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HEU to LEU Conversion and Blending Facility

UNH Blending Alternative to Produce LEU UNH for Commercial Use

Nuclear Materials Disposition Program Office
Y-12 Plant Defense Programs

September 1995

MANAGED BY
LOCKHEED MARTIN ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

UCN-13875 (8 8-95)

MASTER

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Predecisional Draft

**Nuclear Materials Disposition Program Office
Y-12 Plant Defense Programs**

**HEU to LEU Conversion and
Blending Facility**

**UNH Blending Alternative to Produce
LEU UNH for Commercial Use**

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Predecisional Draft

MASTER

**Oak Ridge Y-12 Plant
managed by
Lockheed Martin Energy Systems, Inc.
for the U.S. Department of Energy
under contract DE-AC05-84OR21400**

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UNH

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PREFACE

The United States Department of Energy (DOE) is examining options for the disposition of surplus weapons-usable fissile materials and storage of all weapons-usable fissile materials. Disposition is a process of use or disposal of material that results in the material being converted to a form that is substantially and inherently more proliferation-resistant than is the original form. Examining options for increasing the proliferation resistance of highly enriched uranium (HEU) is part of this effort.

HEU is uranium (U) with a ^{235}U isotopic content greater than or equal to 20% of total uranium by weight (20% ^{235}U assay). Blending HEU with depleted, natural, or low enriched uranium (LEU) diluent (called blendstock) has been proposed as a disposition option for HEU to permanently reduce its enrichment. The resultant product is LEU, which has a ^{235}U assay less than 20% and is not weapons-usable. Any country or sub-national group would require uranium enrichment capabilities to re-enrich down-blended HEU. There are existing facilities in the United States that can provide HEU blending capabilities with little capital investment. This option mirrors similar disposition actions in Russia. In addition to providing better resistance to proliferation, HEU blended to 3-5% ^{235}U assay can be sold to the electric power generating industry for use as fuel for their light water reactors (LWR). The sale of this material can recover the cost of converting the HEU into such fuel and could provide additional revenue for the U.S. Treasury. High concentrations of minor uranium isotopes in some HEU inventories prevent the down-blended LEU product from meeting specifications for LWR fuel. Blending to a low assay for waste disposal is a viable approach for these inventories. Therefore, blending HEU to LEU for LWR fuel or waste disposal is an attractive disposition option.

On June 21, 1994 DOE published a Notice of Intent to prepare a Programmatic Environmental Impact Statement (PEIS) for the Long-Term Storage and Disposition of Weapons-Usable Fissile Materials. DOE is amending the scope of the PEIS by removing the disposition of all surplus HEU from the PEIS. Instead DOE will address the disposition of surplus HEU in a separate Environmental Impact Statement (EIS). Five technologies for blending HEU will be assessed: blending as uranium hexafluoride (UF_6) to produce a UF_6 product for commercial use; blending as uranyl nitrate hexahydrate (UNH) solutions to produce a UNH crystal product for commercial use; blending UNH and then producing an oxide for disposal; blending as oxide to produce an oxide product for commercial use; and blending as molten metal and then producing an oxide for disposal. The surplus HEU inventory is characterized by a variety of physical forms, chemical and isotopic impurities, and ^{235}U assays. Potential blendstock inventories exhibit similar characteristics. Any one of the proposed blending technologies has comparative advantages and disadvantages for blending select batches of HEU and blendstock materials. Inventory variability and the dual nature of the product destiny (LWR fuel or waste) make it unlikely that any one technology can provide for the disposition of all surplus HEU.

This document provides data to be used in the environmental impact analysis for the UNH blending HEU disposition option. This option provides a yearly HEU throughput of 10 metric tons (MT) of uranium metal with an average ^{235}U assay of 50% blended with 165 MT of natural assay triuranium oxide (U_3O_8) to produce 316 MT of 4% ^{235}U assay UNH crystals for LWR fuel. Since HEU exists in a variety of forms and not necessarily in the form to be blended, worst case scenarios for preprocessing prior to blending will be assumed for HEU feed streams.

1. MISSIONS AND ASSUMPTIONS

1.1 MISSIONS

This Conversion and Blending Facility (CBF) alternative will have two missions: (1) convert HEU materials to pure HEU uranyl nitrate (UNH) and (2) blend pure HEU UNH with depleted and natural UNH to produce LEU UNH crystals. The primary emphasis of this blending operation will be to destroy the weapons capability of large, surplus stockpiles of HEU. The blended LEU product can only be made weapons capable again by the uranium enrichment process. To the extent practical, the chemical and isotopic concentrations of blended LEU product will be held within the specifications required for LWR fuel. Such blended LEU product will be offered to the United States Enrichment Corporation (USEC) to be sold as feed material to the commercial nuclear industry. Otherwise, blended LEU will be produced as a waste suitable for storage or disposal.

1.2 ASSUMPTIONS

As described in Appendix A, the function of this CBF alternative is limited. In summary, the following assumptions apply.

- The assumed bounding case scenario for the CBF will be to convert and blend down 10 MT per year of impure, unalloyed 50% assay HEU metal to pure 4% assay UNH crystals. The diluent feed used in the bounding case scenario will be pure, natural assay uranium oxide.
- Product assumptions include:
 - Blended LEU produced for LWR fuel feed will be 4.0% assay UNH crystals that meet American Society of Testing and Materials (ASTM) specifications for LWR fuel.
 - All other blended LEU produced will be 0.9% assay U_3O_8 suitable for storage or disposal.
- Surplus HEU feed assumptions include:
 - All surplus HEU feed will be above 20% assay.
 - The levels of ^{234}U and ^{236}U isotopes in any surplus HEU feed blended-down for LWR fuel will be sufficiently low to yield some LEU products that meet ASTM specifications for LWR fuel.

- Surplus HEU feed can be either pure or impure.
- Surplus HEU feed can be in the form of (1) metal and metal alloy, (2) uranium oxide or other uranium compounds, and (3) solutions.
- Diluent uranium feed assumptions include:
 - Diluent uranium feed can be either depleted uranium (DU) or natural uranium (NU).
 - All diluent uranium feed will be in the form of uranium oxide.
 - The levels of ^{234}U and ^{236}U isotopes in any diluent uranium feed blended to produce LWR fuel will be sufficiently low to yield some LEU products that meet ASTM specifications for LWR fuel.
 - No diluent uranium feed will require chemical purification prior to blending.
- General assumptions relating to the CBF include:
 - All surplus HEU will be supplied from DOE inventories.
 - Adequate supplies of uranium for diluent feed will be supplied by USEC.
 - Existing domestic facilities will be used as the CBF.

1.3 COMPLIANCE ASSUMPTIONS

1.3.1 Rules, Regulations, Codes, and Guidelines

1. New facility design or existing facilities comply with all applicable federal, state, and local laws and regulations. Additional industry consensus codes and standards are applied to the design as appropriate.
2. If new facilities or upgraded existing facilities are needed, structures, systems, and components are designed, fabricated, erected, and tested in accordance with the DOE Order 5700.6 series quality standards. These standards are commensurate with the risks associated with the facility and the significance of each structure, system, and component in mitigating releases of radioactive and other hazardous materials or minimizing risk. As low as reasonably achievable (ALARA) radiological exposure principles are incorporated appropriately throughout the design of the facilities.

1.3.2 Safeguards and Security

1. Programmatic Environmental Impact Statement data do not include facility features to support International Atomic Energy Agency inspections or possible future treaty obligations.
2. Special Nuclear Material (SNM) will be safeguarded through the use of in-process vaults that meet the intent of the requirements for production areas to be considered as nuclear material vault-type areas.

1.3.3 Environmental, Safety, and Health

1.3.3.1 Buffer Zones

1. Existing site conditions may preclude compliance with the "greenfield" requirement for a 1-mile buffer zone between plant operations and the plant boundary. This requirement has been waived for existing facilities. However, public radiological exposure limits will be achieved and every effort will be made to maintain the present buffer zone for any new facilities that need to be constructed as part of the CBF.
2. Distances between any newly constructed modules/facilities are based on technical, safety, and security considerations.

1.3.3.2 Decontamination and Decommissioning

All facilities must consider and incorporate provisions for decontamination and decommissioning.

1.3.3.3 Toxicological/Radiological Exposure

1. Worker exposure to toxic agents will not exceed 80% of the regulatory standard. The ALARA process will be implemented in the design as it affects worker exposure to toxic agents.
2. Worker exposure to radiation will not exceed an annual dose of 1.0 rem effective dose equivalent (EDE). The goal for the CBF for worker radiation exposure is 0.5 rem EDE per year. The ALARA process will be implemented in the design for radiation exposure of workers.
3. Public exposure to radiation at the site boundary from routine operations will not exceed 100 millirem (mrem) EDE per year per DOE 5400.5, Radiological Protection of the Public and Environment and the Radiological Control Manual. The goal for the CBF for public radiation exposure is 1 mrem EDE per year. The ALARA process will be implemented in the design for radiation exposure of the public.

4. The goal is for all facilities to be operated such that operators are not required to wear respiratory protection to meet radiological exposure limits while conducting routine operations.
5. The number of personnel required to work in contaminated areas is minimized and controlled.
6. The use of carcinogens is minimized or eliminated, where possible.

1.3.4 Waste Management

Waste treatment and disposal associated with the CBF will occur on-site or off-site at approved facilities. The following waste management assumptions may apply to the CBF depending on site requirements:

1. Generation of all wastes is minimized subject to the constraints of ALARA.
2. Mixed low-level waste (mixed LLW) is burned in approved local incinerators or stabilized and stored on-site on a long-term basis as LLW until regulations allow disposal.
3. LLW disposal in a permitted site.
4. Unclassified hazardous waste is shipped off-site to an authorized Resource Conservation and Recovery Act (RCRA) site for treatment and/or disposal.
5. Sanitary wastewater is treated in a permitted facility.
6. Sanitary and industrial solid waste is disposed of in a permitted landfill.

2. CONVERSION AND BLENDING FACILITY DESCRIPTIONS

The UNH Conversion and Blending Facility will probably use existing facilities at a plant location that already has support infrastructure in place. The facility will be a multi-story structure that contains all of the operations needed to convert and blend HEU in a variety of forms and assays into UNH with 4% ²³⁵U or U₃O₈ with 0.9% ²³⁵U. The facility will be divided into radiological and nonradiological areas. Radiological areas will be divided into areas for processing and storing Category I quantities of SNM and areas for non-SNM. Further division of the areas will be process related. Specifically, storage areas will be separated from processing areas.

The facility must be capable of receiving blending materials. A dock for Safe Secure Trailers (SSTs) is required for receiving HEU. A separate dock is required for receiving blendstock materials and shipping blended product.

Facilities that contain significant amounts of hazardous materials (radioactive materials being a category of hazardous materials) are classified by DOE as Category 1, 2, or 3 hazard facilities. Facilities that contain significant amounts of radioactive materials are classified by DOE as "nuclear facilities." The design criteria for hazard classified nuclear facilities are defined in DOE Order 6430.1A, DOE Order 5480.28, and DOE-STD-1020-94. New facility design and construction must meet these criteria. Existing facilities must meet the intent of this criteria. Facilities at non-DOE sites must be licensed by the Nuclear Regulatory Commission (NRC) and must meet equivalent NRC criteria.

