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Safety Aspects of the IFR Pyroprocess Fuel Cycle

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This paper addresses the important safety considerations related to the unique Integral Fast Reactor (IFR) fuel cycle technology, the pyroprocess. Argonne has been developing the IFR since 1984. It is a liquid metal cooled reactor, with a unique metal alloy fuel, and it utilizes a radically new fuel cycle. An existing facility, the Hot Fuel Examination Facility-South (HFEF/S) is being modified and equipped to provide a complete demonstration of the fuel cycle. This paper will concentrate on safety aspects of the future HFEF/S operation, slated to begin late next year. HFEF/S is part of Argonne's complex of reactor test facilities located on the Idaho National Engineering Laboratory.

HFEF/S was originally put into operation in 1964 as the EBR-II Fuel Cycle Facility (FCF) (Stevenson, 1987). From 1964-69 FCF operated to demonstrate an earlier and incomplete form of today's pyroprocess, recycling some 400 fuel assemblies back to EBR-II. The FCF mission was then changed to one of an irradiated fuels and materials examination facility, hence the name change to HFEF/S. The modifications consist of activities to bring the facility into conformance with today's much more stringent safety standards, and, of course, providing the new process equipment. The pyroprocess and the modifications themselves are described more fully elsewhere (Lineberry, 1987; Chang, 1987).

The HFEF/S consists primarily of two hot cells (air and argon atmosphere cells, see Fig. 1), a contaminated equipment wash/repair area (Fig. 2), support areas, and associated equipment. Fuel assemblies are received from the EBR-II reactor in an inter-facility shielded cask which is transported through an airlock (Fig. 3) that connects the reactor and the hot cells. In the air cell, fuel assemblies are dismantled into individual fuel elements, and are then transferred through a small air/argon lock to to the argon cell. The following operations all take place within the argon atmosphere cell: fuel element chopping, high temperature (500°C) electrorefining, distillation of cadmium and salts from the electrorefiner product, fuel injection casting,

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processing of the cast fuel rods into finished rods, and reassembly of the new fuel rods, new cladding, and fuel assembly hardware into a new fuel assembly. Operations in the air atmosphere cell are limited to only those with fuel having intact cladding, i.e., disassembly and reassembly of fuel assemblies containing 61 individual elements.

Both HFEF/S hot cells are surrounded by operating areas that are served by an exhaust ventilation system that is separate from the hot cell ventilation exhaust and off-gas systems (Fig. 1). This results in a minimum of two separate confinement barriers. The hot cell atmosphere pressures are maintained negative with respect to the operating areas to prevent the backflow of contamination. In addition, all ventilated areas containing loose contamination are provided with high efficiency filters at ventilation inlets. The argon cell is cooled with recirculated argon that is refrigerated in the out-of-cell portion of recirculation loops. There are two such cooling loops each with a flow rate of 4.72 m^3/s. The loops contain High Efficiency Particulate Attenuation (HEPA) filters. Since the volume of the cell is 1870 m^3, the atmosphere volume is exchanged every 6.6 minutes; therefore, the filtration in the cooling loops maintains suspended particulates in the argon cell atmosphere at very low levels. This is important in minimizing the particulate release that accompanies a small purge of argon atmosphere necessary to control nitrogen levels for fuel reprocessing.*

Modifications to the HFEF/S facility are being conducted in accordance with the Department of Energy (DOE) general design criteria manual (U.S. DOE, 1989), the codes and standards guide developed by the Brookhaven National Laboratory (BNL), BNL 51444 (Brynda, 1986), and the mandatory DOE standards (U.S. DOE, 1984). Earthquake analyses of the cells, foundations, and building, i.e., the new hot repair area and other critical items have, or are being conducted by dynamic methods using the finite element ANSYS code. Department of Energy-sponsored guidelines for site-specific natural phenomena (Kennedy, 1989) are being utilized in this effort. Although the HFEF/S facility is

*Any air ingress to the argon cell has oxygen removed in a O_2-H_2 catalytic combiner, nitrogen is untreated. To control nitrogen buildup, the argon cell atmosphere is continuously purged with a small flow of fresh argon.

presently classified as moderate hazard under DOE guidelines for hazard classifications, it is being modified in accordance with high hazard natural phenomena guidelines. The design basis earthquake has a zero-period asymptatic acceleration of 0.21g and the design basis wind is 42.5 m/s.

The HFEF/S hot cells were originally analyzed by static methods, and with less severe earthquake accelerations than presently required for nuclear facilities. It has been necessary to reanalyze their seismic performance using dynamic analysis methods, as now preferred by the DOE. These new analyses have shown that the basic structural integrity of the cells and their foundations are adequate. However, it is not practical, and might not be possible, to show that the argon cell remains leak-tight following occurrence of the design basis earthquake. This has resulted in a requirement for the installation of a Safety Exhaust System (SES), to maintain adequate inward flow through any breaches that might occur in the cell boundary. This special exhaust system (Fig. 4) is being designed to applicable safety-class standards.

Following a postulated breach in the HFEF/S argon cell boundary the SES must maintain particulate capture velocities (>0.635 m/s) across the breach area. To assure this capability under the accident condition of a cell boundary breach and subsequent in-cell metal fire, the exhaust system must remove cell atmosphere at a rate that provides this minimum flow, in addition to removing cell atmosphere at a rate that accommodates expansion of cell gas due to heatup (i.e., from the sensible heating effects of the in-cell metal fire and radioactive decay of fuel and waste in storage). In evaluating sources of heat and their potential to cause atmosphere expansion, it is not necessary to consider continued electric power input to the furnaces or cell lighting, since they are to be automatically disconnected from the power source when the argon cell pressure rises.

The HFEF/S will contain a "hot repair" area in the basement, with two confinement levels, in which equipment can be washed/decontaminated and subsequently repaired, either by suited-entry hands-on maintenance, or by use of a glove wall to protect the operator from excessive radiation exposure. All

contaminated waste water from washing (and all other minor streams of contaminated water generated in the facility) are evaporated so that no contaminated liquid waste will be released to the environment.

