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DESIGN CRITERIA FOR AN HTGR REFERENCE FUEL REPROCESSING PLANT

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DESIGN CRITERIA FOR AN HTGR REFERENCE REPROCESSING PLANT

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ABSTRACT

Design criteria are given for a conceptual reprocessing plant capable of processing HTGR-type graphite-based fuel. The single-purpose plant is designed to reprocess 260 metric tons of fuel per year consisting of HTGR reference-type and Fort St. Vrain fuel plus a small amount of Peach Bottom fuel. The design incorporates a burn-leach type headend, separate modified Acid-thorex flowsheets for solvent extraction recovery of the heavy metals from both the fertile and fissile particles, and denitration of both the U-233 and U-235; in addition, extended storage of thorium as a nitrate solution is provided, high- and intermediate- level wastes are converted to granular solids in a fluidized-bed calciner and stored indefinitely on site, and low-level waste is essentially completely decontaminated. These design criteria will be used by an Architect-Engineer to prepare a capital cost estimate for the conceptual plant. The cost estimate will be part of an HTGR Reference Plant Study to develop a reprocessing charge for those HTGR fuels that will be received by the AEC for financial settlement.

SUMMARY

In view of the fact that there are no commercial reprocessors for fuel from High Temperature Gas-cooled Reactors (HTGR), the AEC will make financial settlement for this fuel. Because of this, Idaho Nuclear Corporation was requested by the AEC Division of Production to prepare an HTGR Reference Plant Study as a part of the development of credible processing costs This report, the first part of the study, specifies the design criteria for a conceptual, single-purpose, self-contained plant for reprocessing up to 260 metric tons of heavy metals per year. These design criteria will be used by an Architect-Engineer to prepare a conceptual design of the plant and a capital cost estimate.

The conceptual plant is capable of processing various types of HTGR fuel, but the HTGR reference and Fort St. Vrain fuels with a small amount of Peach Bottom fuel now appear to be the most likely fuels requiring financial settlement. The reference fuel is assumed to contain a SiC-coated, two-particle fuel system. Each fuel particle consists of an inner uranium and/or thorium fuel particle with successive coatings of buffer carbon, SiC, and pyrolytic carbon. Before burnup, fertile particles contain thorium, and fissile particles contain uranium-235. The latter fuel particles, however, can also contain thorium and U-233 Thus, after burnup, both types of particles may eventually contain mixtures of thorium and uranium-233 as well as uranium-235 in the fissile particles.

Proven processes and those that appear to be the most highly developed and promising are specified for the conceptual plant and are depicted schematically in Figure 1. A burn-crush-leach process is assumed for use in reclaiming the heavy metals from the fuel; first, bulk graphite is burned from the cuushed fuel blocks in a fluidized-bed burner, the fuel particles are removed continuously from the bed and are screened prior to separately crushing the two types of particles. The inner buffer carbon coatings are then burned in a fixed bed burner and the heavy metals are leached from the particles. Two conventional-type solvent extraction systems using the modified Acid-thorex processes are assumed for use in separating and purifying the uranium and thorium. The two separate U-233 and U-235 streams are denitrated to UO_3 in fluidized-bed denitrators, and the thorium would be stored as a second-cycle-raffinate solution indefinitely pending a decision on further treatment.

The facilities envisioned for the self-contained commercial reprocessing plant

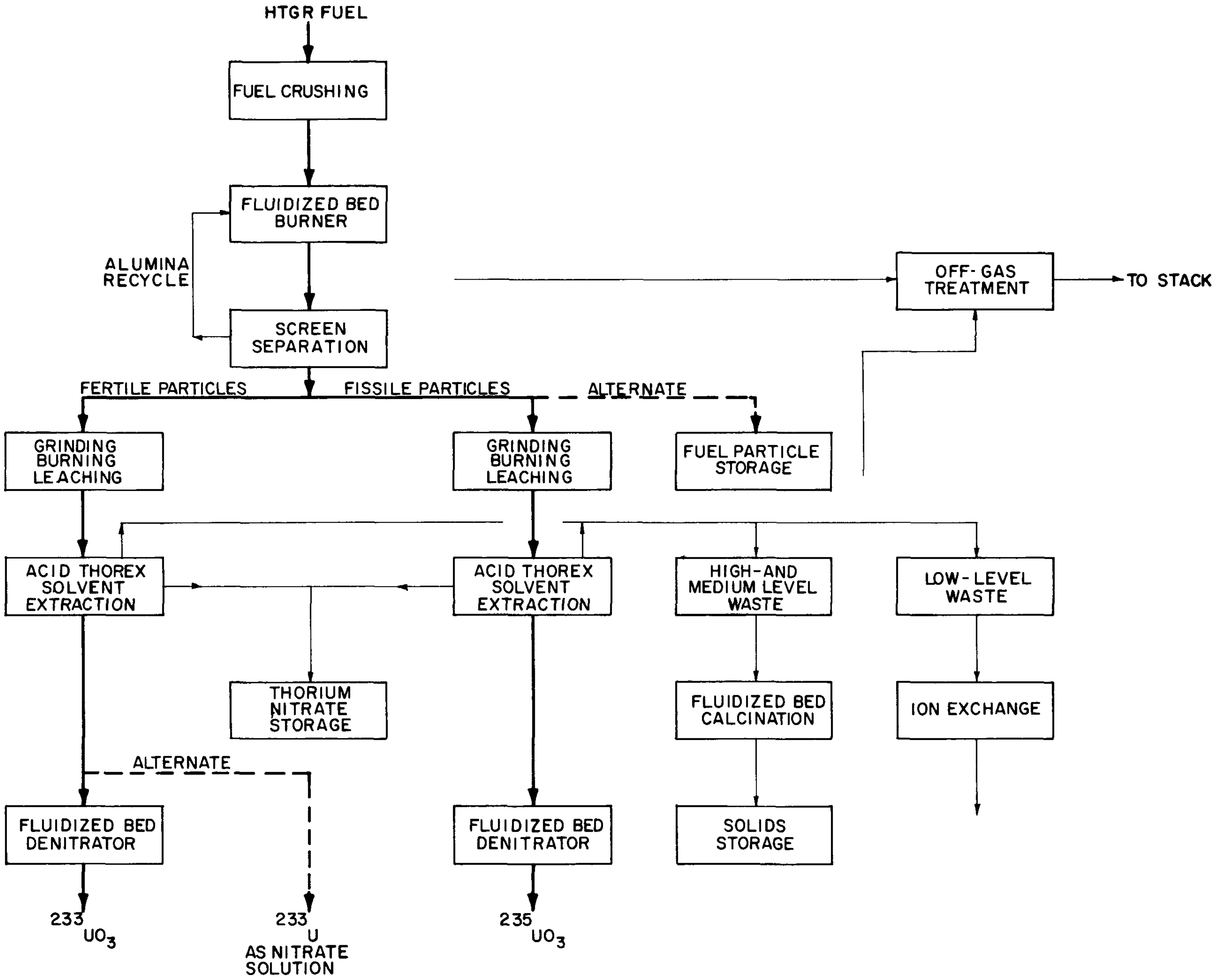

Figure 1. Simplified Block Flow Process Diagram

would consist primarily of a main processing building that would also incorporate various service facilities housing analytical and technical personnel, an administrative building, and a utilities building. The main processing building would incorporate an area for placing the dry fuel elements in storage containers, a storage area for the spent fuel, a headend process, solvent extraction and denitration processes for the uranium from the two types of fuel particles, and fluidized-bed waste calcination, ion exchange, and filtering processes for waste disposal. The administration building would incorporate the main management offices, the administrative and controller offices, medical and engineering offices, and a lunch room. The utilities building would contain the water, steam, air, and other similar facilities for the plant.

The capital cost estimate for the HTGR Reference Plant must be detailed enough to allow identification of the incremental capital associated with various alternative schemes, such as storing the fissile fuel particles or shipping U-233 as a solution. In addition, a short report and sufficient drawings must be provided Idaho Nuclear Corporation so that a knowledgeable person will be able to accurately estimate the number of operating and maintenance personnel required in the conceptual plant and also to estimate other pertinent costs necessary for a detailed present-worth-type economic analysis.

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I. INTRODUCTION

The Conceptual Plant Policy(1) announced in the Federal Register of March 12, 1957, allowed a commercial reactor operator to deliver spent fuel elements to the AEC for financial settlement if reasonably priced private reprocessing services were not available. The financial settlement involved charges for reprocessing (based on cost data for a conceptual plant), charges for conversion of the uranium to UF_6, as well as credits for the contained nuclear material in the spent metallic-clad fuel. This policy made it possible to identify the reprocessing cost for spent commercial fuels from light-water reactors. Analogous to this, a need now exists for similar cost data applicable to a conceptual plant capable of handling fuel from High-Temperature Gas-Cooled Reactors (HTGR) because there are no commercial processors for the graphite matrix fuels. Using cost data for a conceptual processing plant, the Government could establish fair charges for financial settlement and storage of HTGR fuel from this relatively new type of commercial reactor in the U.S.A. The new conceptual reference plant is to be a single-purpose, self-contained plant with a capacity of 260 metric tons per year of heavy metals from HTGR fuels.

All HTGR-type thermal reactors have adopted or are considering use of coated-particle fuel(2,3) because of its high-temperature and high-burnup capabilities. Gulf General Atomic, Incorporated, has designed the existing Peach Bottom Atomic Power Station, Unit No. 1, as well as the Fort St. Vrain Nuclear Generating Station now being built in Colorado; both use or will use coated-particle HTGR fuel. The reactors for these stations are based on the use of a gas coolant and graphite moderator. The coolant circulates through channels in the moderator in which the coated fuel particles are discretely distributed.

A modified thorium fuel cycle is presently being used for the HTGR fuels that would be handled in the conceptual reference plant. In this fuel cycle, fissile fuel particles containing primarily U-235 are used for achieving and sustaining criticality initially in the reactor; separate fertile fuel particles containing primarily Th-232 are used for conversion to U-233. The U-233 in turn sustains criticality as the U-235 is depleted. Eventually, when enough U-233 has been generated in the reactors and reclaimed, U-233 will be substituted for some or all of the U-235 in the fissile particles. Initially, however, the two types of particles will be in the fuel and they will have to be processed separately.

Since the HTGR fuel contains ceramic-coated particles and gross amounts of graphite, it requires a different type of initial treatment for reprocessing than do the more familiar metal-clad commercial and test reactor fuel. The head-end process, described in this report for use in the conceptual reference plant for HTGR fuel, consists of crushing and burning the graphite to isolate the coated fuel particles. The fissile and fertile particles would then be separated and crushed, followed by burning the inner buffer carbon coating and then recovering the heavy metals by leaching and solvent extraction in separate systems.

The purpose of this report is to define the design criteria necessary for an Architect-Engineer (A-E) to prepare a conceptual design for the HTGR Reference Plant and to determine its capital cost as part of an HTGR Reference Plant Study. The overall objective of the Reference Plant Study is to define the unit reprocessing charges for spent HTGR-type fuels in a conceptual commercial-type plant. Personnel of the Idaho Nuclear Corporation will use the capital costs generated by the A-E in calculating the unit reprocessing charge and the effect of a number of variables, such as throughput rate, on the charge. The capital cost estimate must be broken down into a number of categories, described in Section 7, so that the costs of particular processing steps needed for some fuels but not for others can be isolated.

The design criteria in this report are defined only to the extent believed necessary. It is intended that the A-E apply to this conceptual design its accumulated industrial experience and knowledge from similar projects. The chemical process to be assumed for the conceptual plant has been detailed with the use of flowsheets and descriptions, and some equipment has been described in detail because of its highly specialized nature and because of the immature state of technical development or the nuclear safety aspects that are involved. Other items, however, such as the building layout and specific equipment designs, have been left to the discretion of the A-E.

Equipment and process technology on which the conceptual plant are to be based ranges from proven technology to that requiring some extensive development work. The former category, of course, requires essentially no development effort, and it includes:

a. Acid Thorex solvent extraction process
b. Centrifugal contactors
c. Pulsed extraction-columns
d. Fluidized bed calcination (and off-gas cleanup) of product and aqueous wastes.

Varying amounts of pilot plant development effort[a] are required for the following:

a. Extent of SiC-coated particle breakage in the headend process
b. Life of sintered metal filters during extended use in calciners and burners
c. Extent of fuel particle segregation in a fluidized bed of alumina, fuel particles, and graphite
d. Design and operation of a fixed-bed-type of crushed fuel burner
e. Efficiency of separating reference-type fuel particles from each other and from alumina by screening
f. Effect of disposing of waste solvent in a waste calciner using the in-bed combustion process
g. Solids separation following the leaching operations.