This facility will have the following features and capabilities:

1. Redundancy and safety-class systems, as defined in DOE 6430.1A, to maintain building atmospheres during natural phenomena events and credible accident scenarios
2. Three major power systems (uninterruptible power, standby power, and emergency power) to provide safe shutdown and containment (during and after accidents)
3. One or more Material Access Areas (MAAs) for proper safeguards and security of the HEU materials
4. One or more radiation control areas where personnel access and egress will be controlled

5. Heating, ventilation, and air conditioning (HVAC) systems that comply with DOE 6430.1A criteria for containment and filtration
6. Location in a protected area (such as the Perimeter Intrusion Detection and Assessment System [PIDAS] at the Y-12 Plant) that complies with DOE safeguards and security requirements

3. PROCESS DESCRIPTIONS AND REQUIREMENTS

3.1 UNH BLENDING PROCESS DESCRIPTIONS

Criticality safety considerations require that safe handling, transfer, and storage practices be observed for HEU materials. Processing equipment will be designed for safe geometry to avoid dependence upon administrative controls to prevent any possibility of a criticality accident. Processing paths for this blending option are outlined in Figure 3.1.

3.1.1 Size Reduction

The sizes and shapes of HEU feed materials will vary. Size reduction is required for two principle purposes: to produce roughly uniform size pieces to facilitate process handling and protect process equipment; and to facilitate oxidation or dissolution. Size reduction can be accomplished by crushing, machining to chips or turnings, or rolling and shearing. Propylene glycol is used as a machine coolant during this process. Nitrogen may be used as a cover (blanket) gas.

3.1.2 Oxidation

Oxidation of uranium is an exothermic reaction carried out at elevated temperature using air. A heated rotating kiln can be used. The uranium oxide product is a powder and is generally preferred over metal for nitric acid dissolution, although the size-reduced metal can be dissolved in nitric acid directly.

3.1.3 Nitric Acid Dissolution

Either the uranium oxides or size-reduced uranium metal is dissolved in nitric acid (HNO_3). The aqueous solution of uranyl nitrate, $[\text{UO}_2(\text{NO}_3)_2 \cdot X \text{H}_2\text{O}]$, also contains any impurities present in the HEU being processed. Impure uranyl nitrate solutions are purified as described in Subsection 3.1.4. Hazardous nitrogen oxides, a co-product of the dissolution process, are scrubbed with water prior to release.

3.1.4 Purification

Purification of the uranyl nitrate solution consists of a two-step solvent extraction process. The uranyl nitrate transfers selectively from the aqueous uranyl nitrate solution into the immiscible organic extraction medium leaving impurities in the aqueous medium. The pure uranyl nitrate is then transferred back to an aqueous stripping solution and subsequently it is concentrated by evaporation. The concentrated solution of HEU uranyl nitrate is transferred to UNH blending.

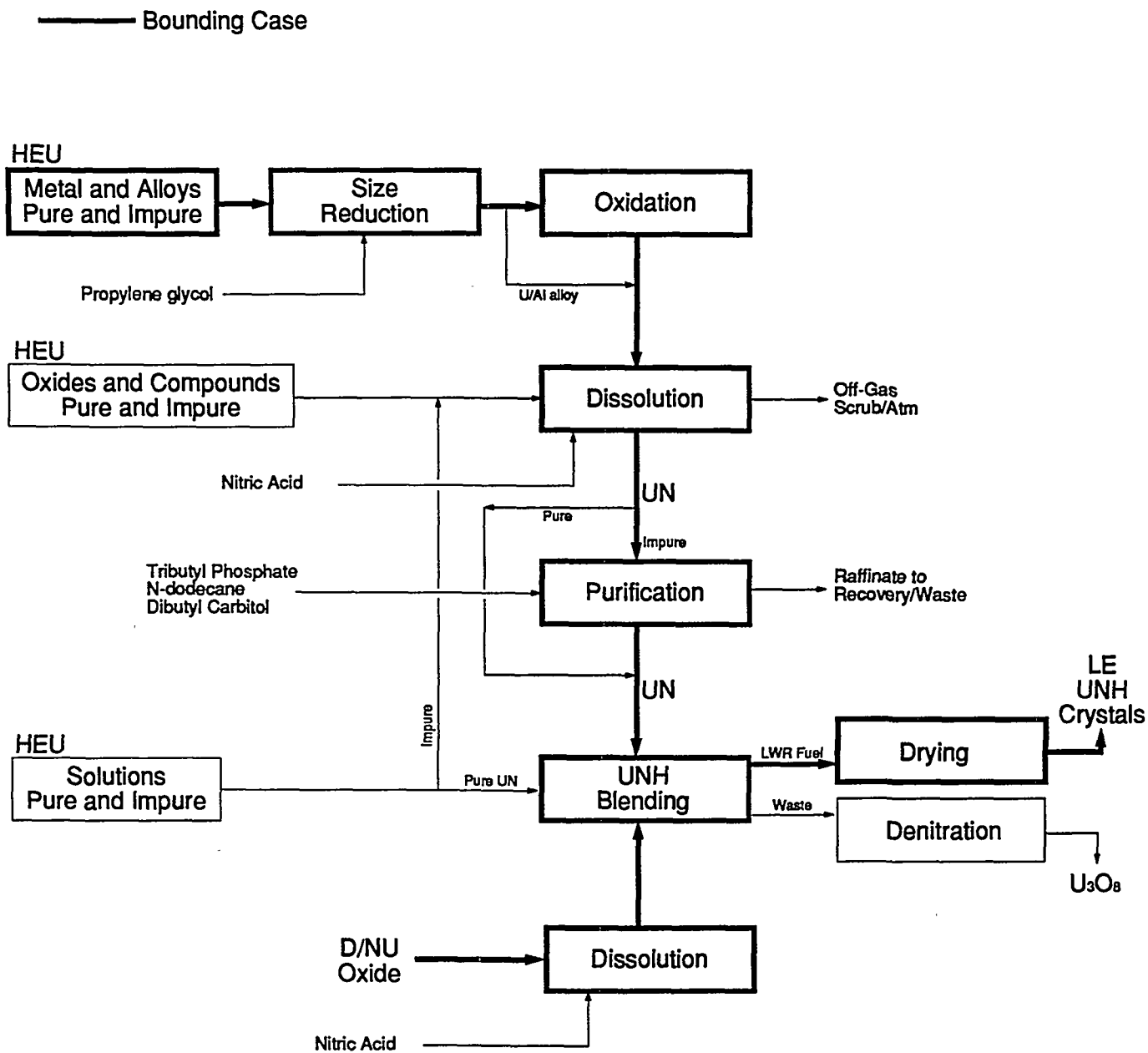


Fig. 3.1 Blending HEU as UNH.

Primary Extraction. The impure uranyl nitrate/nitric acid solution (additional nitric acid may be added to the solution from the nitric acid dissolution step) is fed to a counterflow extraction column where the uranyl nitrate is extracted into a countercurrent flow of organic solvent (dibutyl carbitol). The resulting aqueous raffinate containing the impurities from this extraction column is tested to ensure the uranium content is <25 ppm before the raffinate is sent to a waste treatment and disposal facility for recovery of nitric acid and other treatment. The organic stream is then contacted with dilute nitric acid in a strip column to back-extract (strip) the uranyl nitrate from the solvent, producing a dilute uranyl nitrate/nitric acid stream that is concentrated in the primary and intermediate evaporators.

Secondary Extraction. The product from the primary extraction/evaporation step requires the addition of nitric acid before the stream is fed to the secondary extraction column where it is contacted by a countercurrent flow of solvent consisting of tributyl phosphate (TBP) in a N-dodecane (or high-grade kerosene) diluent. The resulting uranyl nitrate-TBP complex is then contacted by a countercurrent flow of dilute nitric acid in the secondary strip column to strip the uranyl nitrate from the solvent. The dilute uranyl nitrate/nitric acid solution produced in the strip column is concentrated in the secondary evaporators. The raffinate from the secondary extraction column is routed to the primary columns for further processing.

3.1.5 UNH Blending

Pure uranyl nitrate solutions from NU and HEU are blended in criticality safe vessels (e.g., 6-in. diam. columns). Mixing can be accomplished by agitation, stirring, or multiple transfers between two tanks.

3.1.6 Drying and Crystallizing

The blended uranyl nitrate solution is evaporated to remove the remaining water and produce molten UNH. The UNH is fed to a crystallizer for controlled cooling to produce UNH crystals.

3.2 FEED STREAMS

The UNH blending scenario has two feed streams:

1. Pure and impure HEU metal, alloys, solutions, and compounds with an average ^{235}U assay of 50% (bounding case is impure HEU metal)
2. Pure U_3O_8 with a ^{235}U assay of $\leq 0.711\%$ (bounding case is $0.711\% ^{235}\text{U}$)

3.3 PRODUCT STREAMS

The UNH blending scenario has two potential product streams:

1. Pure and impure LEU oxide with a 0.9% ²³⁵U assay, for storage or disposal
2. Pure LEU UNH with a ²³⁵U assay of 4% (bounding case)

3.4 UTILITIES REQUIRED

The UNH blending scenario requires the following utility services:

- Electricity
- Water for fire protection
- Sanitary water
- Tower cooling water
- Chilled water
- Steam
- Compressed air/breathing air
- Compressed gases
- Telecommunications

3.5 CHEMICALS/MATERIALS REQUIRED FOR THE PROCESS

The bounding case requires the following chemicals/materials:

- Potassium hydroxide
- Nitric acid
- Dibutyl carbitol
- Sodium hydroxide
- Tributyl phosphate
- Nitrogen
- N-dodecane
- Argon
- Propylene glycol

3.6 SPECIAL REQUIREMENTS

The following special requirements apply to this process:

1. Radiological hazard protection for internal (inhalation/ingestion) exposures to alpha particles from uranium

2. Criticality safety in all phases of material handling, process design, and accident analysis, with safe geometry as the preferred method of criticality control
3. Safeguards and security issues associated with personnel access to and the handling, transportation, and disposal of classified data related to uranium processes and associated with protection of special nuclear material from theft, diversion, or sabotage
4. Consideration of pyrophoric properties of finely divided uranium metal
5. Design of equipment, processes, and storage systems for a rapid and accurate periodic SNM inventory determination
6. Elimination or reduction of the use or generation of hazardous materials to minimize the generation of mixed radiological/hazardous waste streams
7. Attention to maximization of by-product recycle to reduce the opportunity for radiological waste generation
8. Consideration of human factor designs, especially in the handling of large, high-density uranium parts and materials
9. Consideration of the need for classified shape processing and manufacture
10. Burn protection for handling hot parts
11. Design to reduce material oxidation and provide dust control