Fuel assemblies, both prior- and post-processed, may be stored in cylindrical holes or "pits" in the floor of the air cell. Waste cans are stored in similar pits in the argon cell.

Passive safety in the HFEF/S facility has been a primary objective. The protection provided personnel by the highly shielded hot cell walls, natural-circulation/radiation coolability of all fuel and waste in storage, natural-ciruclation/radiative cooling of fuel assemblies if forced cooling is lost, and finally passive cooling of process equipment such as the electrorefiner (even if argon cell cooling is lost) are major aspects of passive safety. The passive cooling of waste cans, located in the pits in the argon cell is a particularly difficult requirement to address. The desire to maximize heat in the can, in order to minimize storage volume, requires accurate heat transfer analyses under conditions which were difficult to analyze; conditions of combined natural convection and radiation. Another restraint is that the can, when removed from the argon cell, must be able to meet acceptance criteria of a local temporary dry-tube storage facility. These acceptance criteria also impose a passive cooling requirement that cadmium metal wastes remain in a solid state, which places additional constraints on the waste can design.

To ensure passive cooling when received in HFEF/S, an EBR-II fuel assembly must be cooled approximately 100 days or longer for the anticipated fuel burnup. This will also allow adequate time for decay of the Iodine-131 and other short-lived fission product contributors to accidental radiological doses. The primary remaining gaseous radioisotope is Kr-85. Initial plans were to collect a portion of the Kr-85 gas at the fuel chopping station at time of fuel element puncturing. In addition, a recovery system was planned for Kr-85 released to the cell atmosphere. Subsequent analysis has established that the Kr-85 radiological doses are sufficiently low, for the approximate 3.7×10^{14} Bq annual normal release, that the recovery of Krypton is

unnecessary. Therefore fission gas recovery is being treated only as a desirable option, to be implemented as a demonstration after initial startup, if funding is available.

The basic process hazards that have been identified in HFEF/S are similar to those that would be found in a future commercial IFR facility -- although the method of mitigation may differ because of the difference in confinements. Preliminary analyses were conducted without credit for mitigation features. This allowed direct comparison with accident dose limits, to determine whether or not safety-class mitigation systems were required.

The events that lead to radiological dosages are described below.

Fission Gas Release Due to Loss of Cell Atmosphere

There are several events that might lead to abnormal release of fission gas. These are:

1. Over-pressurization of the argon cell due to loss of cell cooling and subsequent heatup of cell atmosphere, with the pressure buildup relieved by activation of the safety exhaust system.

2. Over-pressurization of the argon cell due to failure of the controls for the normal argon supply (a large dewar containing 2.6 cell volumes of argon).

3. Over-pressurization of the argon cell due to failure of the controls for the emergency argon supply (a bottled supply containing 0.033 cell volumes of argon).

The radiological consequences of all the above events can be "bounded" by a hypothetical event in which all cell atmosphere is released. Radiological consequences are shown in Table I. For this accident and in the following accident discussions, site boundary doses are evaluated at the point of nearest boundary location with respect to the facility, a distance of 5000 m from

the facility. Meterological dispersion parameters were derived from Regulatory Guide 1.145 (U.S. NRC, 1983). In preliminary analyses all doses were evaluated for a ground level release, even though the release would actually be at the 61-meter stack exhaust point. The calculated meterological dispersion factor is 2.1×10^{-3} s/m^3.

Fission Gas Release from Kr-85 Recovery System

Although the HFEF/S project does not intend to install a fission gas recovery system for initial operations, an accident in this system is included because of possible future installation, and its possible application to commercial concepts. For this accident, it is assumed that Kr-85 has been collected into a bottle over a period of one year and that during changeout the bottle is dropped, possibly resulting in valve failure. This results in a release of approximately 3.7×10^{14} Bq.

Metal Fire in Argon Cell

The processing of hot metals in the argon cell leads to the possibility of spontaneous ignition and a metal fire if sufficient air leaks into the cell. An initiator of this event is loss of inert atmosphere due to an earthquake-related breach in cell boundary. As previously discussed, the SES is being installed as a safety class system to filter any airborne particulate products that result from this postulated event. In addition, as a "defense-in-depth" measure confinements for individual process furnaces are being designed to survive a design basis earthquake.

A load drop from the in-cell crane onto the large equipment transfer lock in the floor of the argon cell might be another initiator of this event. In HFEF/S, the use of this lock for potentially damaging loads is to be limited to times when hot metals are inside the process confinements.

Failure of a floor penetration is considered another possible initiator of a metal fire. There are many small flanged penetrations for electrical and other services that penetrate the cell floor. Although these penetrations are passive and rugged, it is considered possible that an operator mistake, during

changeout of a service, could cause an inadvertent opening into the cell. In addition an earthquake might result in an unevaluated failure mode in these penetrations.

In preliminary analyses, both large and small breaches of the HFEF/S argon cell boundary were analyzed. Failure and complete opening of the argon cell large equipment transfer lock (1.83 m diameter) in the floor of the cell was assumed for the large breach. Failure and complete opening of a 0.126 m diameter penetration of the cell boundary was the assumed small breach.

A chopped fuel batch containing 10 kg of heavy metal was assumed to be exposed and burned as a result of the ingress of air into the cell. The remainder of the hot fuel was assumed to be inside process confinements. The assumed chopped fuel composition prior to irradiation was 71 w/o U, 19 w/o Pu, 10 w/o Zr. The accident sequence involves initially inertia-dominant slug flow through the breach due to the density difference between the argon cell atmosphere and the ambient atmosphere. The cell pressure therefore began to rise. At -25 mm wg differential pressure, cell safety exhaust system began to operate and exhausted at a rate of 0.236 m^3/s.* The modeling predicted that, for the large diameter breach, the time to reach atmospheric pressure in the cell was a very short time (less than one second). For the large breach, the time to reach 4% oxygen concentration in the cell, i.e., an amount that might support combustion of hot metals, was estimated to be about 3 minutes; whereas for the small breach this time was estimated as 25 minutes.