Extensive development work may be required for the following:

a. Graphite burner design and operation
b. Burner off-gas cleanup
c. High-temperature storage of Purex-type waste calcine.

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[a] Some development work is now underway for the first two items.

2. GENERAL DESIGN CONCEPTS

This section covers generalities concerning the conceptual design of the HTGR Reference Plant; details of the various fuels, the conceptual process, and the conceptual design of major equipment pieces and buildings are given later in Sections 3, 4, 5, and 6, respectively.

2 1 TYPE OF PLANT AND PROCESS

The HTGR Reference Processing Plant is a conceptual plant that probably will never be built. For purposes of this study, it should be assumed that the plant will be located in an area similar to that of the National Reactor Testing Station (NRTS) in Southeastern Idaho. Thus, for siting and building criteria, hydrological,(4) geological(5), and meterological(6) data for the NRTS can be used.

In general, the processes and plant and equipment designs should be based on proven and on some advanced technology. Totally unproven schemes should not be considered simply because capital costs for such schemes would be highly speculative. Undoubtedly, many other headend, solvent extraction, and waste processing methods differing from those that are proposed could possibly be used for the HTGR fuel; however, all of the headend methods are in varying stages of development and none have been completely demonstrated. Clearly, however, the burn-leach process(7,8,9) is the most advanced headend process. Likewise, the fluidized bed waste calcination process(10) is the most advanced waste disposal method. Thus, the burn-leach headend process is specified in this study for the conceptual plant to prepare the fuel for solvent extraction, and the fluidized-bed calcination process is specified for disposal of high-and intermediate-level wastes. The processes and equipment for the reference plant are to be designed for processing primarily the HTGR reference and Fort St. Vrain fuels (described in the next section); however, the plant must also be capable of reprocessing Peach Bottom fuel, as well as other future HTGR-type fuels. This versatility will be possible only by keeping the design of the equipment, especially the fuel handling, storage, and headend, as general as possible. Minimum cost, however, is an extremely important goal.

The reference fuel is assumed to contain a mixture of SiC-coated fertile particles (thorium oxide) and SiC-coated fissile particles (uranium oxide) within a graphite block. Both types of spent fuel particles will contain gross amounts of fission products and both will be processed; alternatively, the fissile particles could be stored indefinitely. A maximum of ten percent of the fuel particles could be broken either in the reactor or during headend processing. Because of the size range of the various particles, broken particles will be present mainly in the fissile particle stream.

It is assumed that irradiated fuel will be delivered to the conceptual plant either by rail or truck transportation (after about 210 days of cooling)[a] in standardized casks holding a maximum of 50 elements. The dry fuel storage area should have a capacity for storing fuel elements equal to 60 days of operation at the design processing rate. The fuel should be easily transferable to the headend burn-leach process for cutting (if necessary), crushing, and burning of the bulk graphite in a fluidized bed of alumina. Following the burning operation, the two types of fuel particles (having different particle diameters) are separated from each other and from the alumina by screening. The two types of fuel particles are then separately crushed, burned, leached, and the leachate prepared for extraction of the thorium and uranium. After screening, the two fuel-particle streams follow separate paths to keep the U-233 as pure isotopically as possible.

A modified Acid Thorex(11,12) process is assumed for separation and purification of the thorium and uranium present in both types of reference fuel particles. A partition cycle is assumed necessary for leachate from the fissile particles and alumina if they are processed, since they both will undoubtedly contain Th-232. The uranium from both the fissile and fertile particles is denitrated in separate fluidized beds to a solid UO_3 product; alternatively, the U-233 could be left as a nitrate solution, if desirable, for fuel fabrication The thorium is stored as a nitrate solution for an indefinite period of time pending a decision on further treatment.

A plant life of 15 years and an on-line availability factor of 75 percent are assumed for the conceptual reference plant, which will be operated continuously. Some equipment, however, will have a shorter lifetime than 15 years; the lifetime of equipment should be estimated by the A-E so that accurate replacement costs for the equipment can be calculated The plant and equipment must be designed to pass the AEC licensing requirements.

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[a] To allow for the decay of Pa-233 to U-233.

2.2 GENERAL PHILOSOPHY

Generally accepted practices for radioactive systems are to be followed in plant and equipment layout, equipment design, construction, operation, and maintenance of the conceptual reference plant. Quality equipment, design, and workmanship are desired in the plant to minimize downtime

2 2.1 Plant Layout

It is envisioned that the plant would be composed of three main buildings, although it is possible that more or fewer might be used. The processing building could contain all of the radioactive processing equipment plus any other radioactive operations required, such as spent fuel storage, analytical, decontamination, and waste treatment, plus some office space. An administration building could contain the main corporation offices, reception and conference rooms, medical and first-aid offices, as well as a lunch room, a modest library, and a mail room. An "auxiliaries" building could house the various utilities such as air, water, and steam, and a storage area.

The layout of the main process building should take into consideration such factors as maintenance, analytical, operation, control, material flow, shielding, and contamination. Equipment should be grouped primarily by processing steps and shielding requirements. High-activity processes, such as the headend and first extraction cycle, should be shielded from each other and from the lower activity processes. Adequate spacing of equipment and piping should be maintained to allow efficient contact or remote maintenance and/or remote replacement.

2.2.2 Equipment Design

In general, equipment should be designed for simplicity of operation and maintenance. For instance, air lifts and steam jets are preferable for use in radioactive service to motor-driven pumps Essentially all of the equipment, piping, and instrument tubing in radioactive areas are to be fabricated of stainless steel. All equipment should be sized for continuous operation where applicable. Design criteria for major pieces of equipment are given in Section 5.

2.2.3 Maintenance

A combination of remote and contact maintenance can be used in the plant. Equipment with a high expected maintenance frequency should be either repairable or replaceable remotely; all other equipment should be designed for contact maintenance. Much of the conceptual equipment in the headend process will probably have a high maintenance frequency; either the worn parts of this equipment, such as crusher jaws, screens, and saw blades, or the entire piece of equipment should be remotely replaceable. Similarly, the graphite burners will require considerable maintenance and, therefore, should be designed for either remote or contact maintenance. If contact maintenance is employed, at least two shielded cells should be provided for the several required burners so that reprocessing will not be totally interrupted while a burner is being repaired. Provisions must be made so that cranes in radioactive areas can be repaired; one method is to provide a shielded airlock cell in which both the crane and replaceable equipment can be decontaminated and repaired by contact maintenance. Shielded windows and master slave manipulators should be provided as required for remote maintenance and replacement of equipment and also for remote processing operations that must be viewed. Criteria for maintenance facilities are given in Section 6.3.3.

2.2.4 Operations

A continuous mode of operating will be used in the plant. Remote operation of the headend and solvent extraction steps of the process must be employed because of the radioactivity associated with the solids and liquids. Once decontaminated of gamma and beta activity, the slightly alpha-emitting U-235 solutions or powder can be handled in hoods or glove boxes, respectively. Since U-233 is a moderate alpha-emitter, it must always be handled in glove boxes.

Simple mechanical devices (such as air-cylinders, air-operated valves and mechanical drives), as well as analyzers, instrumentation, and computers should be used where economical to reduce the cost of operations and to free operations personnel of repetitive, time consuming tasks. Simple chemical analyses, such as acid concentrations by hydrometer, etc , on non-radioactive solutions, will be made by operations personnel to minimize costs.

2.2.5 Instrumentation

Instrumentation and controls necessary for efficient and safe operation of the process are to be provided The operating control area should contain all of the control instrumentation and should be centrally located near the main process area.

2.2.6 Analytical

Analytical laboratories are to be centrally located and are to contain all of the facilities and equipment necessary to obtain a knowledge of the chemical composition of the process streams for accountability, nuclear safety, and process control. Sample stations will be provided to obtain the necessary process samples; the sample stations for radioactive solutions should be designed as part of the laboratory hot cell facilities where possible. This would eliminate lost time in transporting hot samples and decontaminating sample carriers. Where feasible, to speed operation and minimize analytical costs, in-line instrumentation should be used Design criteria for analytical facilities are given in Section 6 3.4.

2 2.7 Shielding

Concrete shielding of appropriate thickness, generally four feet, is to be used as the primary protection from radiation; however, lead can be used in locations such as transfer locks or to shield various cell penetrations. Shielding in the process building is to be adequate to protect plant personnel from radiation during normal operations The average dose rate at a distance of one foot from the non-radioactive face of a shielding wall shall not exceed 2.5 mrem/hr in areas where personnel will be located for 40 hr/wk (general working areas) and 10 mrem/hr in areas where personnel will be located for short periods of time daily (limited access areas)

The shielding thickness for the headend equipment, fuel storage and receiving, H extraction cycle, and calciner areas generally is to be four feet; for the first extraction cycle and H cycle solvent treatment areas, three feet; and for the second extraction cycle, solvent treatment, and between the various process areas, two feet. The estimated shielding requirements were based on the following assumptions: (1) shielding material would be magnetite concrete ($\rho = 3.29$ g/cm^3), (2) an air gap of two feet would be between a wall and any piece of equipment and between pieces of equipment, (3) an air gap of six feet would be between the top of equipment and the shielding in the headend, fuel storage and receiving, calciner and HA contactor areas, and (4) equipment would be grouped by various subprocesses, eg, burners, crushers-burner feed hoppers, stripper-HA extraction, etc.

Penetrations through shielding walls for doors, hatches, windows, tools, driveshafts, piping, ventilation ducts, etc , will be designed to provide shielding equivalent to the wall, as required

2.2.8 Ventilation and Contamination

Traffic flow and ventilation within the plant are to be designed to prevent the flow of contaminants from a high-concentration to a low-concentration area; health physics checkpoints should be located to serve areas of high contamination potential. The entire processing building will be kept under a slight vacuum to prevent any unfiltered leakage from the building. Access from the building will be through vestibules or normally cold areas that serve as buffer zones between the outside and areas of contamination within the building. Radioactive areas will be designed to be operated at a negative pressure, as compared to operating areas, with exhaust capacity adequate to insure that a linear velocity of at least 135 ft/min will be maintained at all times through any opening to the working areas.

2.2.9 Nuclear and Chemical Safety

Normally accepted radiochemical safety design practices are to be followed for protection of both personnel and equipment. Nuclear criticality will be controlled in process equipment and vessels by limiting mass concentrations or by designing geometrically safe systems, when feasible. Alternatively, soluble neutron poison could be added to solutions, or grids containing a nuclear poison (such as boron-stainless steel) can be designed into the equipment. Design criteria covering criticality are detailed in Section 5 for specific pieces of equipment.

2.2.10 Waste Disposal

The various gaseous waste streams arising during fuel reprocessing contain radioactive contaminants that must be removed to levels that permit safe environmental release. Process off-gas is passed through silica gel adsorbers to remove primarily ruthenium, then filtered through roughing and high-efficiency filters, and monitored before discharge via a 400-foot-high stack to the environment. Ventilation air from the cells is also filtered through both roughing and high-efficiency filters and then monitored before discharge. Discharge of gaseous and liquid wastes will be controlled to approximately one-tenth of existing AEC and Federal pollution regulations; low-level liquid waste can be dumped to the ground water after being stripped of essentially all radioactivity by ion exchange, if it meets these criteria. Intermediate and high-level liquid wastes will be solidified by the fluidized-bed calcination process and stored in underground vaults in small-diameter bins or pipes. Other bulk solid wastes that are radioactive will be packaged for on-site burial. Flowsheets for waste disposal are given in Section 4.5, and equipment descriptions are given in Section 5.

3. DESCRIPTION OF FUEL

On the basis of the foregoing general design concepts and specific design criteria in the following sections, the conceptual fuel reprocessing plant should be designed to process 260 metric tons of heavy metals from the HTGR reference fuel. In addition, the plant should also be capable of efficiently processing fuel from Peach Bottom and Fort St. Vrain reactors. The HTGR reference fuel is basically the same fuel proposed for the Fort St. Vrain reactor and amounts to greater than 95 percent of the fuel load assumed for the reference plant. This two-particle, SiC-coated system is expected to be the most difficult type of HTGR fuel to reprocess. Thus, most any type of HTGR fuel should be capable of being processed in the conceptual reference plant equipment.