3.7 WASTE MANAGEMENT

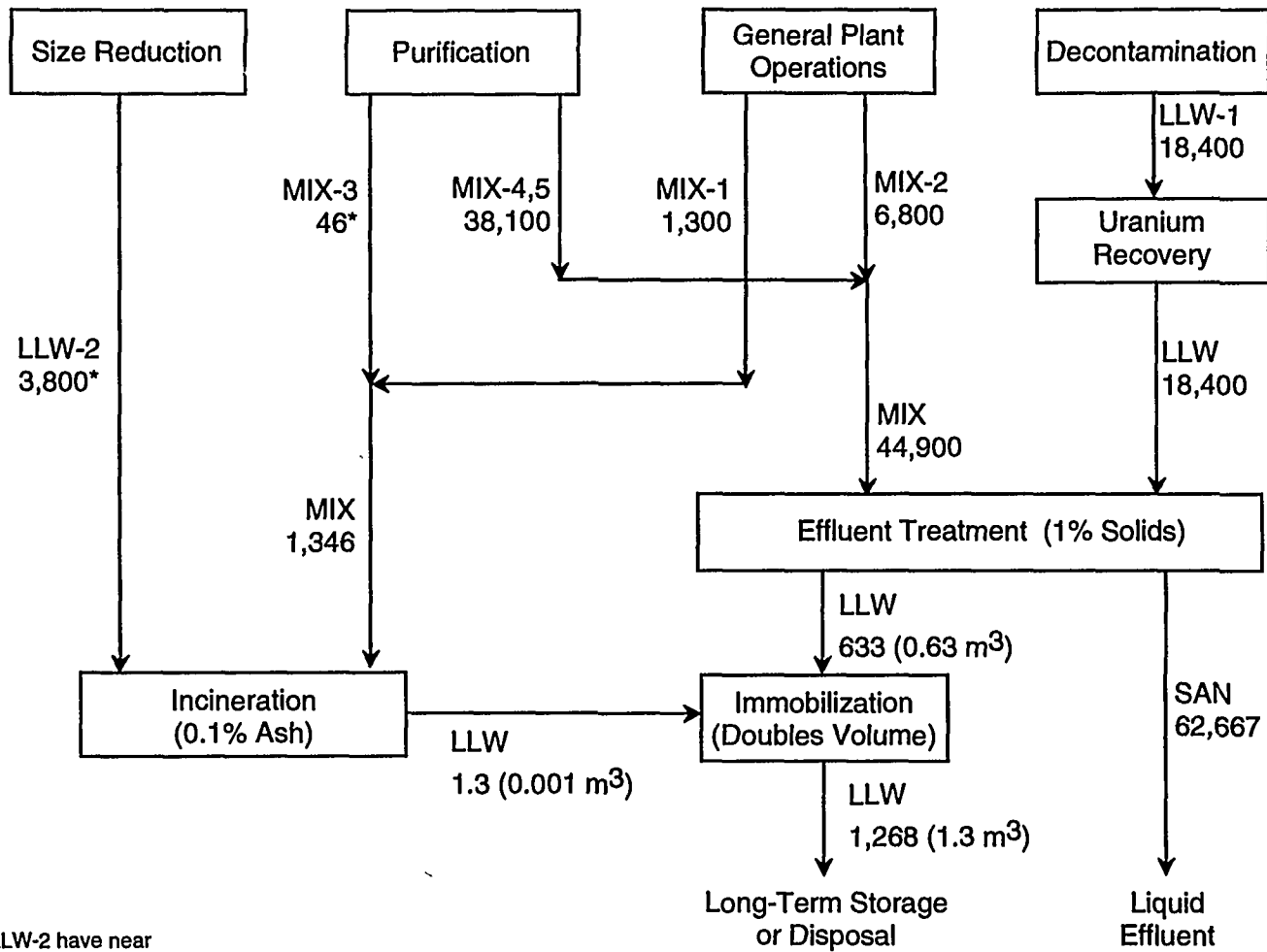
The primary waste streams generated during the processing of the HEU material are identified in Table 3.1. Each primary waste stream has been assigned in alpha numeric number, listed as the *first* column in the table. The 3-digit alpha portion of each number indicates the waste type (i.e., HAZ for Hazardous, MIX for Mixed, LLW for Low-Level Radioactive, SAN for Sanitary). The numerical portion of each number is a sequential identifier. The waste streams are listed in groups. The *second* column in the table describes each primary waste stream. The *third* column in the table identifies the source of each primary waste stream. The *fourth* column in the table quantifies the volume of each primary waste stream's generation rate, expressing liquid streams in liters per year (L/yr) and solid streams in cubic meters per year (m³/yr). The *fifth* column in the table identifies any treatment provided by

Table 3.1 Waste Stream Identification for a UNH Conversion and Blending Facility

Type	Description	Rate	Treatment Provided	Additional Treatment Required	Storage Required	Disposal Required	Source
HAZ-1	Liquid Waste Treatment Excess/Flush Water	87,000 L/yr	distillation, evaporation	neutralization	long-term	surface water	liquid waste treatment
HAZ-2	Chemical Spillage	640 L/yr	none	incineration	none	none	chemical receiving
MIX-1	Liquid Lab Waste	1,300 L/yr	none	incineration and immobilization	long-term	none	lab analyses
MIX-2	Sump Collection Wastes	6,800 L/yr	none	precipitation, filtration, and immobilization	long-term	surface water	facility cleanup
MIX-3	Spent Solvent	46 L/yr	cleaning, recycle	incineration	none	none	purification process
MIX-4	Solvent-Contaminated Aqueous Waste	6,800 L/yr	distillation	organics removal and immobilization	long-term	surface water	solvent treatment
MIX-5	Raffinate	31,300 L/yr	acid recovery	neutralization, volume reduction, and immobilization	long-term	LLW burial	purification & drying offgas scrubber
LLW-1	Decontamination Wastewater	18,400 L/yr	none	uranium recovery and immobilization	long-term	surface water	decontamination
LLW-2	10% Propylene Glycol, 90% water	3,800 L/yr	none	incineration	none	none	size reduction
LLW-3	Decontamination Solids	6 m ³ /yr	none	uranium recovery and immobilization	long-term	LLW burial	decontamination
LLW-4	Solid Lab Waste	0.06 m ³ /yr	none	immobilization	long-term	LLW burial	lab analyses
LLW-5	Scrapped Equipment	28 m ³ /yr	decontamination	none	long-term	LLW burial	decontamination
LLW-6	HEPA Filters	14 m ³ /yr	none	volume reduction	long-term	LLW burial	offgas filtration
LLW-7	Miscellaneous Contaminated Solids	28 m ³ /yr	none	volume reduction	long-term	LLW burial	facility operations
LLW-8	Air Sampling Filters	0.03 m ³ /yr	none	volume reduction	long-term	LLW burial	offgas sampling
SAN-1	Sanitary Sewage	18,000,000 L/yr	none	biological treatment	none	sanitary landfill	facility operations
SAN-2	Cooling Tower Blowdown	87,000 L/yr	none	dechlorination	none	surface water	Recirculating Cooling Water (RCW) system
SAN-3	Condensate Blowdown	680,000 L/yr	none	none	none	surface water	evaporation, area heat
SAN-4	Contaminated Rainwater	6,400 L/yr	none	incineration	none	none	chemical receiving
SAN-5	Sanitary Solid Waste	820 m ³ /yr	none	none	none	sanitary landfill	facility operations

the process facility. The *sixth* column in the table identifies secondary treatment that may be required in order to comply with current DOE, State, and Federal requirements.

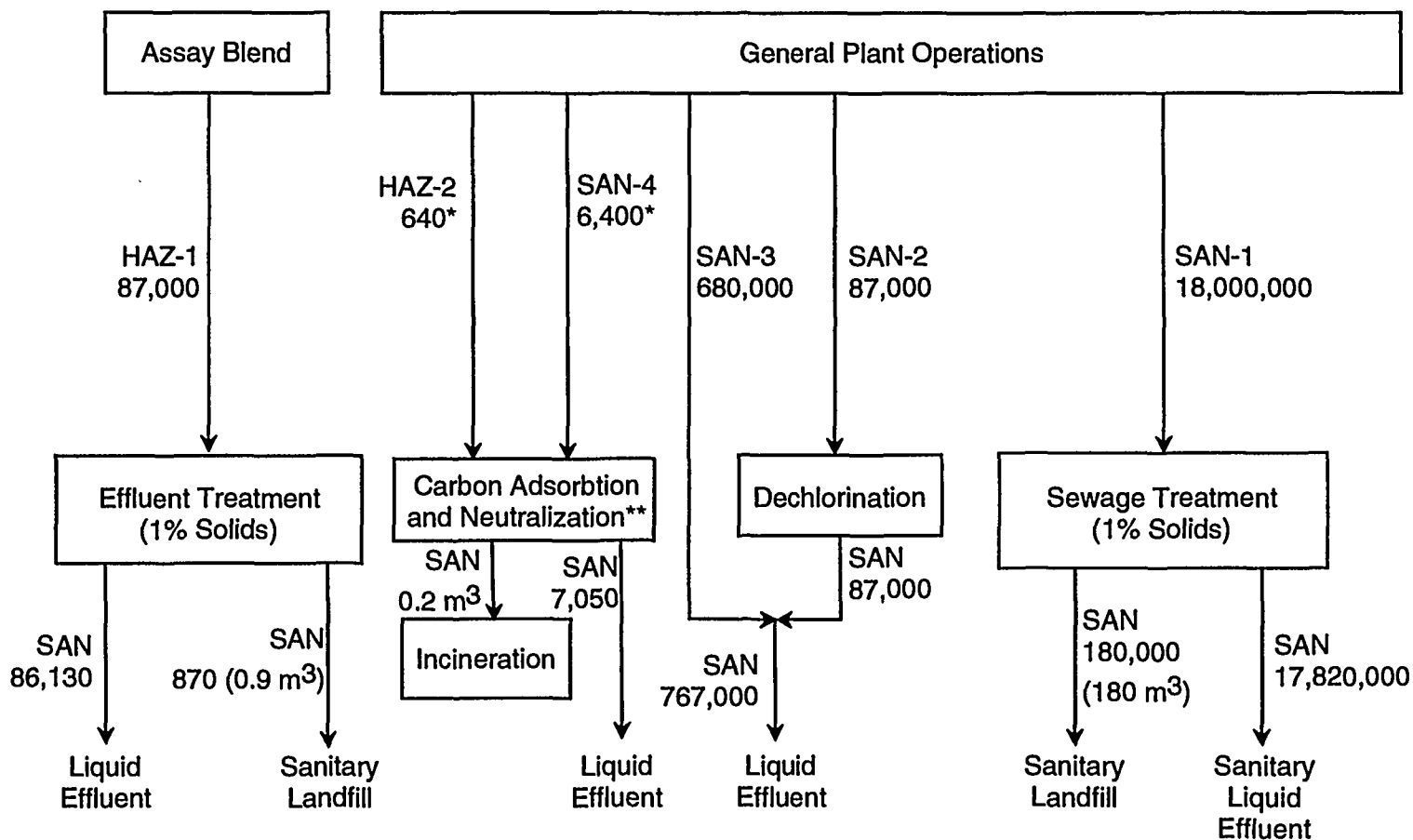
Figures 3.2, 3.3, and 3.4 depict, in block flow format, the methods expected to be used for waste treatment, storage, and disposal. For the development of these figures, it was assumed that no listed hazardous wastes are present and that the indicated treatment eliminates the hazardous characteristic of the primary waste.



* MIX-3 & LLW-2 have near 0 ash from incineration.

(All volumes are in liters per year except as noted.)