The relationship between burning rate and oxygen concetration was based on the data of Baker and Fischer (Baker, 1966) for ternary U-Pu-Mo alloy. Once burning is established, the rate of burning would be controlled by oxygen diffusion through the oxide layer that is formed. The burning rate is therefore dependent upon the partial pressure of oxygen, the diffusion coefficient for the layer of oxide buildup on the surface of the fuel, and the temperature

*This was the design flow rate at time of these preliminary analyses. The flow rate in the latest safety exhaust system design has been increased by about a factor of 3.0 in order to maintain particulate capture velocities across assumed breaches in cell boundary.

of the layer. Assuming diffusion through a porous oxide layer, so that the diffusion is described by Knudson flow, the diffusion coefficient (Peterson, 1965) is taken as proportional to the one-half power of the average oxide layer temperature.

The heat transfer coefficient in the oxide layer was taken as constant, dominated by conduction, and not by gas convection. This coefficient was empirically derived. For these preliminary analyses some additional important assumptions were necessary, the most important of which are listed in the following.

1. No credit was taken for heat transfer to the cell boundary or to cell equipment.

2. Air/Oxygen has access to the interior of the bed of chopped fuel (pellets) so that burning was uniform through the pellet bed.

3. The burning surface area was assumed constant and taken as the exposed ends of the chopped pins in their container.

With these assumptions, it was found that for the large and small breach approximately 70 and 130 minutes, respectively, would elapse before complete oxidation of the 10kg fuel batch.

The transient temperature of the cell atmosphere was calculated using an energy balance that included the effects of the addition of heat due to the burning of the fuel, the energy input and output from the cell due to air exchange, and the enthalpy increase of the cell atmosphere. The temperature transient, from initial to maximum, was less than 30°C for the most conservative (large breach) case. This transient poses no significant stress on to the cell confinement.

For radiological dose calculations, an airborne fractional release of 0.0005 from the fuel was assumed for plutonium and solid fission products. This was based on measurement (Mishma, 1971). For consistency with previous HFEF safety analyses (Courtney, 1986), cesium was assumed to have a fractional

release of 0.35, conservatively high compared to a more recently recommended value of 0.01 (Elder, 1986) for volatile fission products. Credit for fallout/plateout was conservatively taken as a factor of 0.5. Because of the greater-than-100 day fuel cooling time, the iodine inventory is negligible.

More detailed transient analyses are planned for the Final Safety Analyses. The unmitigated radiological doses from preliminary analysis of this metal fire event are summarized in Table I. In final safety analysis, credit will be taken for the safety class filtration of aerosols, to be provided by the Safety Exhaust System. This will reduce calculated radiological doses by several orders of magnitude.

Wastecan Spill or Meltdown

Although the issue of a wastecan meltdown in the argon cell is minimized by the presence of the argon atmosphere, these cans must eventually be transferred into the air cell for loading from a port in the floor into a cask, with subsequent transport to an acceptable storage facility. The hypothetical consequences of a dropped can was addressed. It was assumed that the can was dropped in a manner that results in loss of can confinement, possibly by can damage or by loss of passive cooling capability.

Two general types of radioactive wastes are to be produced by the IFR processes. These are 1) metal wastes and 2) salt wastes. These wastes are produced primarily by the electrorefining and cathode processing operations. The metal wastes are primarily cathode and anode wastes (cadmium and fission products), and the salt wastes derive from the electrolyte. The salt contains the more active fission products (e.g., rare earths) and the metal waste contains primarily the noble metal fission products in a cadmium metal matrix.

The fission product contents of one subassambly were assumed to be contained in the cans, along with 1% of the heavy metal. The results are easily extrapolated to a higher can loading by estimation of the number of subassemblies processed per waste can. The one-subassembly loading corresponds approximately to the decay heat limit imposed at the assumed waste

repository. Further refinement of can loading was not warranted due to the conceptual nature of the process the time of the analyses.

Release fractions and meterological dispersion parameters assumed for this accident were the same as discussed previously for the argon cell metal fire. The calculated unmitigated radiological dose from this preliminary analysis is shown in Table I.

Meltdown of Fuel Assembly in a Storage Pit

At the time of preliminary safety analyses, it was planned that only post-processed fuel assemblies would be stored in the air cell floor pits. Pre-processed assemblies, which have a much higher heat load, were to be stored in racks on the air cell floor to allow for passive cooling by radiation and natural convection. Each pit can hold four post-processed fuel assemblies. This accident assumes that a single pre-processed fuel assembly is mistakenly placed into a pit that contains three freshly processed assemblies. The heat load from the "hot" assembly is assumed to cause melting and/or a metal fire in all four assemblies. Based on results of recent experiments performed a EBR-II in which flow was stopped to a subassembly contained inside a shroud, this accident might be eventually classed as incredible. Nevertheless, the preliminary analysis is summarized here, without regard to the probability of occurrence. The assumed release fractions for this accident were the same as for the in-cell metal fire previously discussed, with one exception. The exception is that the effects of local fallout/plateout inside the storage pit were credited in the overall release fraction. A local (pit) confinement release fraction of 0.01 was assumed, based on assumptions from similar, previous HFEF/S safety analyses (Courtney, 1986) in which data from aerosol tests sponsored by the Atomic Energy Commission were utilized. The unmitigated radiological doses are reported in Table I. It should be noted that an existing mitigation system, the air cell exhaust system, a highly reliable system with two stages of high efficiency particulate attenuation filters, was not credited for these preliminary analyses.