After irradiation, the HTGR fuels will contain U-233 and small amounts of U-232, as well as Th-232, Th-228, U-234, U-235, U-236, U-238, and trace amounts of Pu. Uranium-233 is an alpha-emitter with a half-life of 1.62 X 10^5 years. Its specific activity is 9.51 X 10^{-3}Ci/g. Because of its low specific activity and the low gamma activity associated with the decay of U-233, the external radiation from it alone is negligible. However, in the production of U-233 in the reactor, some U-232 is also formed, the amount depending on reactor conditions. Uranium-232 has a half-life of 74 years and decays to Th-228 by alpha emission. The growth of all daughters of U^{232} is controlled by the 1.9-year half-life of Th^{228}. This chain of daughters is extremely gamma active. Although elimination of a large part of the gamma activity may be accomplished through chemical separation, regrowth is such that fuel fabrication operations would have to be completed in a matter of weeks and preferably days after separation if done under ordinary glove box conditions. Lawerence(13) has reported calculated dose rates from a 0.635-cm thick by 5.08-cm diameter U^{233} disk containing 20 ppm of U^{232} as follows:

Time after Separation	Dose Rates (R/hr at 1 cm)	
	U^{233} daughters	U^{232} daughters
1 day	0.0029	0.19
4 weeks	0.0032	0.37
32 weeks	0.011	3.2
10 years	0.15	14.0

Energies of the significant gamma emitting materials vary from 0.04 to 2.8 Mev. Approximately half of the dose rate is from the Tl^{208}, 2.26 Mev gamma. A discussion of the problems encountered in the handling of U^{233} has been presented previously by Arnold(14).

The reference HTGR fuel and several other fuels which the conceptual chemical processing plant must be capable of processing are described in the following paragraphs.

3.1 REFERENCE HTGR FUEL

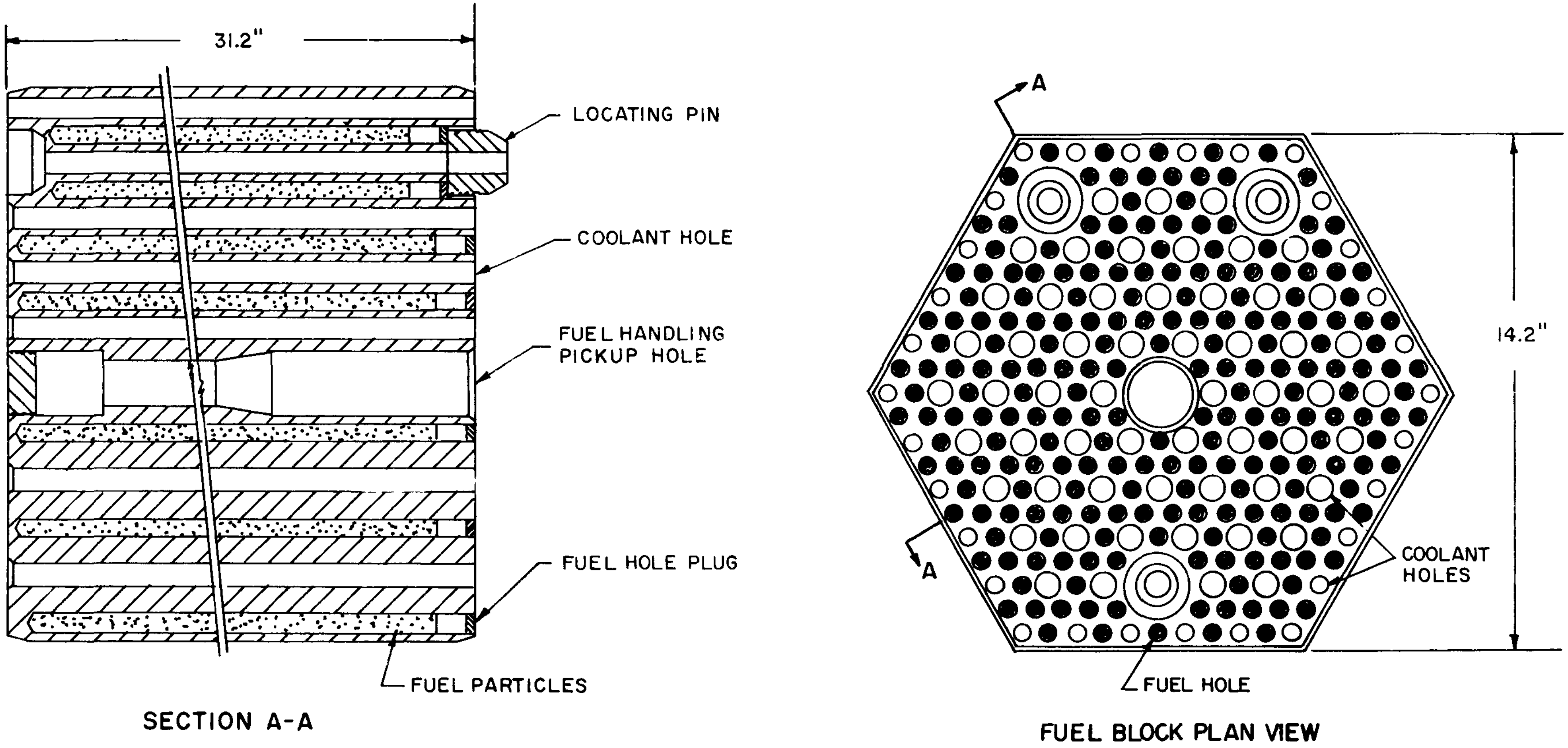
The reference HTGR fuel element, shown in Figure 3-1, consists of a hexagonal graphite block approximately 14 inches wide across the flats and 31 inches high. Coated particle fuel is packed into small vertical fuel channels dispersed within the hexagonal block elements. The fuel elements also contain vertical coolant passages in the form of numerous small vertical holes interspaced among the fuel channels. Three graphite dowels, for aligning the elements within a column in the reactor core, are located on the top face of each fuel block. An engagement hole at the center of each fuel element is provided for handling at the reactor.

The reference fuel consists of fuel kernels of high-enriched (93% U-235) uranium oxide in the fissile particles and fertile thorium oxide fuel kernels in the fertile particles. Both types of fuel kernels in the reference fuel will be coated with: (1) porous carbon surrounding the fuel kernel, (2) silicon carbide surrounding the porous carbon, and (3) pyrolytic carbon surrounding the silicon carbide.

Each fuel element will contain six burnable poison sticks approximately 30 inches long and 1/2 inch in diameter composed of boron carbide plus carbon. Detailed HTGR reference fuel data are given in Table 3-1.

3.2 FORT ST. VRAIN

The fuel elements proposed for the Fort St. Vrain Reactor (15,16) are of the same shape, size, and weight as the HTGR reference fuel. Several types of fertile and fissile particles containing the carbides or oxides of thorium, U-235, U-233, and various mixes of these materials have been proposed for the Fort St. Vrain fuel.



SECTION A-A

FUEL BLOCK PLAN VIEW

Figure 3-1. HTGR Reference Fuel Element

TABLE 3-1

HTGR REFERENCE FUEL DESCRIPTION

Length (in.)	31.22	
Width (in.)	14.17 (across flats of hex block)	
Fertile particles		
Diameter (μ)		
ThO_2 kernel	350	
With buffer carbon coating	410	
With SiC intermediate coating	430	
With pyrolytic carbon coating	610	
Weight at discharge (kg/element)		
Thorium		10.48
Uranium (primarily U^{233})		0.30
Fission products		0.41
Oxygen (oxides)		1.55
SiC Coating		0.87
Pyrolytic carbon and buffer carbon coatings		10.90
		24.51
Fissile particles		
Diameter (μ)		
UO_2 kernel	200	
With buffer carbon coating	260	
With SiC intermediate coating	280	
With pyrolytic carbon outer coating	400	
Weight at discharge (kg/element)		
Uranium (primarily U^{234} and U^{236})		0.15
Fission products		0.42
Oxygen (oxides)		0.08
Buffer carbon		0.30
Silicon carbide		0.36
Pyrolytic carbon		2.22
		3.53
Boron Carbide (kg/element)		0.15
Graphite fuel block (kg/element)		97.46
Carbon binder		4.94
Total weight of fuel at discharge (kg/element)		130.59
Cooling time (days)	210 (min.)	
Average burnup (MWD/tonne of actinides)	68,000	
Heat release (Btu/hr/element)		
90-day cooled	1700	
210-day cooled		
Fissile particle	390	
Fertile particle	380	
Total	770	

However, fuel elements for the initial core will probably contain fissile and fertile particles of uranium and thorium carbide microspheres, respectively. Both types of microspheres will be coated with the same material and in the same manner as the reference fuel. A ceramic burnable poison will be incorporated in the fuel element.

3.3 PEACH BOTTOM

Peach Bottom fuel elements(15,17)--which are 3.5 inches in diameter, 12 feet long, and weigh about 90 pounds--contain thorium carbide and uranium carbide microspheres which are coated with pyrolytic carbon and dispersed in a graphite matrix.

The fuel element, shown in Figures 3-2 and 3-3, consists of an upper reflector section, a fuel-bearing middle section, and a bottom reflector section. A long graphite sleeve extends from the upper reflector section to the bottom connector of the fuel element. A grappling knob at the top of the element is provided for handling purposes. Burnable poison compacts composed of zirconium diboride pressed into a graphite matrix are placed in hollow spines of some fuel elements. Burnable poison, Rh-103, is also present in the fuel compacts. Spent fuel elements will be received at the conceptual plant in aluminum canisters 4.5 inches in diameter by about 13 feet long.