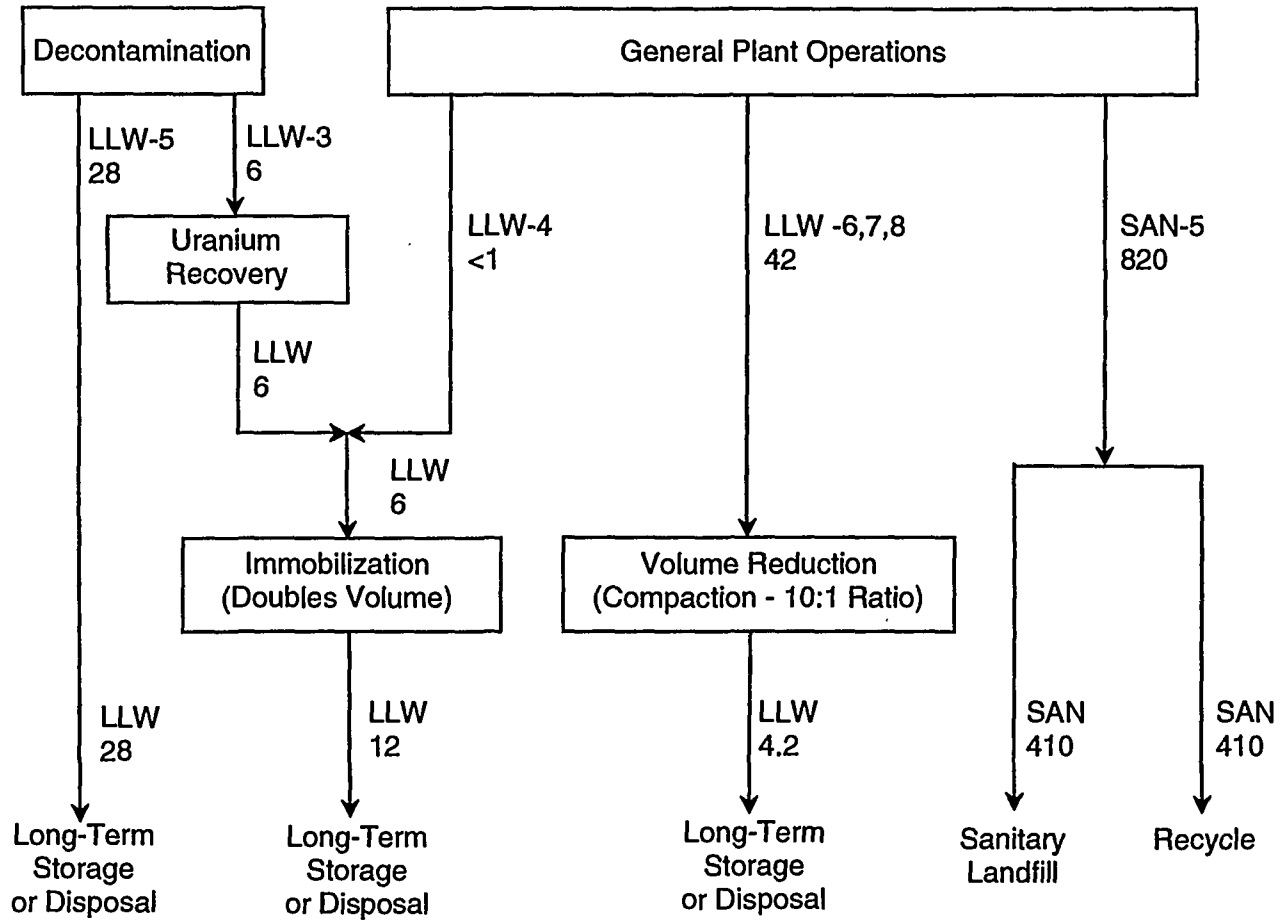
Fig. 3.2. Radioactive liquid waste management block flow diagram.
(UNH blending for commercial use)



* HAZ-2 & SAN-4 have near 0 ash from incineration.
 ** 0.1 kg activated carbon per kg organic; neutralization doubles the volume of acids and bases neutralized.

(All volumes are in liters per year except as noted)

Fig. 3.3. Nonradioactive liquid waste management block flow diagram.
 (UNH blending for commercial use)



(All volumes are in cubic meters per year except as noted.)

Fig. 3.4. Solid waste management block flow diagram.
(UNH blending for commercial use)

4. RESOURCE NEEDS

4.1 MATERIALS/RESOURCES CONSUMED DURING OPERATION

4.1.1 Materials/Resources Consumed

Table 4.1 shows the materials/resources consumed annually during operation.

4.1.2 Chemicals Consumed

Solid, liquid, and gaseous chemical requirements are summarized in Table 4.2.

4.1.3 Radiological Materials Handled

Radiological materials handled in the CBF include uranium materials at all assay levels and in a variety of forms (e.g., metal, alloy, oxide, solutions, etc.).

Table 4.1. Materials/resources consumed during operation - annual

Utilities	Consumption	Peak Demand ^a
Electricity (MWh)	4,000	2 MW
Diesel fuel (gal)	15,000	
Natural gas ^b (scf)	600,000	
Coal (ton)	400	
Raw water (L)	19×10^6	
Steam (kg)	8,700	

^a Peak demand is the maximum rate expected during any hour.

^b Standard cubic feet measured at 14.7 psia and 60°F.

Table 4.2. Chemicals consumed during operation - annual

Chemical	Quantity	Operation
SOLID CHEMICALS		
Sodium hydroxide	1.0 MT	Waste treatment ^a
LIQUID CHEMICALS		
Propylene glycol	400 kg	Size reduction
Potassium hydroxide, 20% by weight	15 MT	Waste treatment ^b
Nitric acid, new, 30% by weight	400 MT	Dissolution and purification ^c
Nitric acid, recovered, 30% by weight	40 MT	Dissolution ^c
Dibutyl carbitol	400 kg	Purification
TBP	50 kg	Purification
N-dodecane (or high-grade kerosene)	1.5 MT	Purification
GASEOUS CHEMICALS		
Argon	5×10^5 scf	Blanket gas
Nitrogen	5×10^5 scf	Blanket gas

^a For neutralizing the nitric acid in the purification operation raffinate.

^b For scrubbing the LEU UNH dryer off-gas.

5. EMPLOYMENT NEEDS

5.1 EMPLOYMENT NEEDS DURING OPERATION

The CBF generally operates with three shifts per day, five days per week, except for some utility systems and security functions which operate continuously. The employment during operation is summarized in Table 5.1. The labor categories used in Table 5.1 are Equal Employment Opportunity (EEO) categories.

5.1.1 Badged Employees at Risk of Radiological Exposure

It is estimated that 83 of the badged employees are at risk of radiological exposure. In addition, a small fraction of badged visitors are expected to enter the radiological area, but this is on a nonroutine basis. The maximum annual dose to workers at this facility has been estimated at 90 mrem.

5.1.2 Labor Category Descriptions

The standard EEO labor categories in Table 5.1 are defined in the following paragraphs.

Officials and Managers. Occupations requiring administrative and managerial personnel who set broad policies, exercise overall responsibility for execution of these policies, and direct individual departments or special phases of a firm's operations. Included in this category are: officials, executives, middle management, plant managers, department managers and superintendents, purchasing agents, and buyers and salaried supervisors who are members of management.

Professionals. Occupations requiring either a college degree or experience of such kind and amount as to provide a comparable background. Included in this category are: accountants and auditors, architects, artists, chemists, designers, editors, engineers, lawyers, librarians, mathematicians, natural scientists, registered professional nurses, personnel and labor relation specialists, physical scientist, physicians, social scientists, and teachers.

Technicians. Occupations requiring a combination of basic scientific knowledge and manual skill which can be obtained through two years of post-high school education, such as is offered in many technical institutes and junior colleges, or through equivalent on-the-job training. Included in these occupations are: computer programmers, drafters, engineering aides, junior engineers, mathematical aides, licensed, practical or vocational nurses, photographers, radio operators, scientific assistants, surveyors, technical illustrators, and technicians (medical, dental, electronic, physical science).

Table 5.1. Employment during surge operation

Labor Category	Number of Employees
Officials and Managers	4
Professionals	3
Technicians	12
Office and Clerical	3
Craft Workers	13
Operatives	51
Laborers	19
Service Workers	20
TOTAL EMPLOYEES	125

Office and Clerical. This category includes all clerical work, regardless of level of difficulty, where the activities are predominantly non-manual, although some manual work not directly involved with altering or transporting the products is included. Included in this category are: bookkeepers, collectors (bills and accounts), messengers and office helpers, office machine operators (including computer), shipping and receiving clerks, stenographers, typists and secretaries, telephone operators, and legal assistants.

Craft Workers (skilled). Manual workers of relatively high skill level having thorough and comprehensive knowledge of the processes involved in their work. Exercise considerable independent judgment and usually receive an extensive period of training. Included in this category are: the building trades, hourly paid supervisors and lead operators who are not members of management, mechanics and repairers, skilled machining occupations, compositors and typesetters, electricians, engravers, painters (construction and maintenance), and pattern model makers.

Operatives (semiskilled). Workers who operate machine or processing equipment or perform other factory-type duties of intermediate skill level which can be mastered in a few weeks and require only limited training. Included in this category are: apprentices (auto mechanics, plumbers, bricklayers, carpenters, electricians, machinists, mechanics, building trades, metalworking trades, printing trades, etc.), attendants (auto service and parking), blasters, delivery workers, furnace workers, laundry operatives, milliners, motor operators, oilers and greasers (except auto), painters (manufactured articles), photographic process workers, stationary firefighters, truck drivers, welders and flamecutters, electrical and electronic equipment assemblers, inspectors, testers and graders, and handypackers and packagers.

Laborers (unskilled). Workers in manual occupations which generally require no special training who perform elementary duties that may be learned in a few days and require the application of little or no independent judgment. Included in this category are: garage laborers, car washers and greasers, groundskeepers and gardeners, stevedores, laborers performing lifting, digging, mixing, and loading and pulling operations.

Service Workers. Workers in both protective and non-protective service occupations. Included in this category are: attendants (hospital and other institutions, professional and personal service, including nurses aides and orderlies), cooks, counter and fountain workers, elevator operators, firefighters and fire protection, guards, doorkeepers, stewards, janitors, police officers and detectives, recreation facilities attendants, guides, and public transportation attendants.

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6. WASTE AND EMISSIONS FROM THE PLANT

6.1 WASTE AND EMISSIONS DURING OPERATION

This section presents the emissions and wastes generated by the CBF and supporting facilities during operation.

6.1.1 Airborne Emissions

The contaminated and potentially contaminated zones within the CBF facilities that handle uranium materials have high-efficiency particulate air (HEPA)-filtered ventilation systems that exhaust to the atmosphere. Some exhausts are provided with liquid scrubbing prior to HEPA filtration to remove chemical vapors such as nitric acid. The annual airborne emissions for the CBF are shown in Table 6.1.

6.1.2 Solid and Liquid Waste

The radioactive waste, hazardous/toxic waste, and non-hazardous sanitary waste are discussed in the subsections below. The annual quantity of solid and liquid waste generated by the CBF is shown in Table 6.2.

6.1.2.1 Radioactive Waste

Small amounts of low-level radioactive waste and mixed waste are produced by the CBF. Radioactive waste consists primarily of scrapped equipment, miscellaneous solids (personnel protective equipment, etc.), metallic air filters, and HEPA filters. Mixed waste include ash and sludge immobilized in grout, contaminated aqueous liquids, and organic solvents.

6.1.2.2 Hazardous Waste

Liquid hazardous waste is treated and sent to an approved permitted RCRA disposal site.

6.1.2.3 Nonhazardous Waste

Solid nonhazardous waste generated at the CBF consists primarily of solid sanitary waste, trash, waste paper, scrap metal, air filters, personnel respirators, plastic bags and gloves. Non-recyclable portions of this waste will be sent to the sanitary/industrial landfill. Quantities in Table 6.2 were generated as shown in Figures 3.2, 3.3, and 3.4.