Wastebox Fire

Miscellaneous contaminated wastes removed from the hot cells and items such as polyethylene sheeting, wipedown rags, boots, etc., are used in the hot repair facility are collected in large (1.2 x 1.2 x 2.4 m) wooden boxes. The wooden box structure, although painted with fire resistant paint, leads to the postulate that a box could be involved in a fire. The alpha curie content of these boxes is limited to 3700 Bq per gram of material; consequently the box can be disposed of as non-transuranic waste. In addition, the fission product content of the box is limited to an amount such that a dose rate of 5 mSv/h at 1 m from the box surface will not be exceeded. The assumed accident involves complete burning of the box when loaded to the limit of both alpha and gamma activity. Calculations indicate that the fission product radiological dose would be negligible compared to the dose from the transuranics. The fractional release of transuranics from the box was taken to be 0.0005 of the of the box contents, as assumed for non-volatiles, in similar analyses (e.g., Sutter, 1984).

Dispersion and meterological assumptions were the same as for the in-cell metal fire. The calculated unmitigated radiological dose is summarized in Table I. It should be noted that a mitigation system, the air cell exhaust system, which includes two stages of HEPA filtration, will protect against the effect of this accident, even though the radiological doses are very small.

Facility Fires and Explosions

IFR fuel processing involves the handling of metals; there are no organics or solvents used in, or required to support the process. This results in mimimum concern regarding fires in facility processing or storage areas.

The facility is constructed primarily of concrete and steel and therefore most portions are considered non-combustible. However the DOE is presently applying "improved risk" insurability criteria, based largely on monetary value rather than a detailed analysis of the potential for a large fire. These criteria, applied in this manner, would require a full facility wet-pipe sprinkler system, except in inerted areas. The HFEF/S modifications project

is installing such systems in all areas in which any significant combustible loading is anticipated, and where criticality is not a consideration. This will result in fire-sprinkler protection for essentially all areas of the facility except the hot cells.

The only identified potential for a significant explosion, from preliminary analysis, was in the argon cell atmosphere purification system. This system is installed to remove oxygen impurities from the cell atmosphere. A small, substoichometric flow of hydrogen gas is combined with a small flow of argon atmosphere in the presence of a palladium catalyst. Water vapor is formed and collected in dryers. The presence of hydrogen leads to the possibility of leakage due to pipe or joint failure. Of particular concern is the possibility of an explosion during hydrogen supply bottle changeout. To alleviate these concerns supply bottles are being relocated outside the facility, and a system is to be installed to detect supply line failure and to isolate the line if such failure occurs. In addition the supply line is being routed within a secondary pipe and the annulus between the two pipes will be vented to a highly reliable exhaust system.

Another possible explosion potential arises from the current concept of a fission gas recovery system. Recent design studies for HFEF/S have established that, if installed, this system should have a cryogenic distillation column, as presently used on the EBR-II fission gas recovery system. The cryogenic column introduces some potential for ozone collection and explosion, although more studies are required to evaluate this potential. These studies are presently inactive due to the decision not to initally install a fission gas recovery system.

Nuclear Criticality

The IFR fuel process is basically a batch process in which the amount of fuel introduced and leaving each step can be accounted for, before placing fuel in the equipment for the next step. This reduces the concern over occurrence for criticality. Nevertheless, it cannot be stated that no combination of errors exist, however improbable, that could lead to a nuclear criticality.

A hypothetical criticality event, assumed to result from overloading of the fuel pin casting furnace, has been analyzed for HFEF/S. Analysis of this event, assumed to involve plutonium bearing fuel, uses the guidance in Regulatory Guide 3.35 (U.S. NRC, 1979) to establish the total number of fissions (1×10^{18}) involved. It was conservatively assumed that all of the fission energy was initially directed toward vaporization of the fuel, and that the latent heat of the vaporized fuel was subsequently transferred to the argon atmosphere, due to near-instantaneous fuel condensation. The result was an over-pressure of approximately 7000 N/m^2 in the argon cell. This pressure would be passively relieved through a seal pot and two stages of HEPA filtration in the safety exhaust system. Because of the low probability of this event, and DOE-adopted guidance that "no credible combination of events" should lead to a nuclear criticality, criticality has been initially treated in HFEF/S safety analysis as a Beyond-Design-Basis-Event, with protective/mitigative features. Release from cell-to-atmosphere was taken to be identical to fractional cell atmosphere release under assumption of uniform mixing. For these initial analyses, 100% of the fission products was assumed to be released. Radiological doses are shown in Table I.

Other Accidents

Many other accidents were considered in preliminary safety analyses, including a dropped subassembly, ventilation flow anomalies, and personnel evacuation with preprocessed fuel pins in the small equipment argon/air lock. These accidents were either benign or there was considered to be adequate time available for operator action to prevent accident progression or significant radiological dose.

One potential accident, the meltdown of a fuel assembly in the HFEF/S-EBR-II interbuilding fuel transfer cask, has been addressed in previous safety analyses. Since the safety envelope providing for usage of this cask has not been significantly changed by the new program, this accident is not presently being re-addressed. However, recent experiments, in which the cooling flow to a subassembly was interrupted, point to the possibility of providing for passive fuel assembly cooling in the cask by allowing for the

radioactive heat to sufficiently decay before transfer from the reactor and further tests are planned.

A comparison of the major confinement features of the Commercial Facility with those of HFEF/S is given in Table II. The commercial size fuel cycle facility will have several advantages over HFEF/S, since it will be a new facility in which the argon cell can be made leak tight after an earthquake, and where the outer building shell can be made resistant to missiles and tornado.

The IFR concept, although not necessarily tied to co-location of the reactor and the fuel cycle facility, offers both fuel theft and diversion advantages when the fuel cycle building is located on-site with the reactor. Because all operations are performed with the fuel under heavy gamma-ray shielding, the process can be adjusted to leave sufficient fission products in the fuel to make diversion or theft of processed fuel unattractive. Present status of the process development indicates that the fission product decontamination factor is sufficiently low that it might be desirable to re-introduce or deliberately leave certain fission products in the fuel product. The transportation of fuel between the fuel cycle building and the reactor is all within the site, making security protection easier.