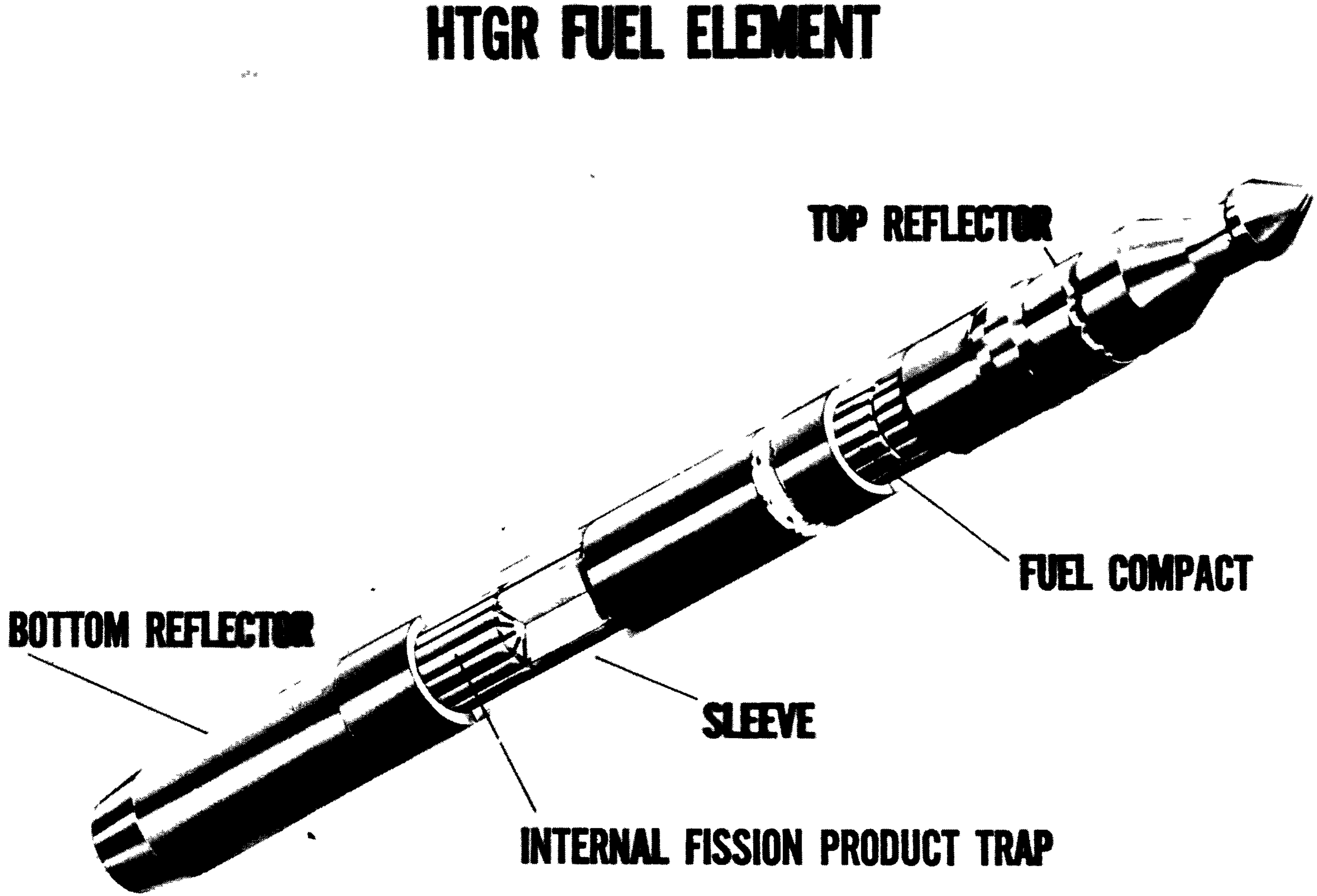


Figure 3-2. Cutaway View of Peach Bottom Fuel Element

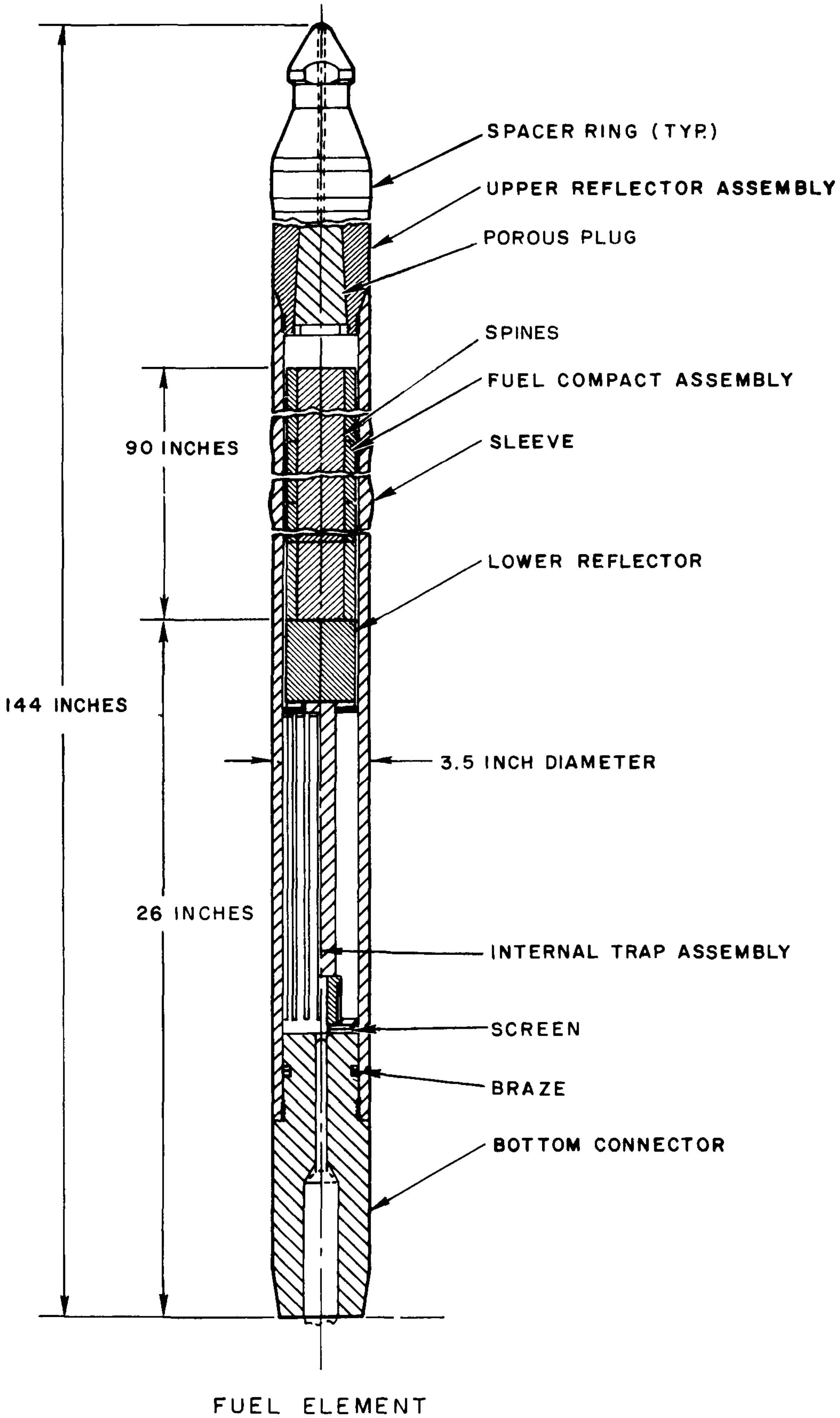


Figure 3-3. Section View of Peach Bottom Fuel Element

4. DESCRIPTION OF PROCESS

A block schematic diagram of the proposed method of separating uranium from thorium and recovering the uranium from irradiated HTGR fuel is shown in Figure 4-1. In the basic flowsheet, the fertile particles are processed to recover the thorium and bred U-233, and the fissile particles are reprocessed to recover the U-235 remaining after burnup. The high- and intermediate-level aqueous wastes generated from reprocessing the fuel are calcined in a fluidized bed and stored in underground vaults. Low-level aqueous wastes are discharged to the ground after suitable cleanup by ion exchange. Gaseous wastes, after suitable treatment, are discharged through the stack.

When received, HTGR fuel elements are placed in containers, which in turn are placed in a dry storage vault prior to processing. The storage containers are used to minimize contamination of the storage area, as well as the cooling and ventilation air. When ready for processing, the fuel elements are transferred to a headend facility where they are crushed to a size less than one-inch effective diameter. The crushed fuel is continuously burned in a fluidized bed of inert alumina particles to expose the SiC-coated fertile and fissile particles. The particles and a portion of the alumina bed material are continuously removed from the burner and separated by screening. Alumina particles are recycled to the burner while the fissile and fertile particle streams are split for separate processing.

Both particle streams pass through the remaining similar-but-separate headend processing steps. The coatings on the particles are broken in roll crushers and the buffer carbon burned in fixed-bed burners. Uranium and thorium are then leached from the particle hulls. Undissolved solids ($SiC + B_4C$) are separated from the leachate, washed twice, and mixed with solid waste from the waste calciner. The leachate (including washes) is adjusted for feed to the solvent extraction systems.

Thorium and uranium from fertile particles are separated and the uranium purified by a conventional aqueous solvent extraction system using a modified Acid Thorex process. Because of the radioactivity associated with Th-228 and its daughters, the partially decontaminated thorium nitrate solution is concentrated and stored for an indefinite period of time, possibly for reuse in the future. The U-233 is denitrated and packaged.

The fissile-particle uranium is purified in a separate but similar solvent extraction process, denitrated in a fluidized bed, and packaged. A modified Acid

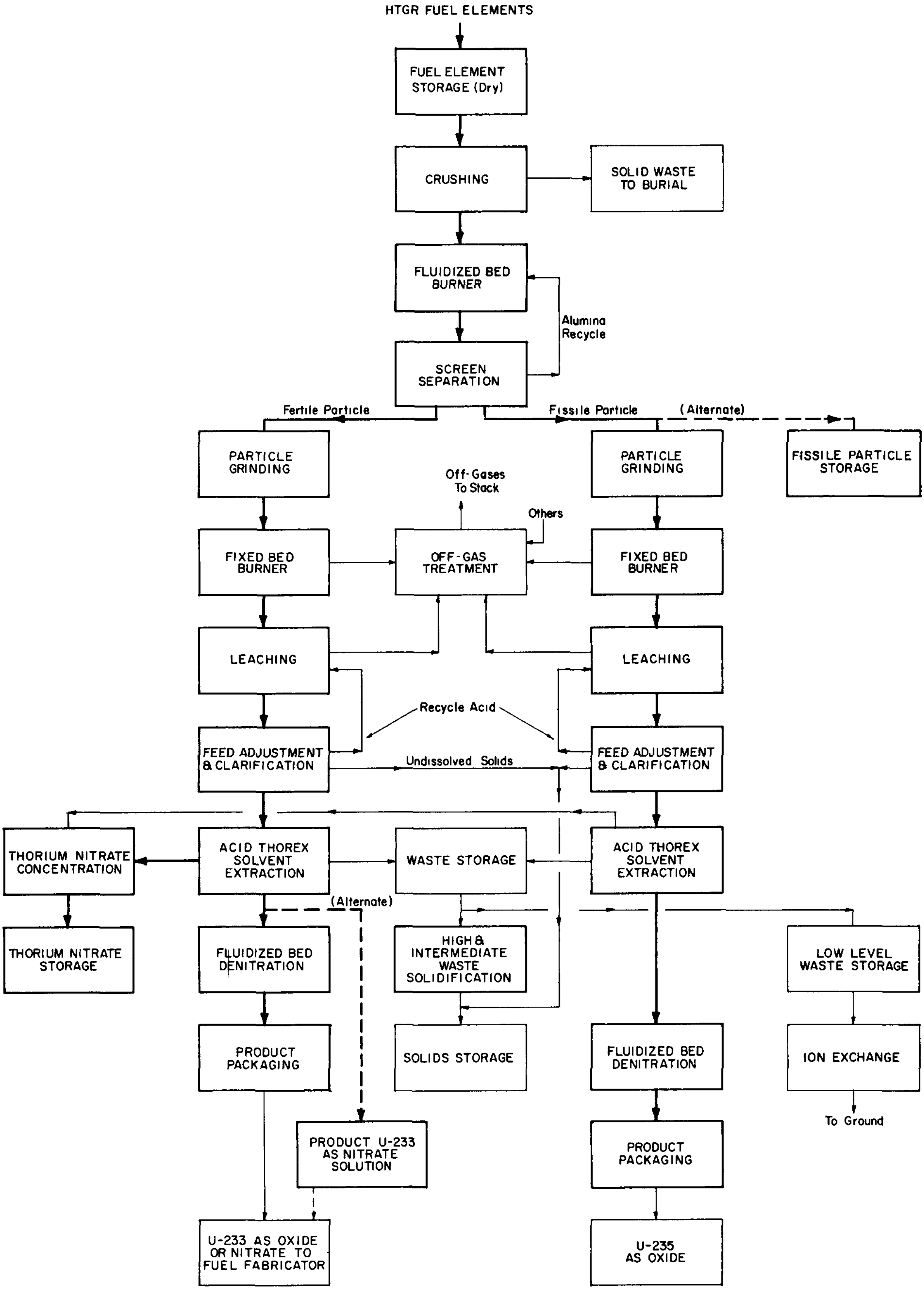


Figure 4-1 Block Flow Diagram of HTGR Reference Plant Process

Thorex process is used because the fissile particles will be contaminated with thorium from broken fertile particles.

4.1 HEADEND

Preparation of burner feed starts when fuel elements which have been cooled for the specified 210 days are transferred either to the fuel cutting equipment or directly to the two crushers, depending upon the particular fuel type under consideration. Significant portions of certain fuel elements, eg, Peach Bottom fuel, may not contain any fuel meat or may not be compatible with either the crushing or burning operations. This type of fuel is to be diverted, therefore, to the fuel cutting equipment for the purpose of reducing its size or removing undesirable constituents.

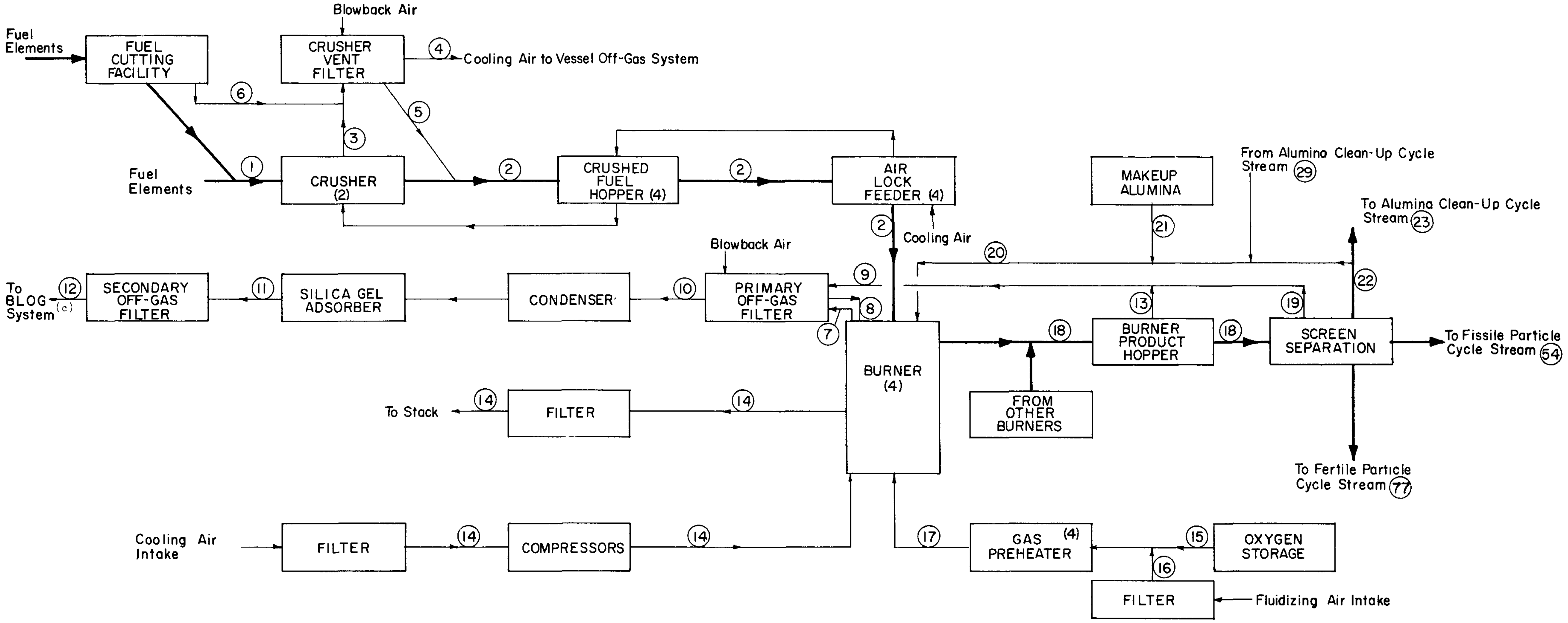
Process flow data are given in four flowsheets for the headend process. The first, for cutting, crushing, burning, and screening, is shown in Figure 4-2.