Table 6.1. Airborne emissions during operation - annual

Pollutants	Process Emissions	Steam Plant Emissions
NONRADIOLOGICAL		
Carbon monoxide	2.0 MT	0.16 MT
Nitrogen oxides	0.4 MT	6.9 MT
Ozone*	0.2 MT	0.015 MT
Particulate matter	0.1 MT	0.07 MT
Sulfur dioxide	0	13.5 MT
Ash	0	37 MT
RADIOLOGICAL		
²³⁵ U	6.93 x 10 ⁻⁵ Ci	0
²³⁸ U	3.19 x 10 ⁻⁴ Ci	0

* Based on estimated generation of volatile organic chemicals (VOCs).

Table 6.2. Waste volumes during operation - annual

Category	Generated Quantities		Post Treated	
	Solid (m ³)	Liquid (L)	Solid (m ³)	Liquid (L)
Low-level waste	76	22,000	46	0
Mixed low-level waste	0	46,000	0	0
Hazardous waste	0	88,000	0	0
Nonhazardous (sanitary) waste	410	18,000,000	590	17,820,000
Nonhazardous (other) waste	0	773,000	0	923,000
Recyclable waste	410	0	410	0

7. HAZARDS DISCUSSION

This chapter describes typical hazards associated with a CBF. Much of the data used in this chapter relates to HEU processing operations existing at the Y-12 Plant in Oak Ridge. Since these operations represent the technologies available for conversion and blending, and since the Y-12 Plant HEU processing operations have adequate production capacity, the hazards described herein can be considered applicable to the CBF that will blend down HEU as UNH.

Accident scenarios associated with the hazards at each operating CBF site may be different than those presented here. The development of more representative accident scenarios for each CBF site will depend on site specific factors such as:

- Design of blending process systems and process support systems
- Size, type, and proximity of equipment utilized in process and support systems
- Capacities of process and support systems to stage and process uranium and hazardous chemicals
- Engineered and administrative safety controls utilized in process and support systems
- Design, construction, and layout of utilities systems
- Design, construction, and layout of process buildings
- Potential impacts from other processes located inside process buildings and in nearby buildings
- Site and infrastructure layout
- Local natural phenomena hazards and meteorological conditions
- Public access to the site boundary

Currently, there are no facilities at the Y-12 Plant (for the handling, storing, or processing HEU) in Hazard Category (HC) 1, as defined in DOE Order 5480.28. The highest level determined for any processing facility at the Y-12 Plant is HC 2. It can therefore be assumed that the CBF located at any potential site will likewise be no higher than HC 2. However, for conservatism, the hazard information contained in this chapter assumes that the CBF will be HC 1.

7.1 CBF HAZARD CONSIDERATIONS

In assessing the bounding accident scenarios for the CBF, the following parameters were evaluated: 1) material at risk (MAR); 2) energy sources (fires, explosions, earthquakes, and process design-related events); 3) barriers to release; and 4) protective features of the facility. These parameters are discussed in the following sections.

7.1.1 Materials at Risk

The CBF is typically a large multi-story structure, wholly or partially, devoted to converting and blending HEU with DU or NU. The MAR consists of uranium metal, solutions, and compounds at various enrichments from depleted to assays of 93% ^{235}U , and various nonradioactive reagents used in the process. The radioactive and nonradioactive hazardous materials used in significant quantities in the CBF processes are discussed below.

7.1.1.1 Radioactive Hazardous Materials

The only radioactive material processed in the CBF is uranium. For the purposes of accident analyses, all uranium is assumed to be highly enriched. The assumed isotopic content for uranium with different enrichment is shown in Table 7.1. From a hazards standpoint, all HEU (50% enrichment) is assumed. The feed material is received in various forms ranging from retired metal parts to contaminated materials. Processing steps include size reduction, oxidation, dissolution, purification, blending, and drying. The forms of HEU in these processes consist of:

- Metal and metal-contaminated materials
- Oxide powders and oxide-contaminated materials
- Nitrate solids (powders and crystals)
- Nitrate solutions
- Organic solutions

Table 7.2 lists the various radioactive materials in the facility that are at risk of release.

Table 7.1. Isotopic content of uranium at various enrichments

Mass Fraction						
Enrichment	²³² U	²³⁴ U	²³⁵ U	²³⁶ U	²³⁸ U	Total
50% ²³⁵ U	4×10^{-8}	4.25×10^{-3}	5×10^{-1}	2.31×10^{-3}	4.93×10^{-1}	1.000
4% ²³⁵ U	4×10^{-8}	3.34×10^{-4}	4×10^{-2}	1.54×10^{-4}	9.68×10^{-1}	1.000
0.9% ²³⁵ U	4×10^{-8}	9.48×10^{-5}	9×10^{-3}	3.25×10^{-5}	9.91×10^{-1}	1.000
0.71% ²³⁵ U	4×10^{-8}	5.41×10^{-5}	7.11×10^{-3}	0	9.93×10^{-1}	1.000
0.2% ²³⁵ U	4×10^{-8}	3.56×10^{-5}	2×10^{-3}	0	9.98×10^{-1}	1.000
Specific Activity (Ci/kg)						
	²³² U	²³⁴ U	²³⁵ U	²³⁶ U	²³⁸ U	
	2.2×10^4	6.2	2.1×10^{-3}	6.3×10^{-2}	3.3×10^{-4}	
Isotopic Activity (Ci/kg U)						
Enrichment	²³² U	²³⁴ U	²³⁵ U	²³⁶ U	²³⁸ U	Total
50% ²³⁵ U	8.8×10^{-4}	2.64×10^{-2}	1.05×10^{-3}	1.46×10^{-4}	1.63×10^{-4}	2.86×10^{-2}
4% ²³⁵ U	8.8×10^{-4}	2.07×10^{-3}	8.4×10^{-5}	9.71×10^{-6}	3.17×10^{-4}	3.36×10^{-3}
0.9% ²³⁵ U	8.8×10^{-4}	5.88×10^{-4}	1.89×10^{-5}	2.05×10^{-6}	3.27×10^{-4}	1.82×10^{-3}
0.71% ²³⁵ U	8.8×10^{-4}	3.35×10^{-4}	1.49×10^{-5}	0	3.28×10^{-4}	1.56×10^{-3}
0.2% ²³⁵ U	8.8×10^{-4}	2.2×10^{-4}	4.2×10^{-6}	0	3.29×10^{-4}	1.43×10^{-3}

Table 7.2. Materials at risk ^a

Chemical	Quantity	Operation
SOLIDS		
Sodium hydroxide	0.5 MT	Waste treatment ^b
HEU metal (50% assay)	2.0 MT	Storage warehouse
HEU metal (50% assay)	20 kg	Process feed
Natural U ₃ O ₈	25 MT	Storage warehouse
Natural U ₃ O ₈	0.5 MT	Process feed
LEU UNH crystals (4% assay)	1.0 MT	Process product
LEU UNH crystals (4% assay)	50 MT	Storage warehouse
LIQUIDS		
Propylene glycol	200 kg	Size reduction
Dibutyl carbitol	200 kg	Purification
N-dodecane or high-grade kerosene	600 kg	Purification
Tributyl phosphate	150 kg	Purification
Potassium hydroxide, 20% by weight	12 MT	Waste treatment ^c
New nitric acid, 30% by weight	45 MT	Dissolution & purification ^d
Recovered nitric acid, 30% by weight	5 MT	Dissolution ^d
HEU uranyl nitrate solution; 125g/L U, ~1.5 M HNO ₃	200 kg	Dissolution
Natural uranyl nitrate solution; 125g/L U, ~1.5 M HNO ₃	2,300 kg	Dissolution
HEU uranyl nitrate solution; 70g/L U, ~0.2 M HNO ₃	300 kg	Purification
LEU uranyl nitrate solution; 70g/L U, ~0.8 M ^e HNO ₃	4,000 kg	Blending
GASES		
Argon	<100 scf	Blanket gas
Nitrogen	<100 scf	Blanket gas

^a Quantities shown represent the estimated maximum amounts of these materials typically in process.

^b For neutralizing the nitric acid in the purification operation raffinate.

^c For scrubbing the LEU UNH dryer off-gas.

^d New nitric acid supplements recovered nitric acid as needed in dissolution; purification uses only new nitric acid.

^e Assumes dilution of natural uranyl nitrate solution to 70 g/l U before blending.

HEU and HEU compounds are stored, transported, and processed in criticality-safe containers. These include polyethylene and stainless steel tubular tanks for liquids and stainless or galvanized steel, cylindrical cans for solids. Metals in particular are stored in reinforced concrete vaults in locked steel boxes in fixed safe arrays. Cans are transported in secured boxes mounted on dollies in fixed safe arrays.

Although all uranium materials are contained, accidents and natural phenomena that would release the contained materials can be postulated. The extent of release and suspension varies with the accident, container, and material form.

Metals are a special case. Due to security and criticality safety concerns, the uranium metal forms are stored in vaults providing substantial protection from accidents and natural phenomena. The secured concrete vaults and internal containers provide additional protection from the only (non-criticality) mechanism for suspending uranium metal, a fire which oxidizes the metal and suspends the oxide. Even if the metal were oxidized, the fraction of oxidized metal suspended would be approximately 10^{-4} to 10^{-5} . Based on this small release fraction, the uranium metal stored in the secure vaults is not considered to be "at risk" of release. Uranium metal being processed at any time (outside the secure vaults) is assumed to be at risk in fire accidents and may contribute to nuclear criticality accidents.

7.1.1.2 Nonradioactive Hazardous Materials

The significant nonradioactive materials in the facility are listed in Table 7.2.

7.1.2 Energy Sources

The HC for the CBF, as defined in DOE Order 5480.28, has not been determined for HEU processing facilities at all potential sites. Facilities at the Y-12 Plant that are considered candidates for the CBF are no higher than HC 2. It can therefore be assumed that the CBF located at any potential site will likewise be no higher than HC 2. However, the hazard information is based upon the conservative assumption that the CBF will be HC 1. Therefore, criteria for HC 1 facilities are provided in the following subsections. Table 7.3 presents the potential energy sources in the CBF.

7.1.2.1 Fires and Explosions

The CBF may contain explosive/combustible materials, such as N-dodecane/kerosene, as well as oxidizing, thermal, and electrical energy sources. Several chemical reactions can evolve hydrogen or potentially explosive nitrified organics (collectively referred to as "red oil"). However, the HVAC and process systems should prevent gases or red oil from accumulating to an explosive level.

Table 7.3. Potential energy sources

Type	Source	Use
Explosive/combustible	Dibutyl carbitol	Primary extraction
	Tributyl phosphate	Secondary extraction
	N-dodecane or kerosene	Secondary extraction
Thermal	Steam	Evaporators
Electrical	2400 volts	Utility services

7.1.2.2 Earthquake

DOE Order 5480.28 and DOE-STD-1020-94 specify the design basis earthquakes (DBE) and the natural phenomena performance goals for HC 1 facilities at DOE sites. A beyond DBE should be evaluated in the accident analysis.

7.1.2.3 Tornado

DOE Order 5480.28 and DOE-STD-1020-94 specify the design basis tornadoes (DBT) and the natural phenomena performance goals for HC 1 facilities at DOE sites. A beyond DBT should be evaluated in the accident analysis.

7.1.2.4 Flood

DOE Order 5480.28 and DOE-STD-1020-94 specify the design basis flood (DBF) and the natural phenomena performance goals for HC 1 facilities at DOE sites. A beyond DBF should be evaluated in the accident analysis.