To a large degree, the advantages of the co-located concept accrue to minimizing fuel transportation of fuel to offsite locations. This advantage is apparent in the case of HFEF/S where, if fuel were not to be processed on-site, more off-site transportation of makeup material, processed fuel, and especially of unreprocessed fuel with high heat loads, would be necessary (see Fig. 5).

Summary

Both HFEF/S and the co-located commercial facility offer decreased risk with respect to fuel theft and the potential for transportation accidents involving fuel with high internal heat source. Also, the potential for process-related fires and explosions are minimized with the pyroprocess.

For accident analyses, the major differences between the HFEF/S facility and the Commercial IFR Facility are 1) the inability, for HFEF/S, to make the claim that the argon cell remains leaktight after occurrence of the design basis earthquake, 2) the location of penetrations of the HFEF/S argon cell where drainage of argon could occur or where penetrations are more vulnerable to dropped loads, and 3) the use of enriched uranium in HFEF/S to support the much smaller-than-commercial-sized Experimetal Breeder Reactor-II.

Deficiencies are largely overcome in HFEF/S by installing a safety exhaust system for the argon cell which maintains inward flow thru any credible breach and which will filter any particulate gasborne products of a metal fire or criticality event. Based on results of preliminary analyses, it is expected that mitigation systems presently available, and that are to be installed, will maintain radiological doses within DOE guidelines and ALARA for all accidents related to the new fuel processing mission.

TABLE I

Major Accidents Considered for HFEF/S Facility
and Site Boundary Radiological Dose
from Preliminary Analyses

Accident Descriptors	Radioactive Source	Unmitigated Radiological Dose at Site Boundary, Sv	Mitigation Features Not Credited[a]
Fission Gas Release			None
• All of cell atmosphere	$<2.52 \times 10^{13}$ Bq, Kr-85	Skin - 1.3×10^{-5} EWBE[b] - 1.3×10^{-7}	
• Fission gas bottle	3.61×10^{14} Bq, Kr-85	Skin - 2.2×10^{-4} EWBE - 1.2×10^{-2}	
Metal fire in argon cell	10 kg heavy metal burned	• large breach - 5×10^{-3}, EWBE • small breach - 7×10^{-4}, EWBE	SES Filters
Waste can spill or meltdown	Fission product content of one fuel assembly	• cadmium waste - -0.0, EWBE • salt waste - 2.7×10^{-3}, EWBE	Air cell exhaust filters
Placement of pre-processed fuel assembly in storage pit	One pre-processed, three post-processed fuel assemblies	9×10^{-5}, EWBE	Air cell exhaust filters
Wastebox fire	3700 Bq (alpha) per gram of wastebox material	2×10^{6}, EWBE	Air cell exhaust filters
Criticality	1×10^{18} fissions	1×10^{-4}, EWBE	SES Filters

[a]Will be credited in Final Safety Analysis.

[b]EWBE - Effective Whole Body Equivalent, 50-year dose commitments.

TABLE II

Comparison of Confinement Features and Hardening for Natural Phenomena-- Commercial Facility vs. HFEF/S

	Commercial Facility	HFEF/S
Number of confinement levels	2	2
Confinement structurally hardened for earthquake?	Yes, both confinement levels	Yes,, both confinement levels
Argon cell leak tight after earthquake?	Yes	No, requires safety exhaust system (SES) to maintain inflow through breaches in cell penetrations.
Confinement structurally hardened for missiles?	Yes, outer confinement provides first level allows location of critical equipment at any building level.	Yes, but relies on inner barrier (hot cells), and location of critical equipment in basement to minimize hazard.
Outer confinement structurally hardened for high winds and tornado?	Yes	Yes, but for high wind forces only-relies on site location.
Can failure of penetrations into argon cell (for support of process equipment) result in rapid loss of cell atmosphere?	No, penetrations are in top of cell -- argon is heavier than air.	Yes, penetrations are below cell, in to subcells. Requires SES connection to the subcells to remove any leakage from argon cell.