4.1.1 Bulk Fuel Process

Following their transfer, either directly from storage or via the fuel cutting equipment, the fuel elements are mechanically reduced in size by two jaw-type crushers to pieces less than one inch in diameter. The primary objectives of the size reduction are: (1) to assure a more continuous, rather than intermittent, feed to the burner, and (2) to promote efficient burner operation by providing a larger surface area for combustion of the fuel.

At the specified maximum operating conditions, carbon combustion will take place at the rate of approximately 10 kg/hr-ft^2, based on the fluidized bed cross-sectional area. The combustion process, conducted in the temperature range from 1292 to 1382°F with varying oxygen concentrations, should allow the silicon-carbide-coated fuel kernels to remain intact(18). However, it is anticipated that up to ten percent of both the fissile and fertile particle coatings will be fractured from a variety of causes. Several significant complications to the overall process result from a consideration of particle breakage; these include: (1) coating of alumina particles with quantities of thorium, uranium and fission product oxides, and (2) the release of both gaseous and volatile fission products in the burner.

Coating of alumina with uranium oxides has been observed(19) and constitutes



STREAM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
DESCRIPTION	CRUSHER FEED	BURNER FEED	COOLING AIR FROM CRUSHER	FILTERED COOLING AIR	FINES RETURN FROM COOLING AIR	COOLING AIR FROM CUTTING	BURNER OFF-GAS	FINES RETURN	COOLING AIR FROM SCREENING	OFF-GAS FROM PRIMARY FILTERS	OFF-GAS FROM ADSORBERS	OFF-GAS FROM SECONDARY FILTERS	OFF-GAS FROM PRODUCT HOPPER	BURNER COOLING AIR	OXYGEN	AIR	BURNER GAS FEED	BURNER PRODUCT	OFF-GAS FROM SCREENER	ALUMINA TO FEED	MAKE-UP ALUMINA	ALUMINA RECYCLE
Carbon, kg/d[(a)]	9918.9	9918.9	20		20	2	6	10	4				2					10	2			1
Thorium, kg/d		91.04	0.182		0.182	Trace	0.182	0.546	0.364				0.182					91.04	0.182			89.42
Uranium, kg/d		3.889	0.007		0.007	Trace	0.008	0.024	0.016				0.008					3.889	0.008			3.82
Fertile Particles, kg/d	1291.7	1291.7																1291.7				
Fissile Particles, kg/d	113.8	113.8																113.8				
Al_2O_3, kg/d							10	40	20				10					5500	10	5500	553.3	4950
FP's (non-volatile), kg/d		4.829					0.009	0.027	0.018				0.009					4.829	0.107			5.750
SiC, kg/d		10.67					0.021	0.063	0.042				0.021					10.669	0.021			5
B_4C, kg/d		12.925					0.026	0.078	0.052				0.026					12.925	0.260			6
Ru (oxide), kg/d		0.443					0.443			0.443												
Cs (oxide), kg/d		0.849					0.255			0.255								0.595	0.001			0.10
Kr, kg/d		0.1216	0.0367				0.0849			0.084	0.084	0.084										
Air, scfm			280	320	20	20		40	275	275	275	275	250	72,000		168			25			
O_2, scfm							53.24			53.24	53.24	53.24			500		532					
N_2, scfm							132.7			132.7	132.7	132.7					132.72					
CO_2, scfm							479.12			479.12	479.12	479.12										

(a) Where multiple pieces of equipment are used in parallel, the flow rates presented represent the combined throughput.

(b) Multiple pieces of major equipment are indicated by numbers in parentheses.

(c) BLOG - abbreviation for Burner-Leacher Off-Gas system.

FIGURE 4-2
HEADEND FLOWSHEET FOR BURNER SYSTEM

a problem, inasmuch as the increased effective density of the particle may hinder fluidization. For this reason, routine leaching of the alumina has been specified in the proposed process; alternatively, the alumina may be recycled without routine leaching; however, it is believed occasional leaching will be required in any case.

The released halides, noble gases, and volatile fission products largely exit with the burner off-gas. Sintered metal filters within the burners serve to remove entrained particles from this stream. Significant development problems conceivably could arise from the behavior of volatilized fission products in the off-gas treatment system to the extent that they may condense or plate-out to varying degrees on any cool surface encountered.

Two modes of temperature control are desired for the proposed fluidized bed burners. Under normal operating conditions, the flow of air through the reactor shroud is designed to remove normal amounts of excess heat along with the expected amount of heat generated in the burner reaction. Based on pilot plant experience, the burner performance is more controllable if less than 100 percent oxygen is utilized in the fluidizing gas stream(19). For this reason, a maximum concentration of 80 volume percent oxygen is specified for the plant burners. Ultimate control of the reaction rate should be delegated to the oxygen concentration control system. Emergency conditions conceivably could arise, eg, malfunction of the charging equipment, which could lead to hazardous thermal excursions. Experience has shown that the best recourse in such instances lies in reducing the oxygen concentration in the fluidizing gas stream.

A sketch of the proposed burner design is shown in Section 5. The dimensions of the burner are dictated largely by criticality considerations. The alumina is added continuously through a side entry line while the crushed fuel is introduced through a line extending through the top flange of the burner. A 1/4-inch opening screen is installed above the solids removal ports to minimize the potential for line blockage.

A finned tube helix installed at the top of the burner is designed to reduce the temperature of the off-gas stream to 550°F just prior to filtration to decrease the volumetric gas flow rate through this off-gas system. Sintered metal filters are located within the burner to minimize dust return problems which are sometimes experienced with external fines recycle systems. A fines return hopper located beneath and around the filters occupies a large percentage of the upper half of the 72-inch-diameter burner section. The bottom of the hopper is designed to return the fines to a point below the surface of the fluidized bed to increase their removal by combustion. It is anticipated that no significant attrition of the alumina will occur; thus, most of the returned material will be of a combustible nature. Fines agitation air is used to prevent solids bridging in the conical section of the fines hopper. Fines transport air is required to counteract the pressure gradient in the fluidized bed and to propel the fines back into the bed.

Burner ash, a mixture of alumina, fuel particles, heavy metals, and fission products will normally be withdrawn through the product removal line near the bottom of the bed. A bed drain line is also provided to allow removal of the entire contents of the bed prior to maintenance operations. Normally, the solids will be transported pneumatically to the product hopper--during emergencies, to the bed storage hopper.

The fluidizing gas composition will be 80 volume percent oxygen-20 volume percent nitrogen, obtained by mixing oxygen with air. Oxygen stored in a liquid storage tank will be vaporized and metered at a rate based on process demands. Normal plant compressed air or recycled cooling air will be used to dilute the oxygen stream to the desired concentration level.

The hot burner off-gases at the outlets of the sintered metal filters consist primarily of carbon dioxide and nitrogen with small amounts of radioactive particulates and vapors that must be removed. First, the gases are cooled to 150°F in a heat exchanger and passed through a packed-bed silica-gel adsorber which is designed to specifically remove ruthenium oxides; any cesium oxide particles escaping the sintered filters probably will be removed also, but to a lesser extent than ruthenium. Prior to discharge via the plant stack, particulate matter is removed from the off-gas by roughing and high-efficiency filters. Trace quantities of gaseous fission products escaping the off-gas clean-up system are diluted in the stack with additional air to maintain concentration levels below release limits.

The burner ash from the four burners is transported pneumatically to a single product hopper. From the product hopper, the solids enter the screen separation equipment. The burner ash may contain a significant quantity of fines, some of which will be unreacted graphite. The exact quantity of graphite will depend largely on burner operating conditions. To minimize the quantity of graphite fines that is transported beyond the burners, the cooling air for both the screen separator and the product hopper should pass in direct contact with the solids and at a velocity high enough to entrain the fine graphite (about 0.25 ft/sec). These fines are to be removed from the cooling air stream by sintered metal filters; a pulse blowback system can be used to return the fines to one of the fluidized bed burners.

The screen separator will operate continuously, dividing the burner product into the following three main streams: (1) alumina, (2) fissile particles, and (3) fertile particles. Inevitably, there will be some cross-mixing of the material in each stream; however, the predominant species in each of the three streams will identify the stream.

4.1.2 Alumina Cleanup Process

As indicated previously, some coating of the alumina bed material is anticipated from heavy metals and fission products because of fuel particle breakage. In addition, some particulate contamination of the alumina stream is expected due to carryover from the screening operation. The estimated contamination level from these two sources is an equilibrium level of two percent of the alumina mass. Likewise, cleanup of the alumina on a once-per-month basis is believed adequate to remain at or below this level of contamination. To minimize downtime, the alumina is reprocessed on a continuous basis, ie, approximately one-thirtieth of the alumina stream is processed daily, as shown in Figure 4-3.

Following separation of the alumina stream from the bulk of the burner product ash, a diversion valve splits the stream of solids into two parts, the major portion being recycled directly back to the burners, while the alumina to be processed is sent to an alumina storage hopper.

The alumina stream is leached in a batch-type operation requiring approximately twelve hours to complete. A sketch of the proposed leacher is shown in Section 5. The leacher acid consists of 13.0 M HNO_3, 0.04 M HF, and 0.075 M $Cd(NO_3)_2$. The acid is added to the leacher and heated to boiling prior to introduction of the alumina.* The alumina is added to the leacher over a several-hour period of time for adequate

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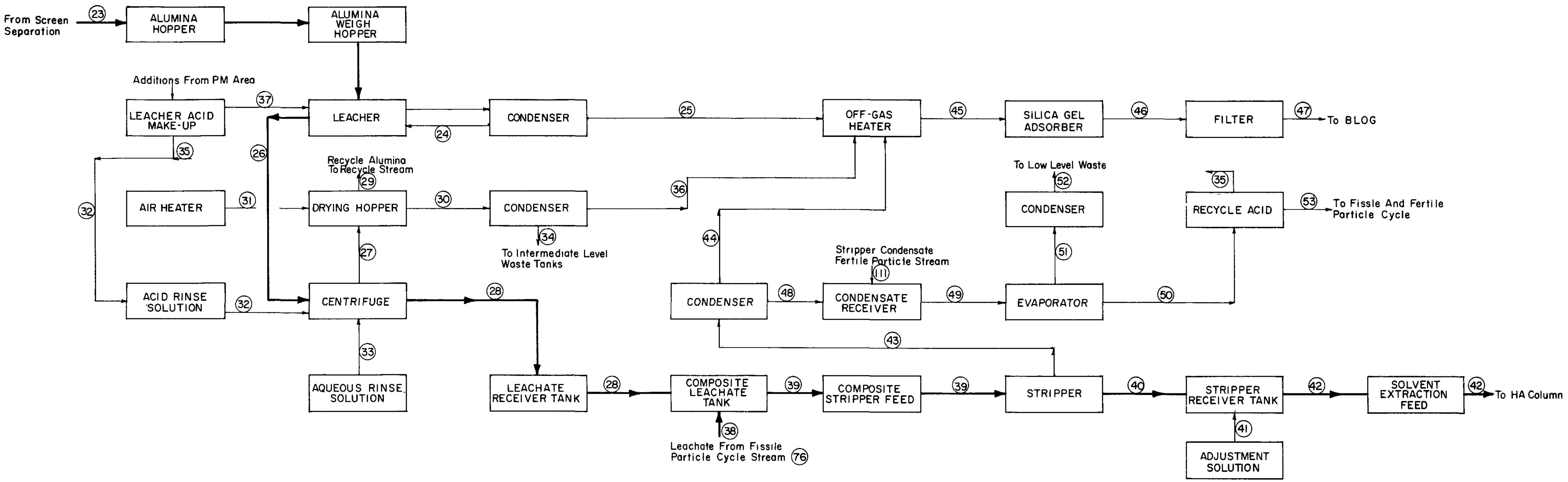
* Exploratory development work indicates that less foaming may occur with this procedure rather than adding hot acid to the alumina