7.1.2.5 Nuclear Criticality

The CBF contains multiple critical masses of uranium. Therefore, a criticality event cannot be ruled out, especially associated with a major earthquake or tornado.

7.1.2.6 Process Design Related Events

Process design related events include potential fires and explosions. No other significant process design-related events were identified.

7.1.3 Barriers to Release

The CBF utilizes a multibarrier system to prevent the release of radioactive and toxic materials to the atmosphere. The primary barriers include metal containers, gloveboxes/enclosures and processing equipment, such as pencil tanks and piping. The secondary barriers include the building structure and the HVAC system.

Tanks, pans, storage cans, and other vessels contain the feed and products generated by the various systems. Since these processes may be batch operations, intermediate storage may be required.

Large volumes of solutions may be stored in tank arrays located in various places throughout the building. The tanks are stainless steel and have glass or stainless steel ends. Each has an inner diameter of 5 to 6 in. and varies in length from 6 to 44 ft. Due to spacing requirements, the tanks are geometrically favorable containers for

uranyl nitrate solutions. The tanks are normally vented, and overflows are generally connected to a common overflow manifold which empties to a safe bottle.

7.1.4 Protective Features

The CBF uses several protective features for personnel safety and radioactive material confinement during normal and accident operations. Ventilation systems barriers and nuclear criticality safety features are briefly discussed below.

Ventilation Barriers. Ventilation system barriers employed in the CBF range from hoods and enclosures for personnel protection to the processing of exhaust streams through filters and scrubbers to minimize releases. In general, filtration and scrubbing are used for exhausts from processes with a high potential for uranium release. Exhaust stacks are sampled to identify quantities of uranium released.

Criticality Safety. Active and passive design features are employed to prevent nuclear criticality. The principal feature employed is use of safe geometry piping, tanks, drains, and spill-retaining features of the process area floors. Uranium metals and powders are secured in metal-framed birdcages or inside concrete vaults to maintain criticality-safe spacing. A limited number of containers that are not safe geometry are provided with borosilicate rashig rings (neutron poison) to prevent criticality. In addition, radiation detectors and alarms allow rapid evacuation of personnel in the event of a criticality accident.

7.2 ACCIDENT SCENARIOS CONSIDERED

7.2.1 Earthquake

The DBE for the CBF site is assumed to be of sufficient magnitude to cause major damage to of the building. A site-specific evaluation can demonstrate that a beyond DBE and building collapse are not credible event.

Building damage in the DBE is accompanied by widespread failure of process vessels and piping. Organic solutions are spilled to the floor where fires result from various sources. Storage racks containing HEU cans or polyethylene bottles are damaged by seismic shaking as well as falling debris. This results in spillage of powders and liquids. A criticality can occur due to loss of safe spacing or due to aqueous or organic solutions reflecting neutrons into a layer of uranyl nitrate solution.

In the aftermath of such a large earthquake most emergency services, such as firefighting, are overburdened and may not be available for the CBF. The risk of spills, fires, and criticalities is great enough that this accident scenario can bound

process-related accidents and is therefore carried through for further analysis in Section 7.4.

7.2.2 Tornado

It is assumed that the DBT severely damages the exterior walls of the facility. Most damage occurs from missiles, such as pieces of pipe, and debris that the tornado picks up and propels through the air.

7.2.3 Straight Wind

A straight wind should be considered as an external initiating event. This can damage the buildings and some equipment, and possibly injure onsite personnel. The consequences, however, are lower than those caused by a tornado. Thus, the straight wind scenario is not a bounding scenario.

7.2.4 Flood

The DBF is assumed to be of sufficient magnitude to disrupt the perimeter of the CBF and cause water, under force, to contact the process equipment and materials. Process equipment may be damaged causing HEU dispersal into the building environment. Water may mix with HEU in potentially critical configurations.

7.2.5 Aircraft Crash

An aircraft crash is considered a bounding accident initiator because a crash of a large aircraft can: 1) penetrate a building wall or roof, 2) generate flying projectiles and missiles from building debris, building equipment, and aircraft debris, and 3) engulf a portion of the interior of a building in an aircraft fuel-fed fire. Although the local damage can be considerable, structural damage is expected to be much greater in the DBE. The exposed uranium within the building is in diverse locations, so it is unlikely that more uranium will be exposed to an external flame source in the aircraft crash than the DBE.

A crash that penetrates any HEU storage vault area can expose the HEU in the storage arrays to both severe impact, crushing, and fuel fire accident environments. Although a criticality is unlikely, a somewhat larger airborne uranium source term due to the fuel-fed fire burning of uranium metal can occur. On the other hand, the vault is a hardened structure that presents a very small cross section for an aircraft impact.

Because a much more likely DBE probably bounds the consequences of any aircraft strike (except perhaps a direct hit by a large aircraft on the vault, and even in that

case, the radiological consequences are not severe), the aircraft crash may be dismissed from further analysis.

7.2.6 Truck Crash

No significant offsite consequences can result from any reasonable truck crash at the CBF.

7.2.7 Nuclear Criticality

Based on reviews of typical operating practices in facilities similar to the CBF and of the criticality safety literature, there is a considerable margin of criticality safety for operations in the CBF. However, multiple critical masses of HEU powder and solution within the building do not allow a criticality (while a low probability event) to be ruled out.

7.2.8 Process Related Accidents

Accidents that are considered as candidates for producing bounding releases of radioactivity from process related accidents are fires, explosions, nuclear criticality, and improper installation of the off-gas filter on the fluidized bed reactor vessel. Accidents that can produce bounding releases of hazardous chemicals are HNO_3 and sodium hydroxide (NaOH) reactions.

Fires involving uranium metal in process, combustible waste, uranium-bearing organic solutions, and the baghouse are possible. However, the organic solution fire and filter fire can be the most significant for the following reasons:

- The quantity of metal available for combustion in process and in wastes is small relative to the total facility inventory.
- The typical airborne release (ARF) fraction for metal fires is relatively small (10^{-4} to 10^{-5}) compared to other accidents (e.g., 3×10^{-2} for uranium oxide powder suspension).
- The relative quantity of combustible waste, that is outside of containers and available to be involved in a fire, should be small.

The consequences of sequences of events leading to a red oil explosion are bounded by the organic solution fire.

A typical filter fire is significant because the air exhausted from the filter area (i.e., baghouse) flows directly to atmosphere with no filtration. If this accident were

initiated by the DBE, the consequences would be less severe because the exhaust fans would not be operational. Thus, the filter fire with continued exhaust flow can be a credible process accident.

Because significant quantities of hazardous chemicals are stored outside of the CBF and present a direct hazard to other onsite personnel, releases from the HNO₃ and NaOH tanks should be considered. It is likely, however, that the only credible mechanism for significant simultaneous releases of these chemicals is the DBE.

7.3 SELECTION OF BOUNDING ACCIDENT SCENARIOS

All the accident scenarios that are considered potentially bounding can be initiated by the DBE. Therefore it is concluded that the DBE results in the worst-case atmospheric release of radioactivity and/or hazardous chemicals.

7.4 TYPICAL SOURCE TERMS

The bounding event for release of radioactive and/or hazardous chemicals is the DBE. This single event initiates all release scenarios described in the following subsections, with the exception of the fluidized bed exhaust filter event and the filter fire.

Specific values for releases are process and site-specific, and are not included here. Rather, the releases are identified. For each scenario described in the following subsections (other than nuclear criticality) all radioactivity that becomes airborne inside the building is released directly to the atmosphere because of building damage; i.e., the leakpath factor (LPF) is equal to 1.0.

7.4.1 Filter Fire

Accident Description. The major process exhaust from the CBF is filtered through bag filters and HEPA filters before being discharged to the atmosphere. Excess filtered material from the bag filters falls into traps below the filters. In this accident, a fire occurs which releases all the uranium in the bag filters, traps, and the HEPA filters to the atmosphere in a matter of minutes.

Energy Source. The energy sources for this accident are the uranium-containing dust, the wool bag filters, the paper HEPA filters, and the Lucite traps. All of these are combustible. An ignition source is assumed.

Key Assumptions.

1. An ignition source exists.
2. Temperature detectors fail to close the dampers and activate fire extinguishing system.
3. The exhaust fans continue to operate.
4. All of the material in the traps and bags and on the HEPA filters is assumed to become airborne.

Release Location. The release location is at the top of the filter location stack.

Source Term. Some bag filters can contain up to 1 kg HEU each. Any HEU that is released is assumed to be released as U_3O_8 particles.

The direct release (DR) is 1.0 because the accident involves direct release of material from primary confinement. The amount of material that becomes airborne, however, is significantly less than the total amount.

7.4.2 Nuclear Criticality

Accident Description. Storage racks containing multiple critical masses of uranium powder and uranyl nitrate solution are damaged directly by seismic shaking and indirectly by falling debris. Safe spacing is lost and moderators added as water from the fire system or organic solutions resulting in the possible formation of one or more critical assemblies. Although this accident is not likely due to administrative controls, the limited use of metal storage racks, and the use of geometrically-safe containers, it is also possible to postulate a criticality event due to either mishandling of HEU-bearing solutions or equipment failure.

Energy Sources. If the event is initiated by the DBE, the energy sources are seismic shaking and falling debris.

Key Assumptions.

1. In an accidental criticality, it is assumed that 1×10^{19} fissions occur prior to reaching a stable, subcritical condition. This total is comprised of an initial burst of 1×10^{18} fissions followed by repeated bursts of 1×10^{17} fissions over an 8-h period as liquid is assumed to be boiled from a solution system.

2. Pools of spilled uranyl nitrate appear unlikely to collect in critical dimensions because the absence of floor drains allows spreading over large floor areas resulting in large surface-to-volume ratios and high neutron leakage. However, several loose polyethylene bottles containing HEU may form critical configurations. The same can happen with other forms of HEU stored in cans.
3. Although most of the critical arrays that may be formed by the DBE are likely to be dispersed by the initial fission bursts, the occurrence of secondary bursts cannot be entirely ruled out. Further, the total number of criticalities cannot be predicted. Therefore, it is assumed that the total fission yield following DBE-induced criticalities is 1×10^{19} occurring within a 2-h period.

Release Location. The fission products from a nuclear criticality are released at ground level.

Source Term. Typical source terms (shown in Table 7.4) are taken from NRC Regulatory Guide 3.34.

7.4.3 Natural Phenomena

Accident Description. The structural resistance of the CBF to natural phenomena must be evaluated. It is assumed that damage to the building is credible given a DBE, DBT, or DBF. Under this condition, the following impacts on the CBF are considered credible either individually or as a whole:

- Toppling containers not permanently fixed due to vibratory motion
- Crushing and rupturing containers due to falling debris
- Repositioning fissile materials into potentially critical arrays
- Rupturing building piping and external tanks resulting in the release of uranium solutions, water (a neutron moderator), toxic gases, flammable gases, and toxic and reactive liquids
- Creating multiple fire ignition sources due to damaged electrical equipment and high temperature process vessels
- Providing a moderator for fissile materials

Table 7.4. Typical atmospheric source terms for criticality

Nuclide	Ci Produced	Ci to Atmosphere*
Kr-83m	1.6×10^2	1.6×10^2
Kr-85m	1.5×10^2	1.5×10^2
Kr-85	1.6×10^3	1.6×10^3
Kr-87	9.9×10^2	9.9×10^2
Kr-88	6.5×10^2	6.5×10^2
Kr-89	4.2×10^4	4.2×10^4
Xe-131m	8.2	8.2×10^2
Xe-133m	1.8	1.8
Xe-133	27	27
Xe-135m	2.2×10^3	2.2×10^3
Xe-135	3.6×10^2	3.6×10^2
Xe-137	4.9×10^4	4.9×10^4
Xe-138	1.3×10^4	1.3×10^4
I-131	8.7	2.2
I-132	1.1×10^3	2.8×10^2
I-133	1.6×10^2	40
I-134	4.5×10^3	1.1×10^3
I-135	4.7×10^2	1.3×10^2

Release time: 0-2 h

*Building LPF = 1.0; ARF = 0.25 for I, 1.0 for others

Energy Sources. Most released materials are at ambient temperature. Energy sources include heats of combustion associated with uncontrolled chemical reactions and energy release associated with nuclear criticality.