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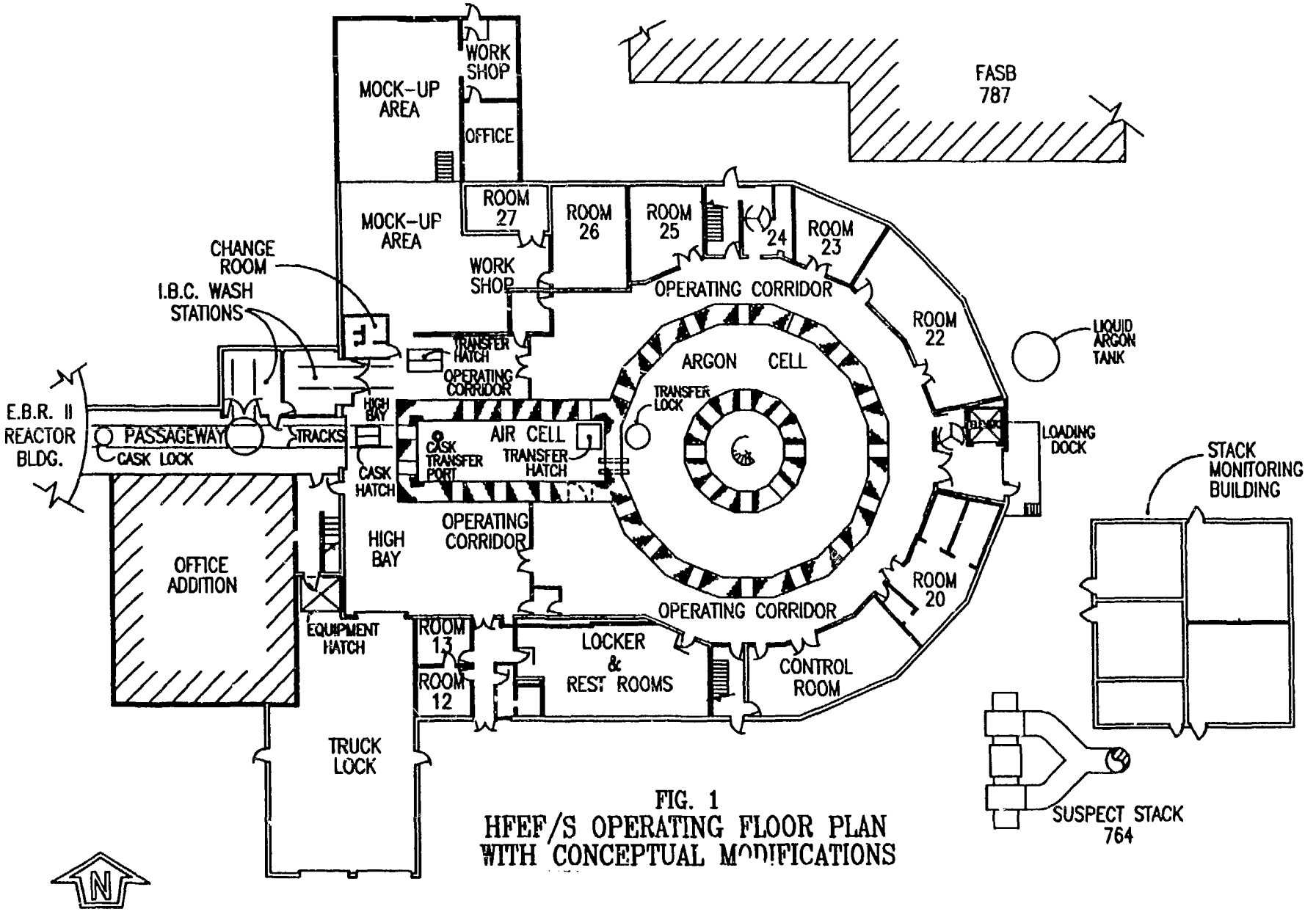

FIG. 1
HFEF/S OPERATING FLOOR PLAN
WITH CONCEPTUAL MODIFICATIONS

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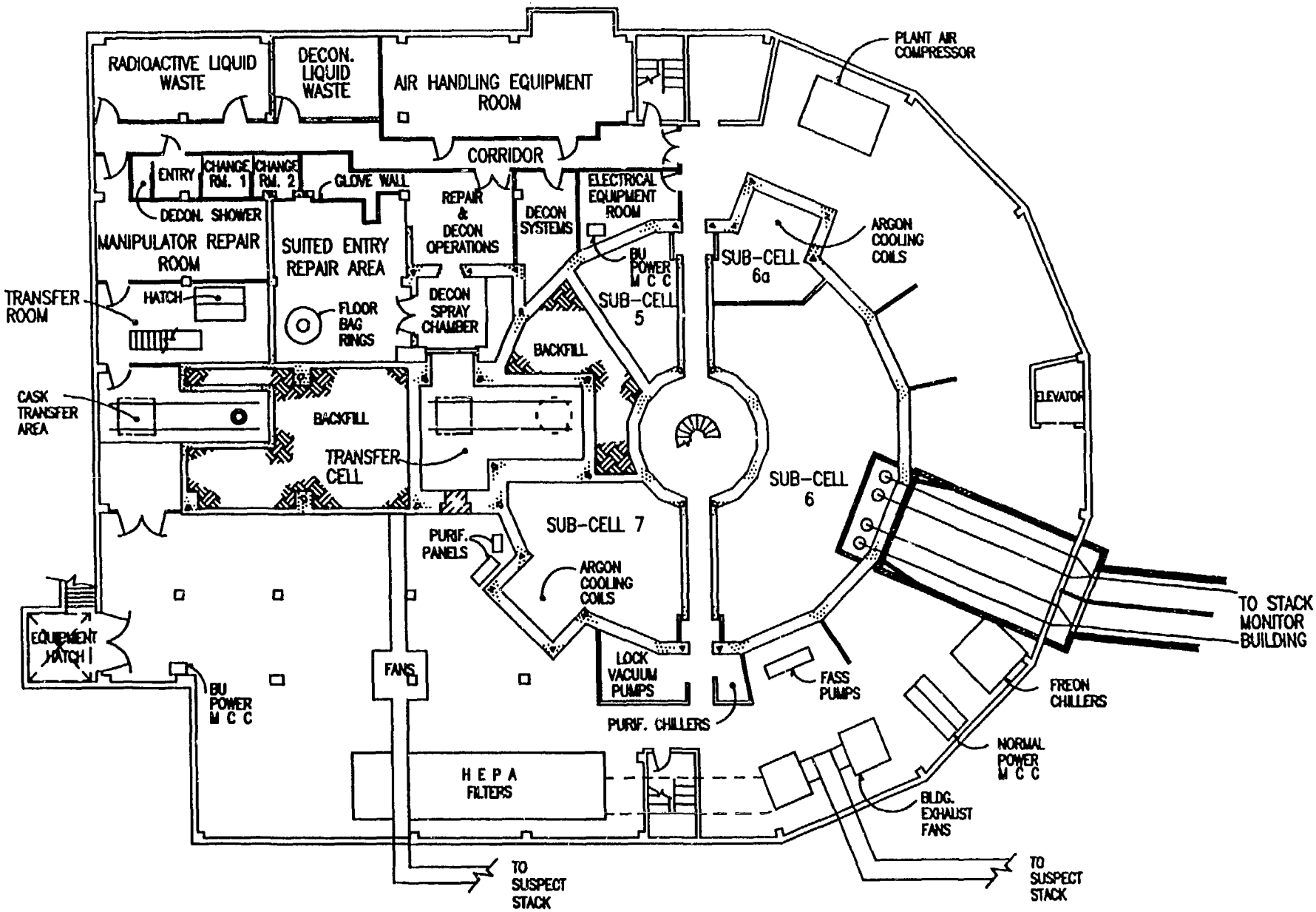

