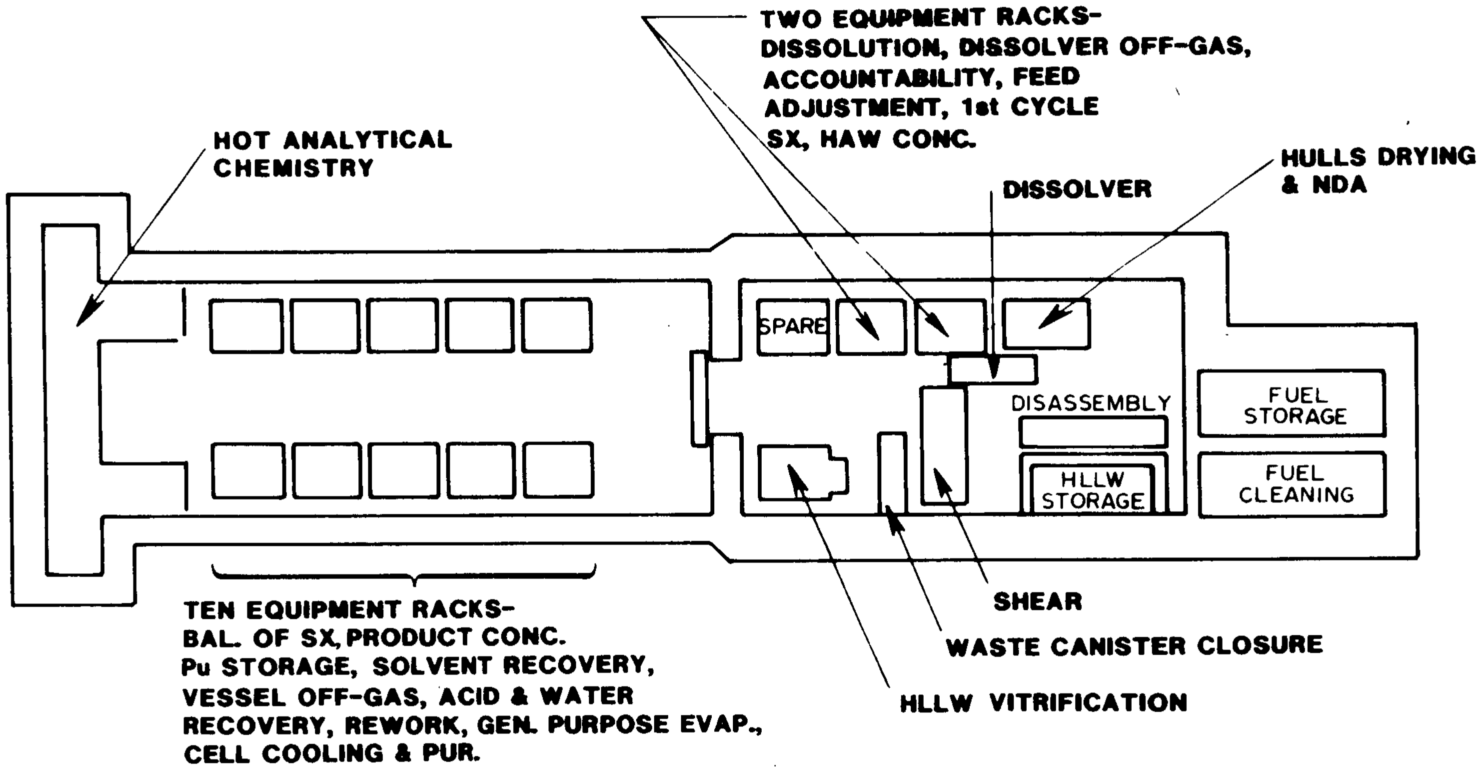

Fig. 8. Reprocessing equipment layout.