Key Assumptions. Although specific combinations of effects of the DBE due to specified partial or complete building collapse accidents cannot be listed with any degree of completeness, the overall effects of this event type can be bound. The procedure used was to consider the effects on each MAR individually. The total source term was obtained by summing the individual releases for each material type. The following assumptions were made in this analysis:

1. Uranium Metal in Process - 10% of the total MAR is assumed oxidized (DR=0.1). For oxidation of uranium metal under turbulent conditions, the ARF is 1×10^{-3} and the respirable fraction (RF) is 0.6 .
2. Uranium Oxide Powders - Spill of 10% of total MAR from an average height of <3 meters is assumed (DR = 0.1). In addition, the material not initially suspended is subject to aerodynamic resuspension for 24 (DR = 0.9). The initial spill results in an ARF of 2×10^{-3} with an RF of 0.2. The aerodynamic resuspension rate results in an ARF of 8.6×10^{-5} (based on a resuspension rate of 1×10^{-9} /sec for 24 h) with an RF of 1.0. This resuspension rate assumes the fallen debris limits the air flow velocities over a majority of the spilled powder.
3. Uranium Nitrate Crystals - Above assumptions for powders applied to an assumed 10% of MAR with particle diameters sufficiently small to allow suspension. The 10% factor was applied to the RF yielding values of 0.02 and 0.1, respectively, for spills and reentrainment.
4. Non-flammable Uranium Solutions in Process Tanks and Piping - Release of 100% of MAR from an average height of <3 meters creating a mist is assumed (DR = 1.0). This approximation bounds the fraction which may be suspended due to evaporation and the possibility of pressurized releases of some small fraction of tanks due to crushing. The ARF for this release is 1×10^{-4} with an RF of 0.5.
5. Non-flammable Uranium Solutions in Polyethylene Containers - 50% of the MAR in polyethylene containers is assumed to leak and evaporate (or be resuspended) over 24 h in part due to heat inputs from fires (DR = 0.5). In addition, 2% of the containers are assumed to be crushed, ejecting the liquid under pressure (DR = 0.02). The ARF and RF for resuspension of liquids are 8.6×10^{-7} (based on a resuspension rate of 1×10^{-11} /sec for 24 h) and 1.0. For pressurized releases of liquids, the ARF is 1×10^{-4} and the RF is 1.0 .

6. Flammable (Organic) Uranium Solutions - Complete release, ignition, and combustion of the liquid solutions is assumed (DR = 1.0). Burning a large volume of a mixture of flammable and aqueous liquids containing dissolved uranium results in a ARF of 3×10^{-2} with a RF of 1.0. Release and burning of organic and inorganic uranium solution mixtures is discussed in Subsection 7.4.4.
7. Combustible solids contaminated with uranium are assumed to be completely oxidized. The combustible solids are modeled as cellulosic material assuming the combustible solids are principally contaminated paper. The ARF and DR for this release are 5×10^{-5} and 0.5.

In addition to the suspension of the radioactive materials discussed above, other accidents are assumed to occur due to the building collapse in the same time frame. These accidents include release and mixing of the HNO₃ and NaOH tank inventories from the exterior storage tanks (Subsection 7.4.5).

Release Location. All releases are at ground level.

Source Term. Based on the MAR quantities and the assumptions and empirical suspension and respirable size fractions previously discussed, the total quantities of the hazardous materials suspended in the air due to postulated major building damage can be estimated. These estimates will yield the material-specific source terms for the building damage accident. Once suspended, the various uranium compounds react with oxygen and water vapor at high temperature (due to postulated fires) resulting in a final suspended mixture of compounds. The resulting source term is HEU mostly in the form of U₃O₈ powder (also from a solvent extraction fire). The additional source terms resulting from a postulated nuclear criticality are summarized in Table 7.4.

7.4.4 Solvent Extraction Fire

Accident Description. In the recovery and purification operations, uranium is recovered from uranyl nitrate solutions in an alternating series of purification and volume reduction steps followed by a series of chemical conversions that consolidate the uranium in the form of uranyl nitrate solution. A two-step purification is achieved by the use of two solvent extraction unit operations in series. In the primary extraction system, the HEU in the uranyl nitrate solution is extracted by the dibutyl carbitol solvent. In the secondary extraction system, the product stream from the primary extraction system is extracted by TBP in an N-dodecane (or kerosene) diluent.

A fire is postulated to occur at the bottom of one of the secondary extraction columns due to a leak of TBP/diluent that ignites as a result of the DBE. The burning pool of organic material spreads to the remainder of the secondary extraction system. The heat generated by the burning pool causes the remaining secondary column to leak and add more organic material to the burning pool. The fire eventually propagates to the primary extraction system via the burning pool and the various feed and product tanks located on higher levels via a "chimney" effect through the openings where the columns are located. As the conflagration spreads, the nearby uranyl nitrate storage tanks also leak when their sight glasses crack or their gaskets burn. There is no automatic fire suppression system to prevent the spread of the fire.

Energy Source. The energy source for this accident is provided by the burning organic material. The dibutyl carbitol can also ignite after the fire propagates to the primary extraction system.

Key Assumptions.

1. The total inventory of combustible liquids is ignited.
2. No fire suppression (either automatic or manual) is available to prevent propagation of the fire to the primary extraction system and to other storage tanks located in the area.
3. The heat from the fire causes the concentrated aqueous uranyl nitrate solutions to evaporate at the same rate that the organic solutions are burning. Empirical data for fires involving aqueous/organic uranium solution mixtures suggests that this can occur. The uranium ARF used for this accident is appropriate for burning aqueous/organic mixtures.
4. All columns and tanks are filled to maximum capacity at the time that the fire occurs.

Release Location. The combustion products are released at ground level following an earthquake.

Source Term. HEU is present in organic solutions in various columns and tanks in the solvent extraction area. Additional HEU is present in uranyl nitrate solutions. This entire inventory is assumed to be the MAR. The DR is assumed to be 1.0 because the heat generated by the fire causes damage to all columns and tanks. The ARF for burning large volumes of nonvolatile liquids is 0.03. The RF is 1.0. The LPF is 1.0 because there is no filtration.

7.4.5 HNO₃ and NaOH Releases

Accident Description. There is a high concentration HNO₃ storage tank and an NaOH storage tank. These may be located in the same area. Should there be major leaks in lines or valves due to the DBE, substantial quantities of HNO₃, NaOH, or both could be spilled outside the building. The bounding accident is a spill of large quantities of HNO₃ and NaOH that react with sufficient heat generation to result in significant quantities of airborne HNO₃.

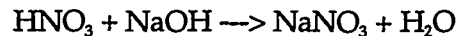
Energy Sources. The HNO₃ and NaOH are at ambient temperature. The only significant energy source is the heat of reaction of HNO₃ and NaOH.

Key Assumptions.

1. The entire contents of the HNO₃ and NaOH tanks are spilled.
2. The structural integrity of the curbing around the tank pits is compromised such that significant mixing occurs.

Release Location. The release location is outside, at ground level.

Source Term. The source terms are 30% HNO₃ and 20% NaOH. These chemicals react violently according to the reaction:



The heat of reaction is sufficient to result in significant quantities of suspended, unreacted HNO₃ vapor and mist.

8. INTERSITE TRANSPORTATION

The quantities of material to be shipped are summarized in Table 8.1 for UNH blending.

If HEU metal is shipped to the CBF, each SST shipment will hold approximately 1728 kg. For 10 MT of feed material, six SST shipments per year, or approximately one SST shipment every two months will be required.

If natural uranium oxide (U_3O_8) is shipped to the CBF, each truck shipment is assumed to hold 11 MT. For 165 MT of U_3O_8 , 15 truck shipments per year, or about one truck shipment per month will be required.

If 4% assay UNH crystals are shipped from the CBF to a commercial fuel fabricator, each truck load will hold 4.5 MT. This is based on 50 approved containers per truck, each containing approximately 90 kg of UNH crystals. For 316 MT of UNH crystals, 70 truck shipments per year or approximately six truck shipments per month will be required.

Table 8.1. Intersite transportation data - UNH blending

Data	Transported Material		
	Input Materials		Output Material
	Blendstock	HEU Feed	
Type	NU	HEU	LEU
Potential origin	Hanford, WA Paducah, KY Portsmouth, OH	Oak Ridge, TN	Oak Ridge, TN Aiken, SC Lynchburg, VA Erwin, TN
Form	Oxide - U ₃ O ₈	Metal	UNH crystals
Chemical composition	Pure 0.711% assay	Impure metal with >95% uranium (50% assay avg.)	UNH, pure 4% assay
Annual quantity	165 MT (140 MT NU)	10 MT	316 MT (150 MT LEU)
Data	Packaging & Shipping		
	Input Materials		Output Material
	Blendstock	HEU Feed	
Type	Metal Box, DOT-7A, Type A	Drum, Type BF	Drum, Type AF
Certified by	DOT/DOE	DOE	NRC
Identifier	Capital Industries Model S-0510-0823	ES-2	BU-7 NRC 9019
Package weight	680 kg	200 kg	Unknown
Material weight/package	2,200 kg (U ₃ O ₈)	36 kg	90 kg
Packages/year	75	278	3,511
Packages/truck	5	48*	50
Trucks/year	15	6	70
Potential destination	Oak Ridge, TN Aiken, SC Lynchburg, VA Erwin, TN	Oak Ridge, TN Aiken, SC Lynchburg, VA Erwin, TN	Fuel fabricator

* Packages per SST, one SST per truck.