FIG. 2
HFEF/S BASEMENT FLOOR PLAN
WITH CONCEPTUAL MODIFICATIONS

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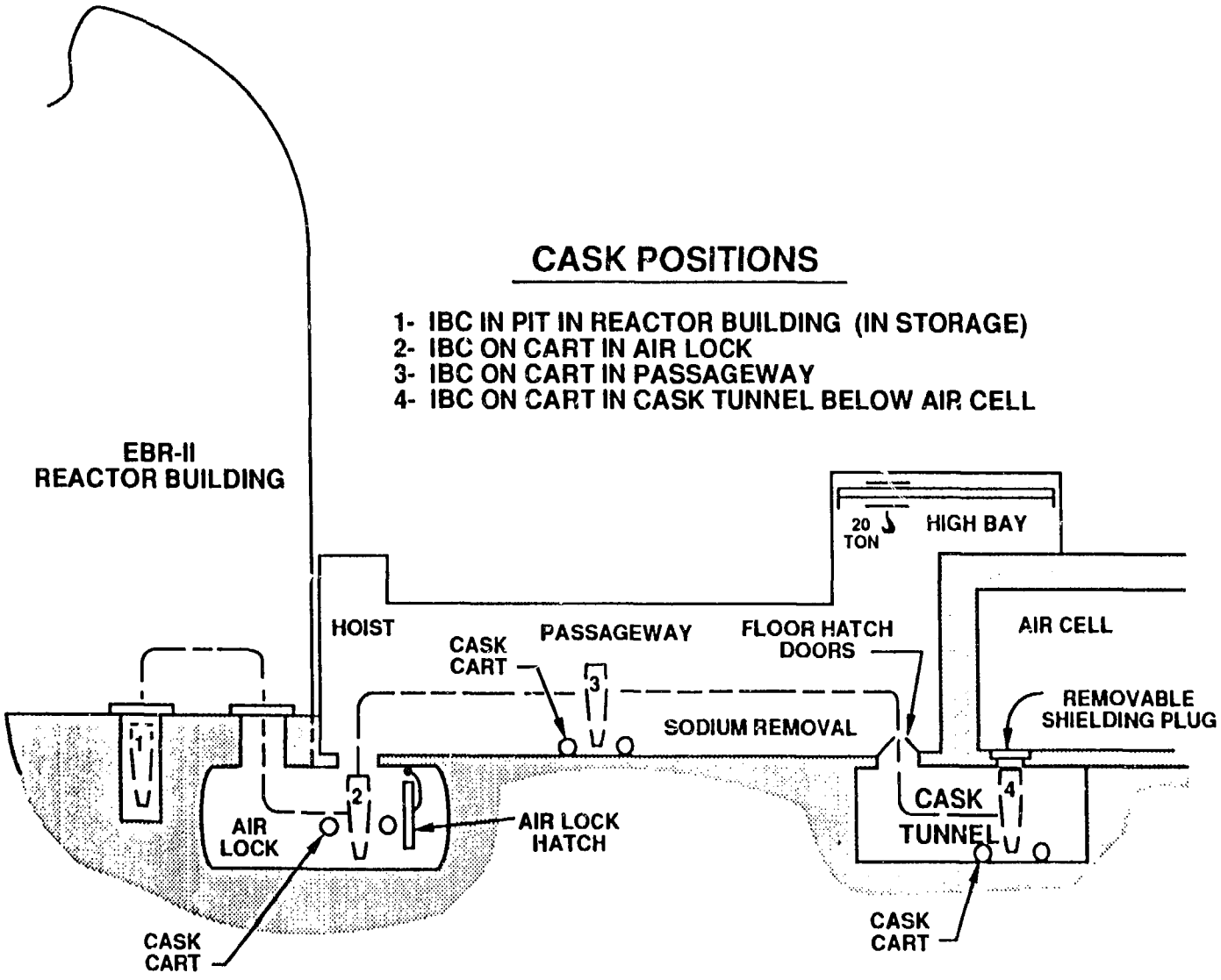
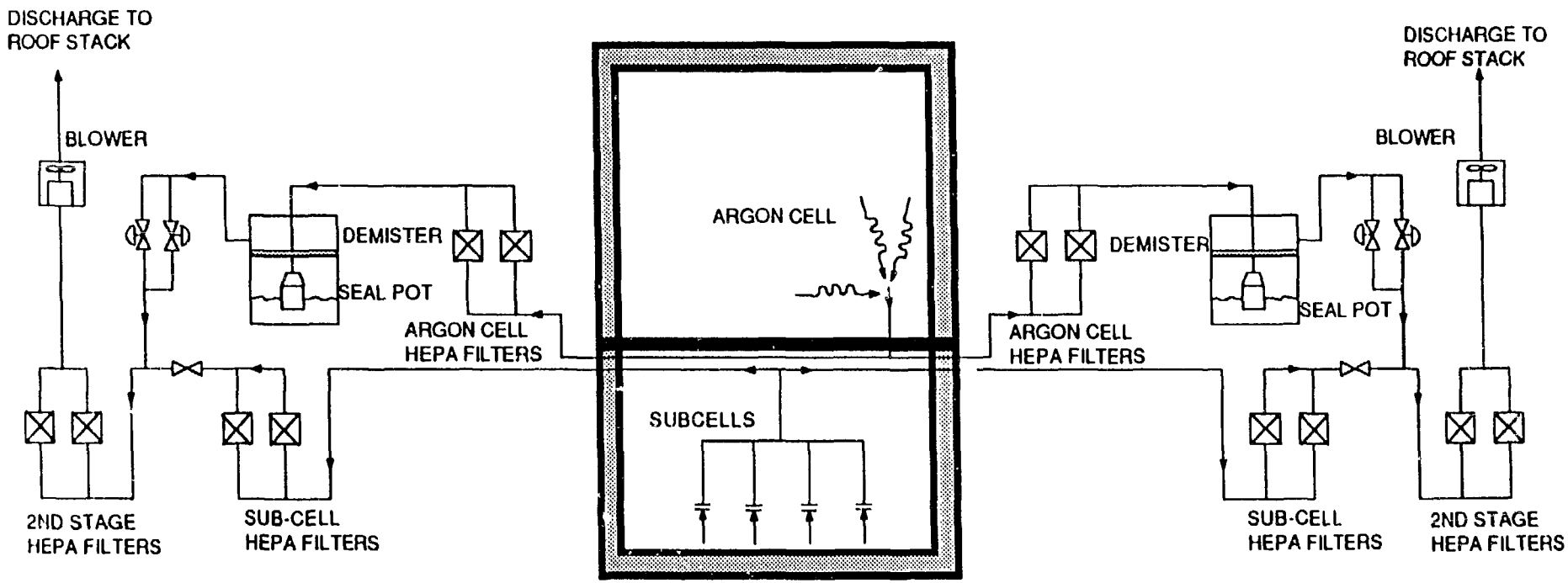