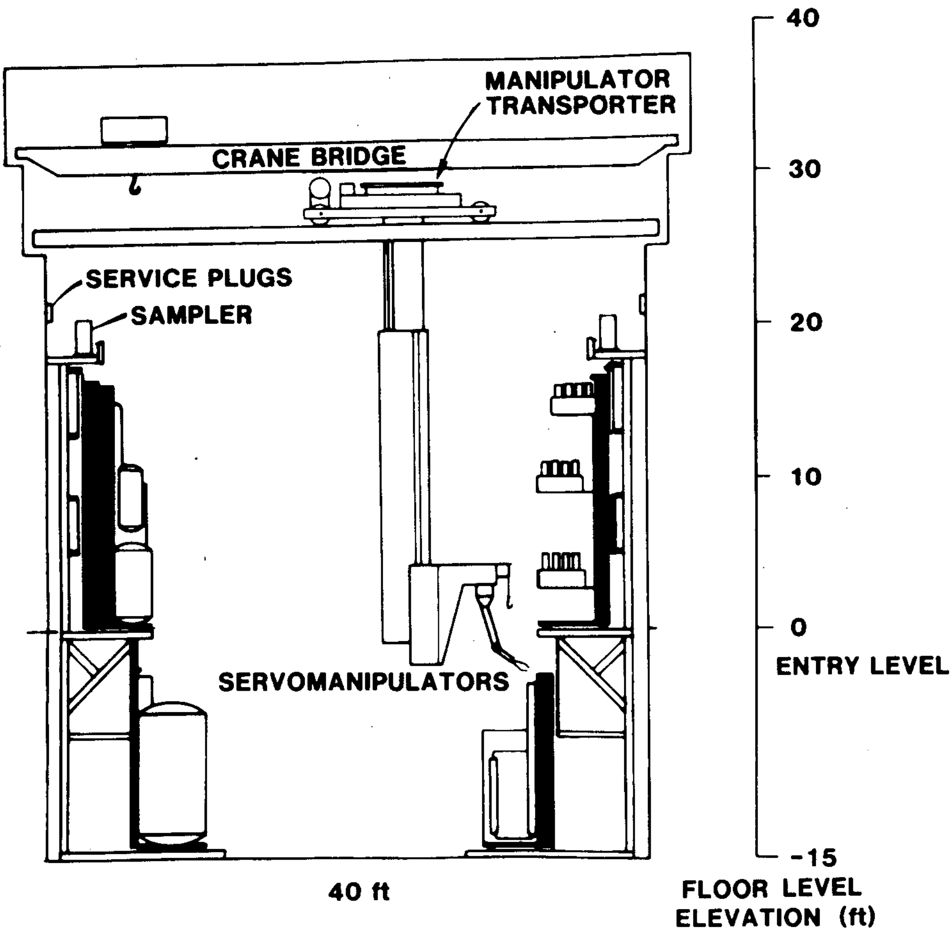

Fig. 9. Center-aisle maintenance concept.

rotary dissolver for dissolution. Centrifugal contactors are employed in the solvent extraction modified Purex process. The high-level liquid waste will be vitrified. Locating the high-activity head-end processes in one cell allowed a reduction in cell wall thickness for the cell containing the balance of the processes. This provided some construction cost savings and also isolated part of the electronic equipment associated with the centrifugal contactors, maintenance equipment, etc. from the higher activity area.

The uranium and plutonium liquid product would each be converted to an oxide—the uranium to UO_3 for storage, while the plutonium and uranium would be co-denitrated to produce a MOX powder for storage in the vault.

The pellet and fuel pin fabrication processes were based upon the SAF technology[4] and laid out as shown (Fig. 10). The pellet fabrication line is highly automated and remotely controlled while the fuel assembly area is highly mechanized. Gamma and neutron shielding are used in both areas to maintain the whole-body exposure of workers to less than 1 rem/year. Both areas incorporate major advances in the technology of MOX fuel fabrication which are directed toward improving worker safety, safeguarding of special nuclear material, process control, and reducing costs.

Handling of the high-level wastes was integrated into the design (Fig. 11). All support services (analytical chemistry, chemical makeup) necessary for both reprocessing and fuel fabrication are provided within the facility (Fig. 12).

The rough order of magnitude capital cost estimate associated with this facility is $300 million in 1984 dollars.