STREAM	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53
DESCRIPTION	ALUMINA LEACHER FEED	LEACHER REFLUX	CONDENSER OFF-GAS	LEACHER SLURRY	CENTRIFUGE SOLIDS	ALUMINA LEACHATE	LEACHED ALUMINA RECYCLE	DRYER OFF-GAS	DRYER AIR	ACID RINSE SOLUTION	AQUEOUS RINSE SOLUTION	DRYER CONDENSATE	RECYCLE ACID	CONDENSER OFF-GAS	LEACHER ACID	FISSILE STRIPPER FEED	COMPOSITE STRIPPER FEED	STRIPPER PRODUCT	DILUTION SOLUTION	EXTRACTION FEED	STRIPPER OFF-GAS	STRIPPER CONDENSER OFF-GAS	COMPOSITE OFF-GAS	ADSORBER OFF-GAS	FILTER OFF-GAS	STRIPPER CONDENSATE	EVAPORATOR FEED	RECYCLE ACID	EVAPORATOR OVERHEAD	WASTE CONDENSATE	RECYCLE ACID
Carbon kg/d	0.033			0.033	0.033																										
Thorium, kg/d	2.980			2.980		2.980										70.45	73.4	73.4		73.4											
Uranium, kg/d	0.127			0.127		0.127										14.07	14.2	14.2		14.2											
Al_2O_3, kg/d	165			162.7	162.7		161.7																								
FP's (non-volatile), kg/d	0.191			0.191		0.191										29.84	29.9	29.9		79.9											
SiC + B_4C, kg/d	0.015			0.015	0.015		0.015																								
Cs (oxide), kg/d	Trace																														
Th^{++++}, M				0.249		0.166										0.261	0.255	1.66		1.15											
UO_2^{++}, M				0.011		0.007										0.052	0.049	0.320		0.221											
H^+, M		10		8.127		8.052				13.0			13.0		13.04	9.060	9.040	-0.39		-0.27						7.85	6.72	13.0	0.52	0.52	13.0
Al^{+++}, M				1.264		0.844										0.098	0.140	0.914		0.630											
Cd^{++}, M				0.075		0.050									0.075	0.054	0.075	0.489		0.337											
NO_3^-, M		10		13.333		11.40				13.0			13.0		13.15	10.997	11.31	14.50		9.95						7.85	6.72	13.0	0.52	0.52	13.0
F^-, M				0.040		0.027									0.04	0.029	0.04	0.260													
Na^+, M																			0.32	0.10											
HSO_3^-, M																			0.32	0.10											
FP's^{+++}, M				0.032		0.021										0.093	0.208	1.357		0.937											
Liters/day		Varies		51.7	2.17	77.3				12.83	12.83	2.17	64.5		51.6	1162	1240	190	85	275						1422	7369	3662	3707	3707	3597
Air, scfm		10	10					40	40					75							20	20	630	630	630						
NO + NO_2 + HNO_3, scfm		0.5	Trace					Trace						Trace							0.2		Trace	Trace	Trace						
Water Vapor, scfm		Varies						2.0													1.5										

FIGURE 4-3
HEADEND FLOWSHEET FOR ALUMINA CLEANUP SYSTEM

control of the foaming which initially occurs.

The following tabulation indicates the individual steps involved in leacher operation and the respective estimated time required to complete each step.

Operation	Time Required, Hours
Add leacher acid	0.5
Heat to boiling	0.5
Charge alumina	2.0
Leach and cool solution	8.0
Jet out slurry	1.0
TOTAL	12.0

Alumina losses can occur by two independent means. The first loss can occur in the screening operation in which up to ten percent will be lost to the fertile and fissile particle streams as a result of particle attrition and carryover. The second loss of alumina can occur in the leacher operation where it is estimated that up to two percent will go into solution(20). These losses are compensated for by adding fresh alumina to the recycle stream just prior to entry into the burner.

After completion of the leaching operation, the remaining slurry is jetted to a centrifuge where the following operations take place sequentially: (1) leacher acid is removed, (2) 13.0 $\underline{M}$ HNO_3 is used to rinse the solids, (3) water is used to rinse the solids, and (4) the solids are discharged and transported to a drying hopper. The alumina is dried using a heated air stream and then returned to the recycle stream.

The leachate and rinse solutions are combined with the leachate-rinse solution produced in the fissile particle cycle (see Section 4.1.3). The composite leachate then enters the feed adjustment system. The leachate-rinse solution from the fissile particle and alumina cleanup systems are combined for the following reasons: (1) no further downgrading of the fissile leachate contents would result through stream combination, and (2) less headend equipment is required, as a result of combining the two streams.

The nitric acid stripping operation is required as a step in feed preparation for the modified Acid Thorex process. The feed solution must be acid-deficient. Pilot Plant studies(20,21) have shown that solution denitration can be satisfactorily accomplished by evaporating and steam-sparging the leachate in a steam stripper.

The overhead from the stripper is a high-molarity nitric acid solution which can be reclaimed for recycle purposes. After passing through a condenser, the condensate is stored in a receiver tank where it is combined with the stripper condensate from a similar operation in the fertile particle cycle (see Section 4.1.4). This composite stripper condensate enters a single stage evaporating facility in which the bottoms concentration is maintained at 13.0 M HNO_3 while the overhead condensate is essentially 0.5 M HNO_3 which is routed to the collection system for low-level liquid waste. The bottoms constitutes the recycle acid which is primarily routed back to the fissile particle and alumina leach-rinse cycles. The remainder of the recycle acid is used in the fertile particle leacher along with some fresh acid.

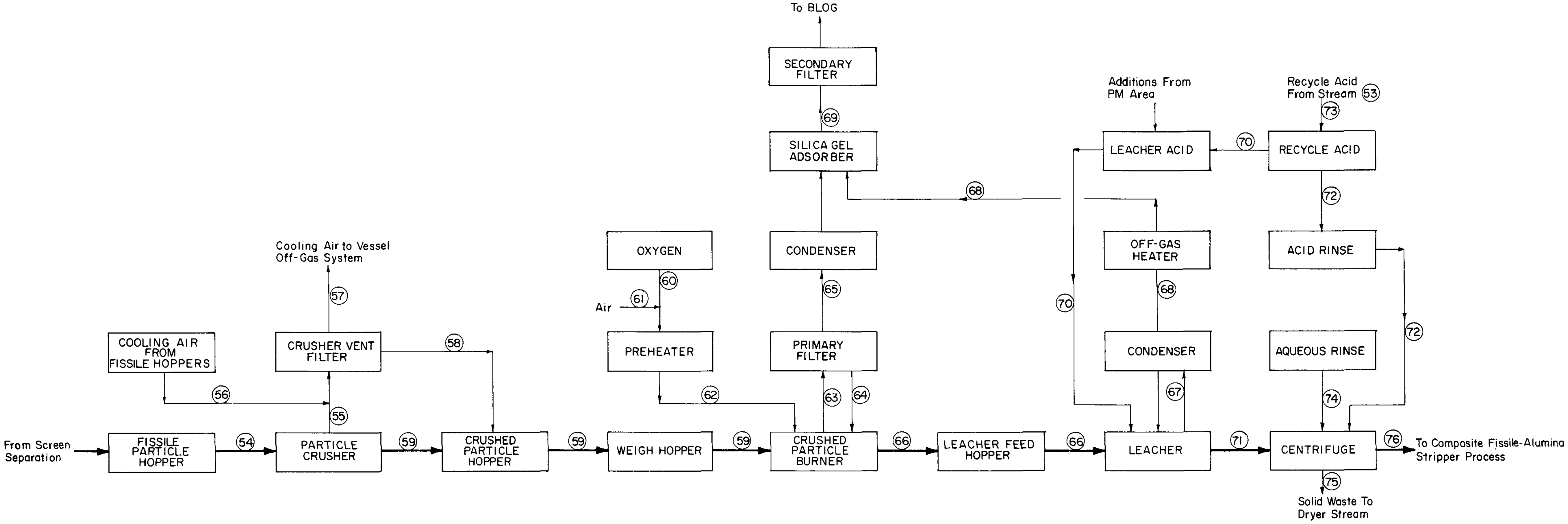
The acid-deficient stripper product is continuously withdrawn from the stripper and enters a receiver tank. An aqueous solution of sodium bisulfite, $NaHSO_4$, is added to the stripper product while it is being held in the receiver tank to improve ruthenium decontamination(20). After the addition of the sodium bisulfite, the adjusted feed solution is transferred to the feed tank for the U-235 solvent extraction process.

4.1.3 Fissile Particle Process

The fissile particle stream contents, in addition to the silicon carbide-coated fuel particles, include a significant quantity of alumina, and a mixture of heavy metals and fission products. As shown in Figure 4-1, the fissile particles may either be sent to storage or reprocessed to recover the U-235 remaining after burnup. In the event they are reprocessed, as shown in the flowsheet in Figure 4-4, the fissile-particle stream is diverted to a hopper prior to entering the crusher. The double-roll crusher is designed to break the silicon carbide coating on the particles prior to burning the buffer carbon and subsequent leaching of the heavy metal and fission product oxides. The fracturing of the silicon carbide coating results in a significant release of gaseous fission products---estimated at thirty percent of those present.

The heat generated by fission product decay is removed from all hoppers and the particle crusher in the fissile particle cycle by direct contact with an air stream. With this practice, more uniform cooling would be possible than with the use of shrouded vessels. An additional benefit is realized from this mode of cooling in that more efficient use is made of the heat capacity of the air, resulting in lower cooling air requirements.

Although in general, the mode of solids transport between vessels is not specified, the most probable means, if gravity flow is not feasible, would be pneumatic transport. Some preliminary calculations have indicated that the cooling air from the



STREAM	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76
DESCRIPTION	FISSILE PARTICLE STREAM	CRUSHER OFF-GAS	COOLING AIR	VENT FILTER OFF-GAS	FINES RETURN	CRUSHED FISSILE PARTICLES	OXYGEN	AIR	BURNER GAS	BURNER OFF-GAS	BURNER FINES RETURN	FILTER OFF-GAS	BURNER PRODUCT	LEACHER OFF-GAS	LEACHER CONDENSER OFF-GAS	ADSORBER OFF-GAS	LEACHER ACID	LEACHER SLURRY	ACID RINSE	RECYCLE ACID	AQUEOUS RINSE	SOLID WASTE TO DRYER	STRIPPER FEED
Carbon, kg/d	4	0.008	0.024		0.032	25.96							1					1				1	
Thorium, kg/d	70.45	0.14	0.42		0.56	70.45				0.14	0.14		70.45					70.45					70.45
Uranium, kg/d	3.01	0.028	0.084		0.112	14.07				0.028	0.028		14.07					14.07					14.07
Fissile Particles, kg/d	113.8																						
Al_2O_3, kg/d	275	0.5	1.5		2.0	275				0.5	0.5		275					269.5				269.5	
FP (non volatile), kg/d	4.289	0.06	0.18		0.24	27.62				0.06	0.06		27.62					27.62					27.62
SiC + B_4C, kg/d	18.87	0.09	0.27		0.36	46.93				0.09	0.09		46.93					46.93				46.93	
Ru (oxide), kg/d						1.854				1.854		1.854											
Kr, kg/d		0.2037								0.475		0.475				0.475							
Cs (oxide), kg/d						3.984				1.066		1.066	2.918					2.918					2.918
Th^{++++}, M																		0.362					0.261
UO_2^{++}, M																		0.072					0.052
H^+, M														10			13.04	10.05	13.0	13.0			9.060
Al^{+++}, M																		0.128					0.093
Cd^{++}, M																	0.075	0.075					0.054
NO_3^-, M														10			13.15	13.052	13.0	13.0			10.997
F^-, M																	0.04	0.04					0.029
FP's^{++}, M																		0.307					0.221
Liters/day																	838	838	162	1000	162	45	1162
Air, scfm		60	500	560	20			3.968			20			10	10								
O_2, scfm							2.312		3.14	0.62		0.62				2.72							
N_2, scfm									3.14	3.14		3.14				11.04							
CO_2, scfm										2.52		2.52				2.52							

FIGURE 4-4
HEADEND FLOWSHEET FOR FISSILE PARTICLE SYSTEM

fissile particle crusher and the intermediate hoppers would provide an adequate air supply for this purpose. Reuse of this cooling air would reduce the total quantity of contaminated air that would require cleanup.