FIGURE 3. INTERBUILDING FUEL CASK TRANSFERS



* NOTE- ONE BLOWER OPERATES CONTINUOUSLY WITH AUTOMATIC SWITCHOVER TO OPPOSI BLOWER ON LOSS-OF-FLOW

LEGEND

- AUTOMATIC CONTROL BUTTERFLY VALVE (NORMALLY CLOSED- OPENS ON HIGH CELL PRESSURE)
- CHECK VALVE
- DOP - TESTABLE HEPA FILTER

FIG. 4 SIMPLIFIED CONCEPTUAL SCHEMATIC OF ARGON CELL SAFETY EXHAUST SYSTEM

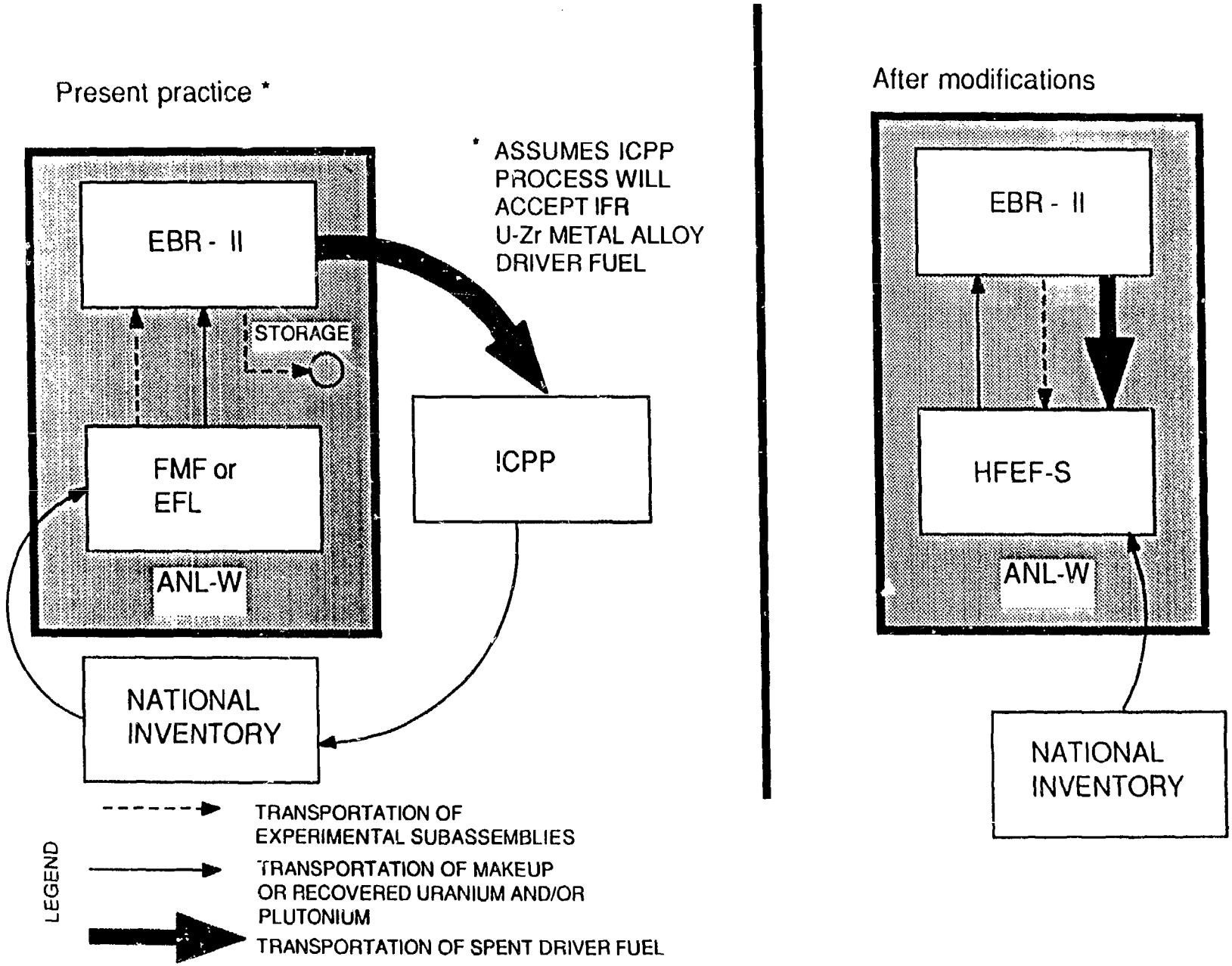


Fig. 5 Comparison of Transportation requirements.