5. DELAYED CLOSURE

The costs of providing the original fuel supply and reprocessing and recycle services with a small facility for an initial LMR is a major impediment to starting such a venture. If costs for the fuel cycle facilities could either be delayed or spread over more than one reactor, the overall economics could be improved considerably. According to a paper[5] presented in 1984, close to 30,000 MT of LWR fuel will have been reprocessed in the world by the year 2000, yielding at least 180 MT of plutonium. While it is recognized that plans are being developed to implement LWR recycle, it seems conceivable that some of this plutonium may be available for use in the U.S. LMRs. The value (dollars per gram) of plutonium has yet to be determined in a market situation. A study is currently under way to establish a range of plutonium values which would absorb the LMR fuel storage and other costs associated with delaying fuel cycle closure while yielding fuel cycle costs that are less than can be achieved in either the BRET/SAF or new small co-located fuel cycle facilities. This part of the study has just begun, so no definitive data are available.

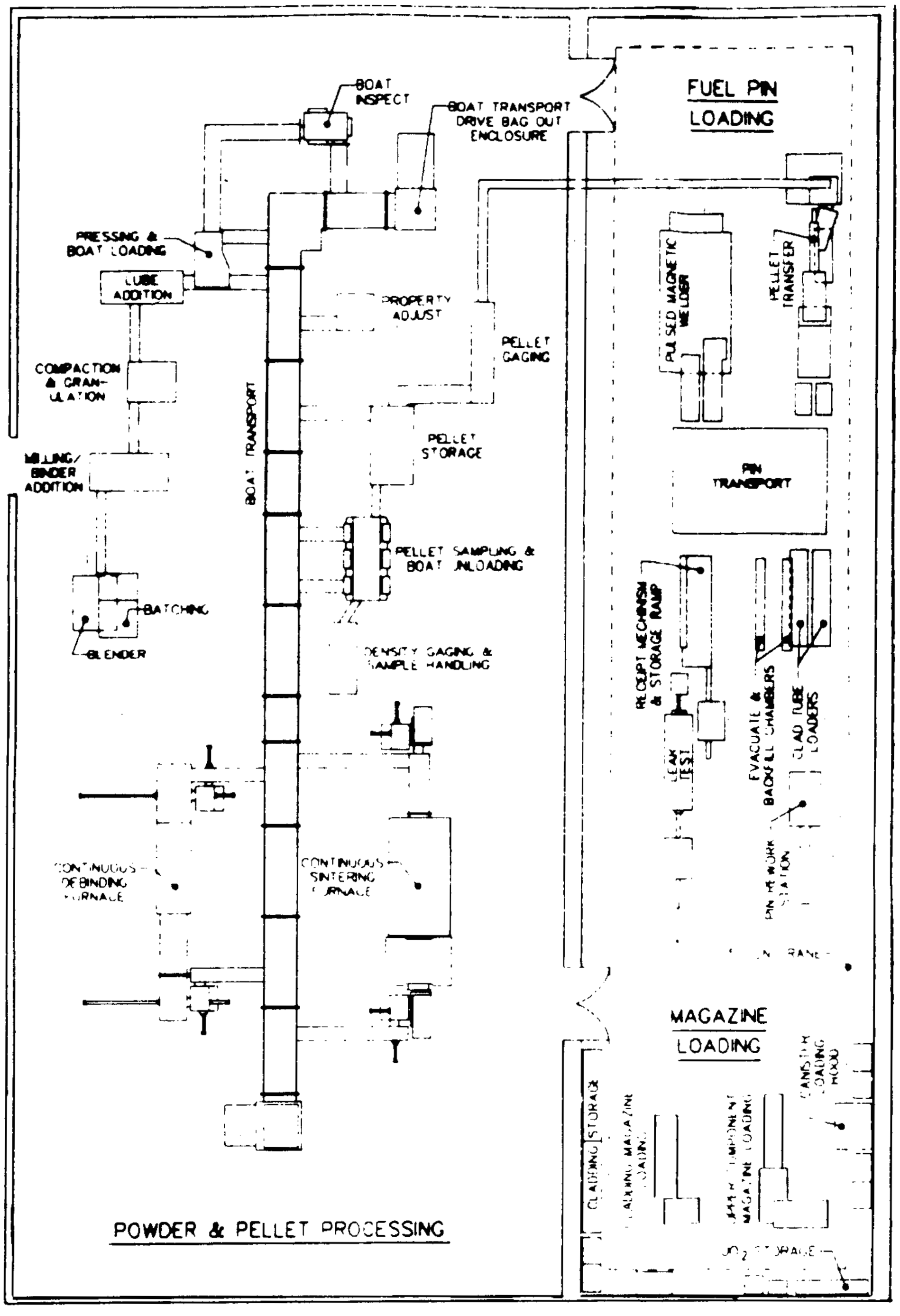

Fig. 10. Pellet and fuel pin fabrication equipment layout.

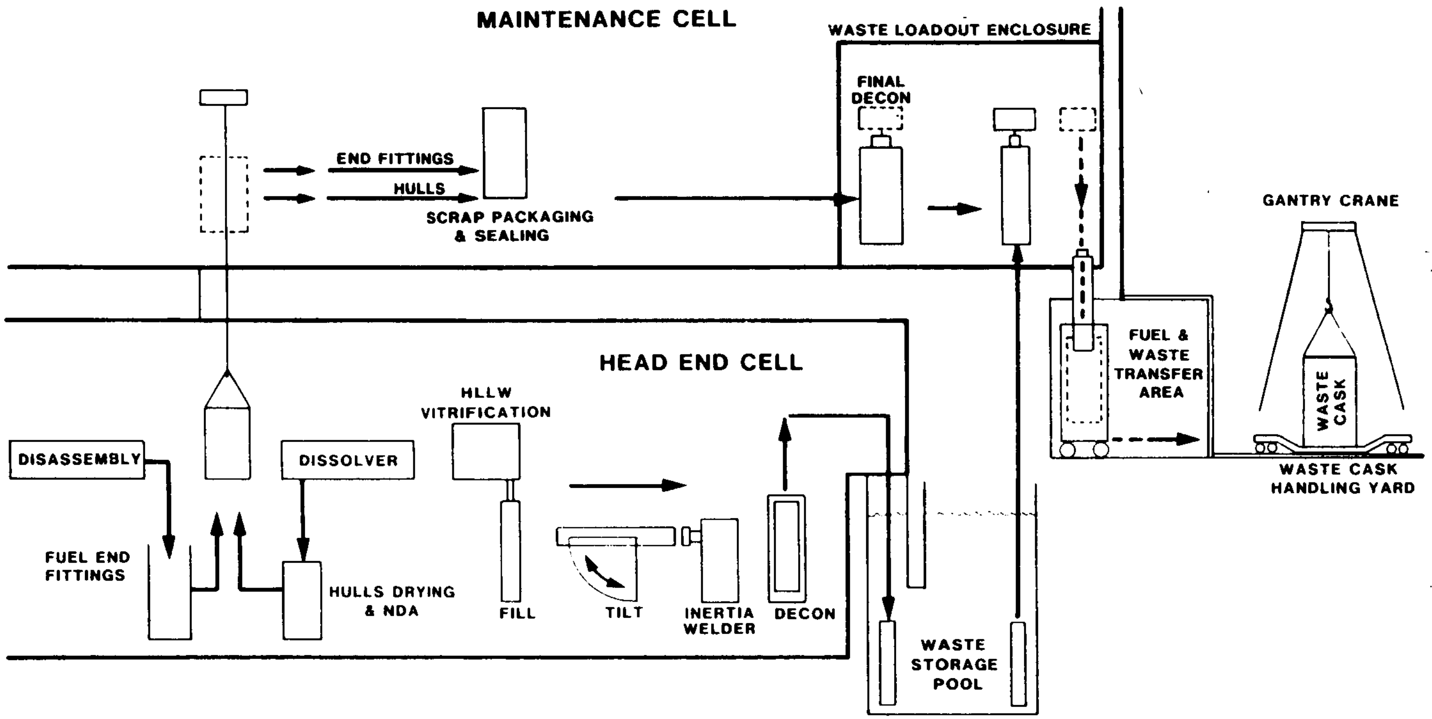

Fig. 11. High-level waste handling.