The off-gas from the particle crusher and storage hoppers are combined and passed through a single roughing filter to remove suspended fines. A pulse blowback system is used to remove the fines from the filter and transport them to the crushed particle hopper. The filtered cooling air is then either diverted for use as transport air or vented to the vessel off-gas system.

The crushed particles pass from the collection hopper to a weigh hopper before being introduced into the fixed bed burner. A fixed bed burner was selected because of the potentially wide range of particle sizes and densities present after crushing. The burner is cooled by air passing through the vessel shroud. Sintered metal filters will be employed to retain the solids within the burner. A significant amount of volatilized fission products, as well as gaseous fission products, will be present in the burner off-gas. A condenser, therefore, will cool the gases prior to their passage through a silica-gel absorber which removes the bulk of the volatile fission products. Following the absorber, the off-gas is once again filtered and sent to the burner-leacher off-gas system.

A mixture of 50 volume percent oxygen-nitrogen was selected for the burner gas supply to reduce the probability of localized temperature excursions which might arise with higher oxygen concentrations. The ash from the fixed bed burner is transported to a storage hopper prior to leaching.

The leacher operation is similar to that described for the alumina leacher; ie, a batch-type operation requiring approximately twelve hours to complete. The off-gas from the leacher passes sequentially through a reflux condenser, an off-gas heater, and a silica-gel absorber to reduce the quantity of nitrous and nitric oxide vapors in the off-gas, raise the temperature of the gas stream above the dew-point of the water vapor, and remove volatile fission products, respectively. The off-gas then enters the burner-leacher off-gas system described in Section 4.1.1.

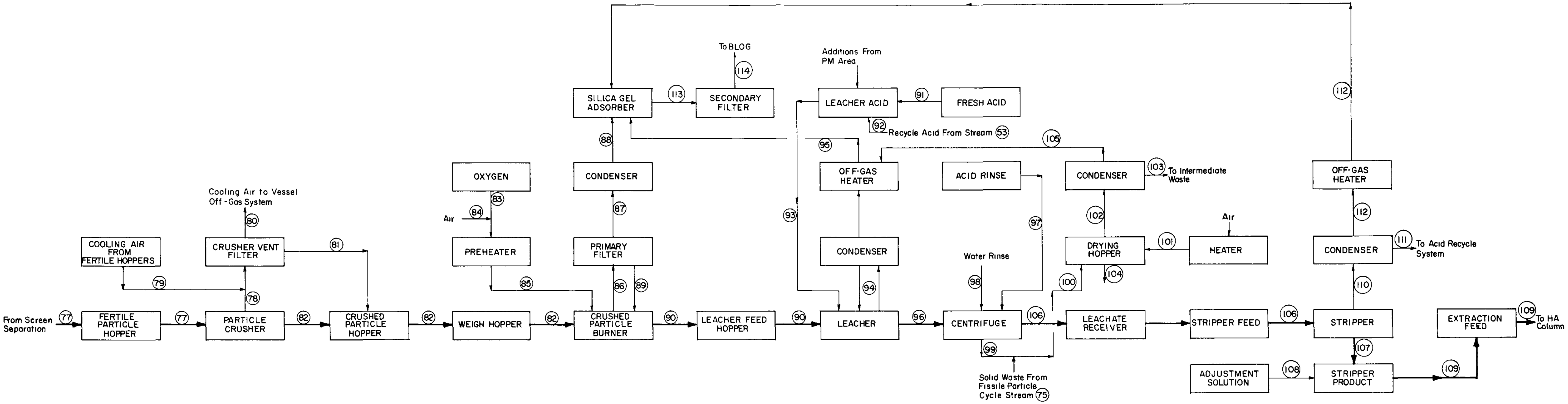
The leacher slurry enters a centrifuge for separation of the leachate from the solids, and solids washing with 13 M HNO_3, followed by water. Solids from the centrifuge, consisting mainly of silicon carbide hulls, boron carbide, and alumina, are transported to a solid waste drier and subsequently stored as high-level waste (see Section 4.1.4).

The leachate and rinse solutions are then combined with that from the alumina cleanup system as described previously (see Section 4.1.2).

4.1.4 Fertile Particle Process

The fertile particle process, as shown in the flowsheet in Figure 4-5, is similar to that described for the fissile particle process in Section 4.1.3 and 4.1.2. Uranium-233 is the main product and its cross-contamination with other isotopes of uranium should be avoided. Briefly, the fertile particles after screen separation pass through the following processing steps: (1) particle crushing, (2) burning in a fixed bed reactor, (3) leaching, (4) nitric acid stripping of the leachate, (5) adjustment of the stripper product to a 1.50M thorium solution in preparation for feeding to the solvent extraction separation and purification system.

Solid waste from both the fertile and fissile particle cycles are shown combined in this flowsheet. These solids which contain alumina, silicon carbide hulls, and boron carbide, as well as some insoluble fission products, enter a drying hopper, are dried with air and are used as a diluent with the high-activity-level waste solids produced from calcining waste raffinate streams.



STREAM	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114
DESCRIPTION	FERTILE PARTICLE STREAM	CRUSHER OFF-GAS	COOLING AIR	FILTERED OFF-GAS	FINES RETURN	CRUSHED FERTILE PARTICLES	OXYGEN	AIR	BURNER GAS	BURNER OFF-GAS	FILTERED OFF-GAS	CONDENSER OFF-GAS	BURNER FINES RETURN	BURNER PRODUCT	MAKE-UP ACID	RECYCLE ACID	LEACHER ACID	LEACHER REFLUX	COMBINED OFF-GAS	LEACHER SLURRY	ACID RINSE	WATER RINSE	CENTRIFUGE SOLIDS	COMBINED SOLID WASTE	DRYER AIR	DRYER OFF-GAS	DRYER CONDENSATE	SOLID WASTE TO STORAGE	CONDENSER OFF-GAS	STRIPPER FEED	STRIPPER PRODUCT	ADJUSTMENT SOLUTION	EXTRACTION FEED	STRIPPER OFF-GAS	STRIPPER CONDENSATE	CONDENSER OFF-GAS	ADSORBER OFF-GAS	FILTER OFF-GAS
Carbon, kg/d	4	0.230	0.690		0.920	114.2								2						2			2	3				3										
Thorium, kg/d		1 821	5 463		7 284	910 4				1 82			1 82	910 4						910 4										910 4	910 4		910 4					
Uranium, kg/d		0 052	0 156		0 208	25 96				0 05			0 05	25 96						25 96										25 96	25 96		25 96					
Fertile Particles, kg/d	1291 7																																					
Al_2O_3, kg/d	275	0 55	1 65		2 20	275				0 55			0 55	275						269 5			269 5	539				539										
FP's (non-volatile), kg/d		0 05	0 15		0 20	25 35				0 05				25.35						25 35										25 35	25.35		25.35					
SiC+B_4C, kg/d	5 2	0 15	0 45		0.60	75.51				0 15				75.51						75 51			75 51	122 4				122 4										
Ru (oxide), kg/d						1 618				1 618	1 616																											
Cs (oxide), kg/d						4 456				1 34	1 34			3.12						3 12										3 12	3 12		3 12					
Kr, kg/d		0 191				0.637				0 446	0 446	0 446																										
Th^{++++}, M																				0.990										0 6598	2.20		1 50					
UO_2^{++}, M																				0 028										0 0187	0 063		0 043					
H^+, M															13 0	13 0	13 04	10		8 685	4 0									6 420	-0 15		-0 10		6 43			
Al^{+++}, M																				0 08										0 532	0 177		0 120					
Cd^{++}, M																	0 075			0 075										0 0499	0 166		0 113					
NO_3^-, M															13.0	13.0	13 15	10		13 241	4 0									9 439	10 05		6 850		6 43			
F^-, M																	0.04			0.04										0 0266	088		0 06					
Na^+, M																																0 157	0 05					
HSO_3^-, M																																0 157	0 05					
$FP's^{+++}$, M																				0 062										0 041	0 137		0 093					
Liters/day															1330	2595	3925			3965	992	992	5	9 5			9.5			5948	1782	834	2616		5947.5			
Air, scfm		60	500	560	20			17 0					20					10	70						60	60			60					20		20	70	70
O_2, scfm							9 90		13 40	2 74	2 74	2 74																									9 04	9 04
N_2, scfm									13 40	13 40	13 40	13 40																									37 1	37 1
$NO+NO_2+HNO_3$, scfm																		0.4	Trace	Trace														44		Trace	Trace	Trace
Water Vapor, scfm																		Varies								7								383				
CO_2, scfm										10 66	10.66	10.66																									10 66	10 66

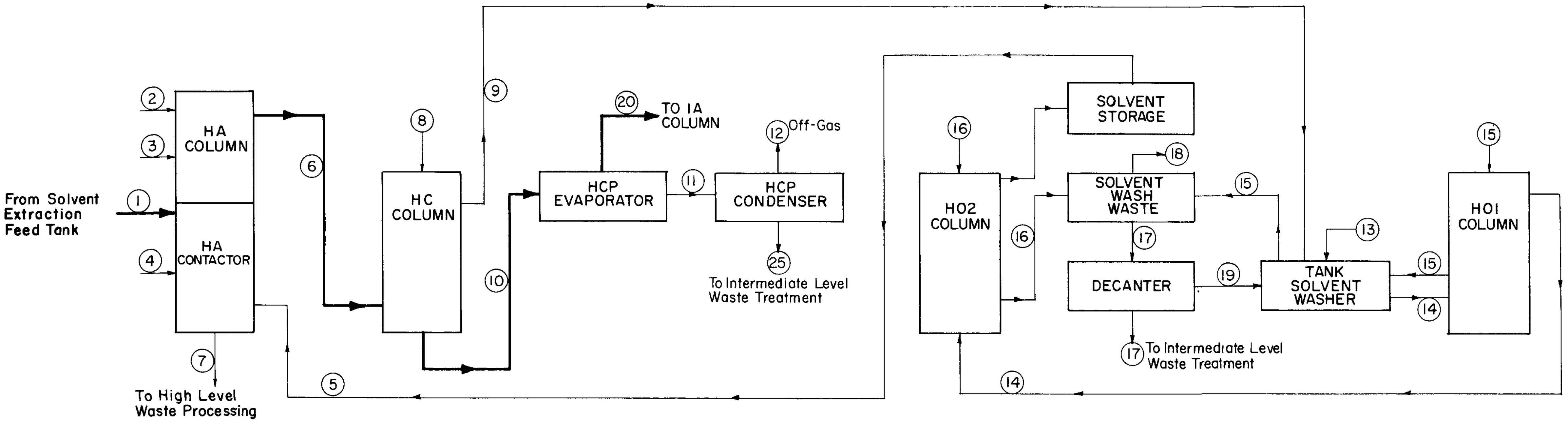
FIGURE 4-5
HEADEND FLOWSHEET FOR FERTILE PARTICLE SYSTEM

4.2 SOLVENT EXTRACTION OF FERTILE MATERIAL

A modified Acid-Thorex flowsheet(11,12) is used to reprocess the heavy metals leached from the fertile particles. The flowsheets for the three required cycles of solvent extraction are shown in Figures 4-6, -7, and -8. Each cycle utilizes an extraction ,scrubbing, and stripping step. The first cycle separates the bulk of the fission products from thorium and uranium, while the second cycle partitions thorium from uranium. Finally, the last cycle consists of an additional uranium purification cycle. The solvent wash system for 5 percent TBP is common for the extractant from the second and third cycles, while the first cycle extractant--30 percent TBP--uses an independent solvent wash system. For design purposes the solvent extraction flowsheet for fertile material is based on the assumption that no particle breakage occurs in head-end processing; however, some particle breakage is very likely to occur and would slightly reduce the throughput of uranium and thorium.