9. ACRONYMS, ABBREVIATIONS, AND INITIALISMS

ALARA	As low as reasonably achievable
ARF	Airborne release fraction
ASTM	American Society for Testing and Materials
CBF	Conversion and Blending Facility
Ci	Curies
DBE	Design basis earthquake
DBF	Design basis flood
DBT	Design basis tornado
DOE	Department of Energy
DOT	Department of Transportation
DR	Direct release
DU	Depleted uranium
EDE	Effective dose equivalent
EEO	Equal Employment Opportunity
EIS	Environmental Impact Statement
gal	Gallons
h	hour
HC	Hazard category
HAZ	Hazardous waste
HEPA	High-efficiency particulate air
HEU	Highly enriched uranium
HNO ₃	Nitric acid
HVAC	Heating, ventilation, and air conditioning
kg	Kilogram
L	Liter
LEU	Low enriched uranium
LLW	Low-level waste
LPF	Leak path factor
LWR	Light water reactor
m ³	Cubic meters
MAA	Material Access Area
MAR	Material at risk
MIX	Mixed waste
mrem	millirem
MT	Metric ton
MW	Megawatt
MWh	Megawatt hour
NaOH	Sodium hydroxide
NRC	Nuclear Regulatory Commission
NU	Natural uranium
PEIS	Programmatic Environmental Impact Statement

PIDAS	Perimeter Intrusion Detection and Assessment System
psia	pounds per square inch absolute
RCRA	Resources Conservation and Recovery Act
RF	Respirable fraction
SAN	Sanitary waste
scf	Standard cubic feet
SNM	Special nuclear material
SST	Safe secure trailer
TBP	Tributyl phosphate
U	Uranium
UF ₆	Uranium hexafluoride
UNH	Uranyl nitrate hexahydrate
UO ₂	Uranium dioxide
U ₃ O ₈	Triuranium octoxide
USEC	United States Enrichment Corporation
VOC	Volatile organic chemical

Appendix A: Blending Assumptions and Limitations

As described in Section 1.1, the primary mission of the CBF is to destroy the weapons capability of surplus HEU by blending with a lower ^{235}U assay uranium material to achieve a level below 20% ^{235}U . In several cases the blending will be carried to a final assay of 4.0% ^{235}U in order to utilize the product as LWR fuel. In cases where the surplus HEU is not suitable for LWR fuel use, because of excessively high concentrations of undesirable minor uranium isotopes (^{234}U and ^{236}U), the HEU will be blended down to 0.9% ^{235}U for long-term storage or disposal as waste. In all cases, the reduction of assay is irreversible.

Five technology options are considered in EIS documents for the disposition of surplus HEU by: (1) U-metal blending with an oxide waste product, (2) UF_6 blending with a UF_6 product suitable for LWR fuel fabrication, (3) UNH blending with a UNH crystal product suitable for LWR fuel fabrication, (4) U-oxide blending with an oxide product suitable for LWR fuel fabrication, and (5) UNH blending with an oxide waste product. This appendix lists, in Table A.1, key assumptions used in the process descriptions for the five blending options. A comprehensive logic block flow diagram showing the decisions involved in processing different HEU feed materials, using all five blending options, is shown in Figure A.1.

Any one of the five options can be utilized for uranium disposition. Metal blending or UNH blending with an oxide waste product, however, will not be considered if the resulting product is intended for LWR fuel. Fuel fabricators generally receive LEU as UF_6 from enrichment plants, and that form would be their preference. Either LWR-fuel grade UNH crystals or LWR-fuel grade U_3O_8 would be probably their second choice. In the EIS documents, the metal blending and UNH blending methods that produce oxide waste apply only to surplus HEU which is determined to be unsuitable for LWR fuel. In these cases, the blended product goes into long-term storage or is disposed of as waste.

On the other hand, UF_6 blending is practical only if the product is intended for LWR fuel rather than a waste product. For UF_6 to be considered for long-term storage or disposal as waste, its conversion to an oxide is required. A potential negative factor with using UF_6 is that none of the surplus HEU is currently in UF_6 form and conversion to UF_6 requires the construction of new facilities.

Oxide blending with a pure oxide product and UNH blending with a pure UNH crystal product are applicable for both LWR fuel production and preparation of material for long-term storage or disposal as waste. It may be possible for the fuel fabricators to accept limited quantities of blended LEU as either UNH crystals or oxide, which they can process through their scrap recovery lines. Table A.2 summarizes the characteristics of both the HEU and the low assay diluent associated with each blending option and intended product.

Surplus HEU may exist in various chemical and physical forms with different chemical and isotopic impurities. Certain technological or economic factors may favor one of the five options for one batch and another option in other cases. No one option may prove to be economically viable for disposition of the entire surplus HEU inventory.

Table A.1. Assumptions for surplus HEU blending

-
- Chemical and isotopic analysis of discrete batches of surplus HEU should enable advance determination of whether the material can be blended to produce marketable LWR fuel or must be blended for long-term storage/waste disposal.
 - Surplus HEU which is determined suitable for LWR fuel use shall be blended to a final product assay of 4.0% ²³⁵U.
 - Surplus HEU which is determined unsuitable for LWR fuel use shall be blended to a final product assay of 0.9% ²³⁵U.
 - The 4.0% blended product for LWR fuel use shall be provided in the form of pure UF₆, UNH crystals, or oxide that comply with material standards.
 - Blending as metal will only be considered for surplus HEU metal and alloy that is not suitable for conversion to LWR fuel.
 - The 0.9% blended product for long-term storage/waste disposal shall be provided in the form of oxide.
 - Blending as UF₆ shall not be considered for any surplus HEU which is determined unsuitable for LWR fuel.
 - For each blending option, the annual process capability is defined by the requirement to blend up to 10 MT of surplus HEU at an average assay of 50% to a final product assay of 4.0%. (This same product mass throughput rate shall also apply if the blended product is 0.9%; in this case a lesser HEU consumption would result.)
 - Capability for purification of the incoming HEU stream using solvent extraction of UNH solution shall be provided except in the case of metal blending, which is applicable only for long-term storage/waste disposal.
 - Adequate supplies of low assay diluent are available in appropriate chemical forms, with the following restrictions: (a) if LEU diluent is used, it is only available as UF₆; (b) if NU diluent is used, it is available either as UF₆ or as oxide; (c) if DU diluent is used, it is available as UF₆, oxide, or metal.
 - No purification will be required for the incoming low assay diluent stream.
-

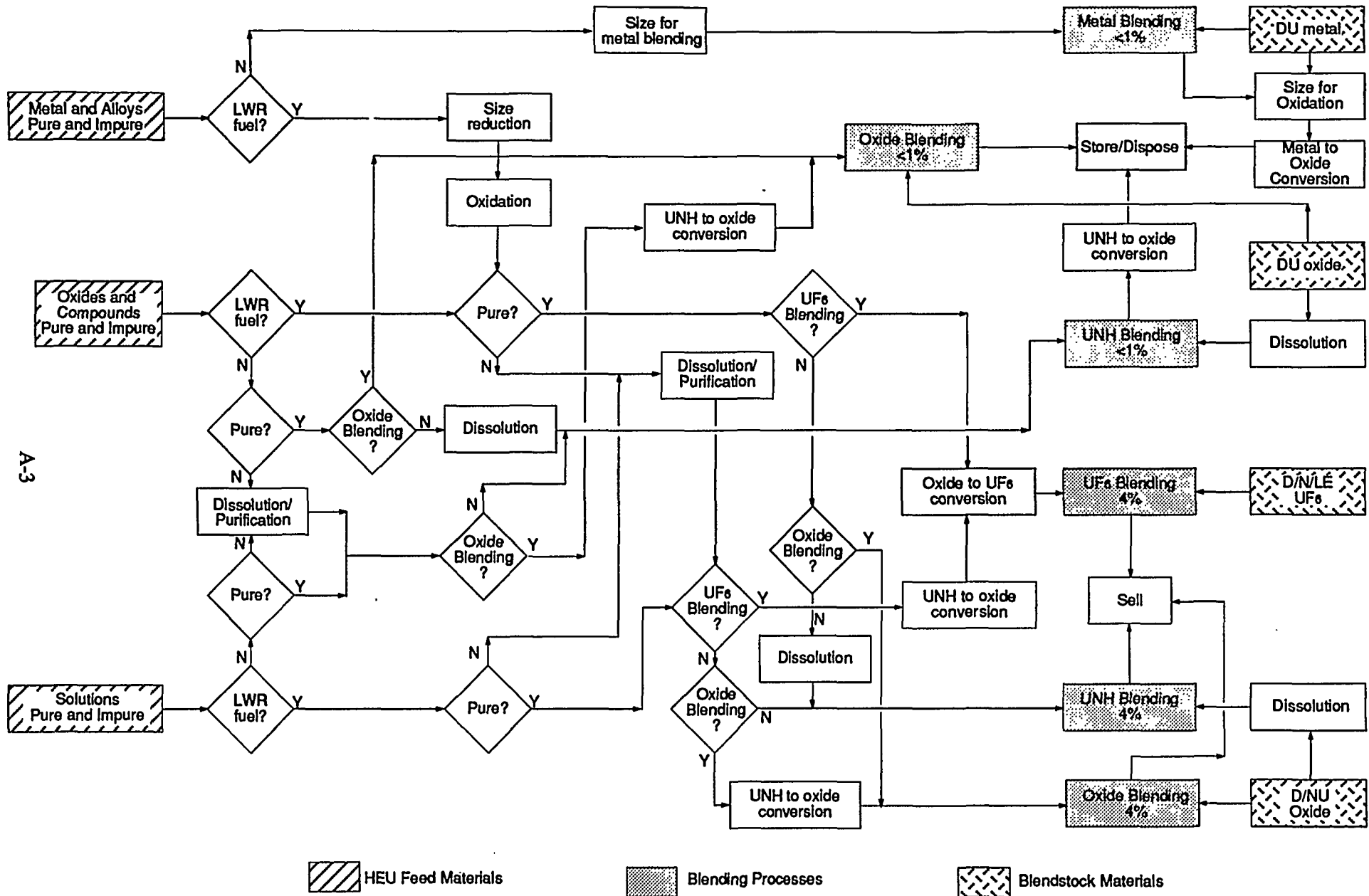


Fig. A.1 Overall blending logic diagram.

Table A.2. Feed streams for various disposition options

Disposition Option	Reasonable Types of Surplus HEU Feed Streams	Reasonable Types of Diluent Uranium Feed Streams
Blending as metal for storage or disposal	<p>Metal</p> <ul style="list-style-type: none"> - all concentrations of ^{234}U or ^{236}U - all HEU assays - alloyed or unalloyed - all levels of chemical impurities 	<p>Metal</p> <ul style="list-style-type: none"> - DU - all concentrations of ^{234}U and ^{236}U - any alloy available - all levels of chemical impurities
Blending as UNH for storage or disposal	<p>Oxide, UNH, & miscellaneous compounds</p> <ul style="list-style-type: none"> - all concentrations of ^{234}U or ^{236}U - all HEU assays - all levels of chemical impurities 	<p>Metal & oxide</p> <ul style="list-style-type: none"> - DU - all concentrations of ^{234}U and ^{236}U - any alloy available - all levels of chemical impurities
Blending as oxide for LWR fuel	<p>Metal & oxide</p> <ul style="list-style-type: none"> - low concentrations of ^{234}U and ^{236}U - all HEU assays - unalloyed metal - all levels of chemical impurities 	<p>Oxide</p> <ul style="list-style-type: none"> - DU or NU - low concentrations of ^{234}U and ^{236}U - low levels of chemical impurities
Blending as UNH for LWR fuel	<p>Metal, oxide, and UNH</p> <ul style="list-style-type: none"> - low concentrations of ^{234}U and ^{236}U - all HEU assays - alloyed or unalloyed metal - all levels of chemical impurities 	<p>Metal & oxide</p> <ul style="list-style-type: none"> - DU or NU - low concentrations of ^{234}U and ^{236}U - unalloyed metal - low levels of chemical impurities
Blending as UF_6 for LWR fuel	<p>Metal, oxide, UNH, & UF_6</p> <ul style="list-style-type: none"> - low concentrations of ^{234}U and ^{236}U - all HEU assays - alloyed or unalloyed metal - all levels of chemical impurities 	<p>UF_6</p> <ul style="list-style-type: none"> - DU, NU, or LEU - low concentrations of ^{234}U and ^{236}U - low levels of chemical impurities

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