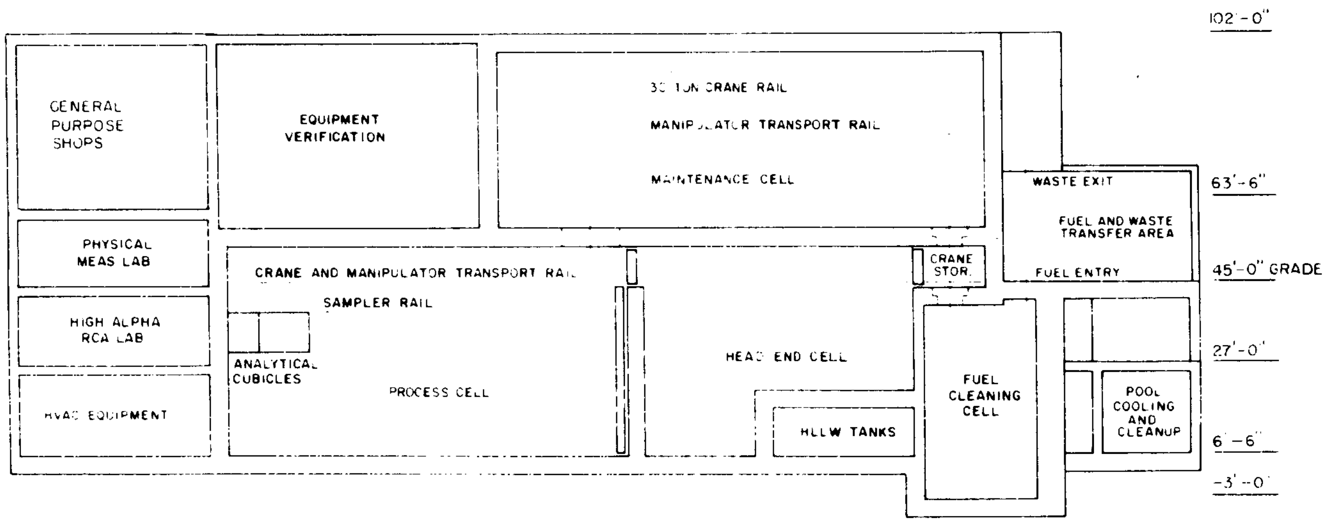

Fig. 12. Section through reprocessing cells.

6. INITIAL PLUTONIUM SUPPLY

All the reprocessing plants operating today in the United States are under the jurisdiction of the defense program, so plutonium is not available from a domestic commercial source for initial fueling of the LMRs. As discussed under the delayed closure, plutonium might be obtained from foreign sources. Another concept[6] put forth to obtain the plutonium necessary for initially fueling an LMR is to build a small hybrid LWR/LMR fuel cycle facility at an existing LWR site. Some preliminary studies are under way to examine this concept by expanding the capability of the LMR plant described earlier. Included will be a brief assessment of the capability and resultant costs for using the FMEF/BRET/SAF for a similar mission.

7. CONCLUSIONS TO DATE

The BRET can be completed and the SAF expanded in FMEF to service the needs (35 MTHM/year) of an initial 1300-MWe reactor station. This can be accomplished for only a modest (5 to 15%) cost increase over the cost estimated to provide a fuel cycle facility with 15-MTHM/year capacity.

A scoping design has been completed for a co-located fuel cycle facility with a 35-MTHM/year reprocessing capability. A rough order-of-magnitude cost estimate ($300 million) was developed.

The importance of understanding the source and cost of the plutonium supply for start-up of a small LMR complex in the absence of a domestic LWR reprocessing industry has been reinforced. Preliminary studies are under way to examine the concept of a small hybrid LWR/LMR fuel cycle plant to provide the necessary plutonium.

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