In the first extraction cycle, shown in Figure 4-6, thorium and uranium are coextracted from the feed solution by a solvent composed of 30 volume percent tributyl phosphate (TBP) in an inert diluent, normally a linear paraffin hydrocarbon like Amsco 125. The acid-deficient feed (HAF) is continuously metered into a multistage centrifugal contactor (HA contactor). Acid-deficiency increases the decontamination factors for the rare earths and ruthenium, while incoming (HAS) scrub from the pulsed scrub column (HA column) provides additional decontamination from protactinium. An intermediate scrub stream (HAIS) provides some of the salting acid, while the remainder is supplied by the 13$\underline{M}$ HNO_3 (HAA) stream added in the centrifugal contactor. Greater than 99.9 percent of the fission products are removed in the waste raffinate stream (HAW). This stream is subsequently routed to waste processing for disposal with other high level waste. The scrubbed extractant stream (HAP) containing thorium and uranium is then fed to the strip column (HC column) where the 0.01$\underline{M}$ HNO_3 stripping stream (HCX) removes thorium and uranium from the organic extractant.

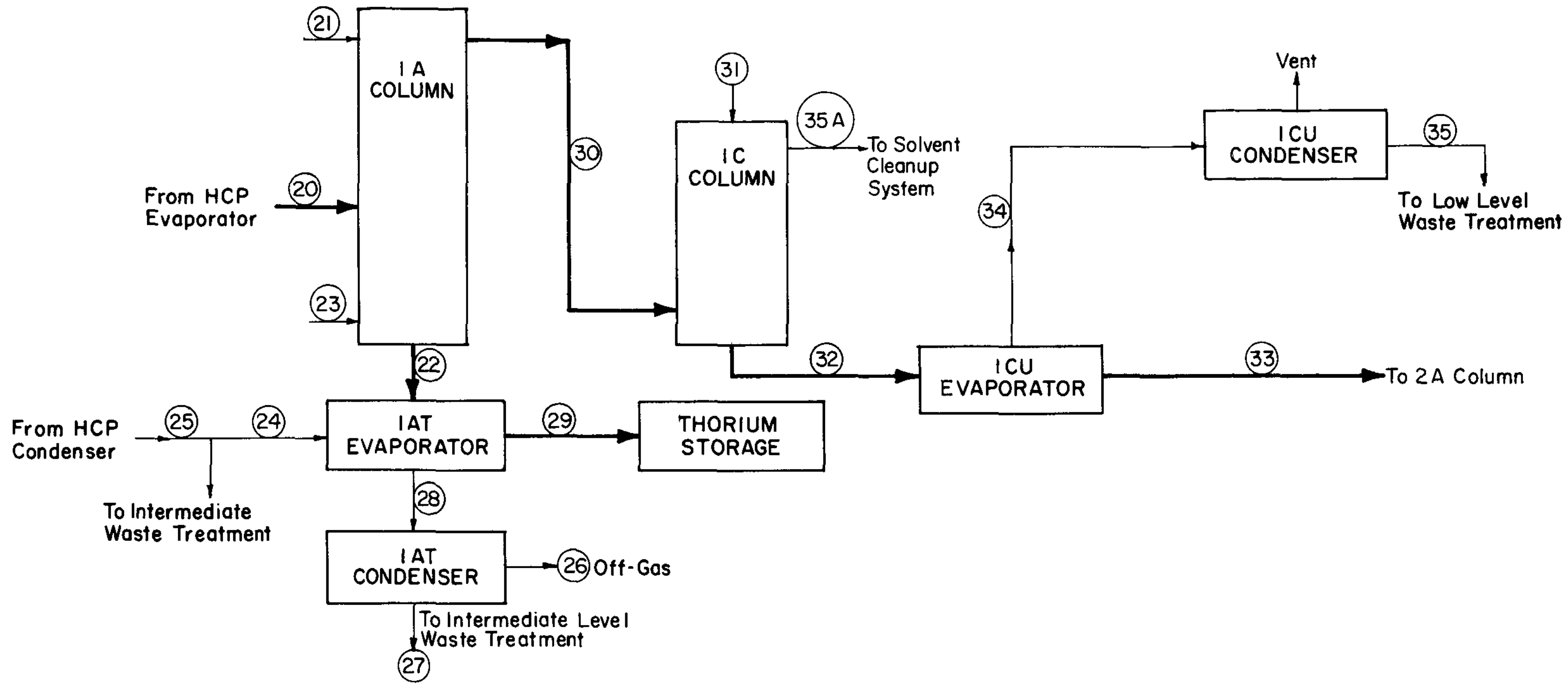
The volume of the thorium-uranium product stream (HCP) from the HC column is about nine times the volume of the HAF feed because of solubility and operability considerations. In order to minimize equipment sizes, the HCP is reduced in volume by evaporation prior to being fed into the second solvent extraction cycle. This evaporation minimizes the quantity of nitric acid needed. Through evaporation, the thorium concentration is restored to a value of 1.5$\underline{M}$. Since an acid-deficient feed is not necessary in the second cycle, the nitric acid present in the HCP appears in the second cycle feed (1AF) and provides some of the salting strength.



STREAM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
DESCRIPTION	HAF	HAS	HAIS	HAA	HAX	HAP	HAW	HCX	HCR	HCP	HCP EVAPORATOR OFF-GAS	HCP CONDENSER OFF-GAS	SOLVENT MAKE-UP	HOF SOLVENT COLUMN FEED	HOB SCRUB	HOS SCRUB	HOW SOLVENT WASH WASTE	SOLVENT TREATMENT OFF-GAS	DECANTER SOLVENT
Carbon, kg/d																			
Thorium, kg/d	910					910	2			908									
Uranium, kg/d	26.0					26.0	0.047			26.0									
FP's, kg/d	35.3					0.009	35.3			0.011									
Al_2O_3, kg/d																			
Th^{++++}, M	1.5					0.166	0.0017			0.166									
UO_2^{++}, M	0.0427					0.00474	3×10^{-5}			0.00474									
H^+, M	-0.10	0.03	5.0	13.0		0.10	1.93	0.01		0.11						0.4			
Al^{+++}, M	0.12						0.0461												
Cd^{++}, M	0.115						0.0442												
NO_3^-, M	6.87		5.0	13.0		0.77	2.27	0.01		0.783						0.4	0.2		
F^-, M	0.06						0.023												
Na^+, M	0.05						0.019								0.4		0.2		
HSO_3^-, M	0.05						0.019												
FP's^{++}, M	0.117					4×10^{-6}	0.045			4×10^{-6}									
Fe^{++}, M		0.01					0.0038												
NH_2SO_3, M		0.02					0.0076												
PO_4^{-3}, M		0.01					0.0038												
CO_3^{--}, M															0.2				
Liters/day	2614	2614	784	784	23,549 (1)	23,549 (1)	6796	23,549	23,549 (1)	23,549			Varies (1)	23,549 (1)	2355	2355	4710		Varies (1)
Gallons/day	690.6	690.6	207.1	207.1	6,222	6,222	1795	6,222	6,222	6,222			Varies (1)	6,222	622	622	1244		Varies (1)
Air, scfm												Varies						Varies	
O_2, scfm																			
N_2, scfm																			
$NO+NO_3+HNO_3$, scfm											Trace								
Water Vapor, scfm											676								
CO_2, scfm																		0.27	
CO, scfm																			
Th, g/l	348					38.51	0.3			38.6									
U g/l	9.95					1.105	0.007			1.105									
FP's, g/l	13.5					0.0004	5.2			0.00048									

(1) 30% TBP in Amsco diluent.

FIGURE 4-6
FLOWSHEET FOR H EXTRACTION CYCLE FERTILE PROCESS

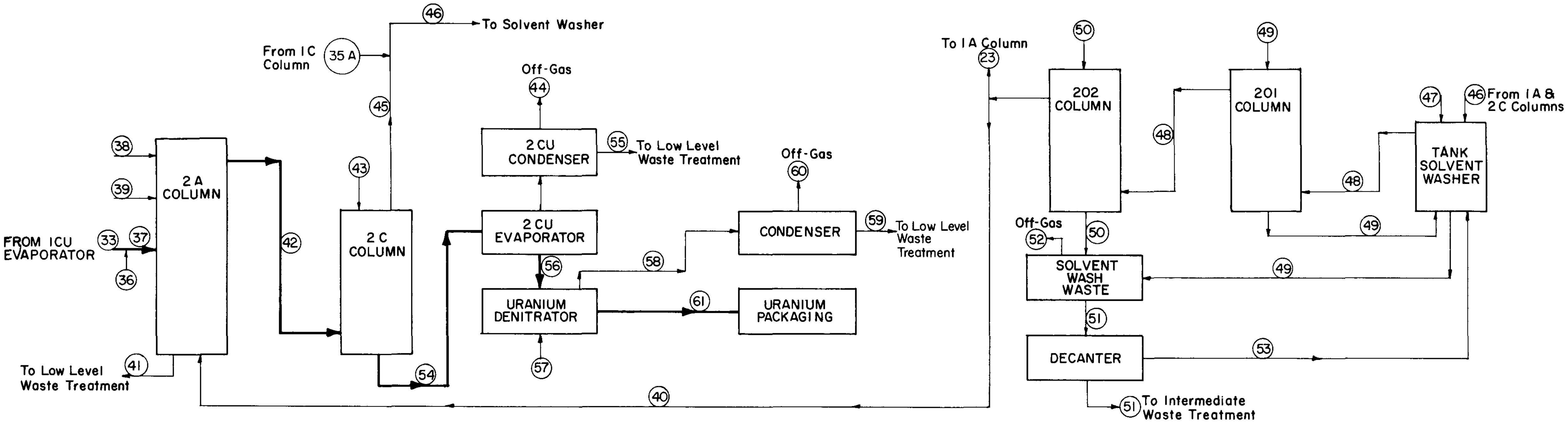


STREAM	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	35 A
DESCRIPTION	IAF	IAS	IAT	IAX	ITA WATER ADDITION	HCP EVAPORATOR CONDENSATE	IAT CONDENSER OFF-GAS	IAT CONDENSATE	IAT EVAPORATOR OFF-GAS	ITT THORIUM PRODUCT	IAU	ICX	ICU	ICU EVAPORATOR PRODUCT	ICU EVAPORATOR OFF-GAS	ICU EVAPORATOR CONDENSATE	ICW
Carbon, kg/d																	
Thorium, kg/d	908		908							$908^{(3)}$							
Uranium, kg/d	26.0										26.0		26.0	26.0			
FP's, kg/d	0.011		0.011							0.11							
Al_2O_3, M																	
Th^{++++}, M	1.495		1.15							2.26							
UO_2^{++}, M	0.0427										0.0328		0.0656	0.697		0.05	
H^+, M	0.911	2.0	1.16	0.01		0.01		1.1		1.0	0.10	0.01	0.21	1.75		0.05	
Al^{+++}, M												0.01					
Cd^{++}, M																	
NO_3^-, M	6.98	2.0	5.76	0.01		0.01		1.1		10.04	0.16		0.341	3.14			
F^-, M																	
Na^+, M																	
HSO_3^-, M																	
FP's^{++}, M	$3.7x10^{-5}$		$2.8x10^{-5}$							$5.5x10^{-5}$							
Liters/day	2614	784	3398	$3398^{(2)}$	340	20,935		2009		1729	$3398^{(2)}$	1699	1699	159.9		1539	$3398^{(2)}$
Gallons/day	690.6	207	898	898	89.8	5531		531		457	898	449	449	42.2		406.6	898
Air, scfm																	
O_2, scfm																	
N_2, scfm																	
$NO+NO_3+HNO_3$, scfm							Varies		1.3								
Water Vapor, scfm							Varies		69.4						Varies		
CO_2, scfm																	
CO, scfm																	
Th, g/l	347		267							524.5							
U, g/l	9.95												15.28	162.4			
FP's, g/l	0.0043		0.0033							0.006							

(2) 5% TBP in Amsco diluent

(3) Volume ThO_2 = 103 l/day

FIGURE 4-7
FLOWSHEET FOR FIRST EXTRACTION CYCLE FERTILE PROCESS



STREAM	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61
DESCRIPTION	2AA	2AF	2AS	2AIS	2AX	2AW	2AU	2CX	EVAPORATOR VENT	2CW	ICW+2CW ORGANIC RAFFINATE	SOLVENT MAKE-UP	SOLVENT COLUMN FEED	2OB SCRUB	2OS SCRUB	2OW SOLVENT WASH WASTE	SOLVENT TREATMENT OFF-GAS	DECANTER SOLVENT	2CU	2CU EVAPORATOR CONDENSATE	DENITRATOR FEED	FLUIDIZING AIR	DENITRATOR OFF-GAS	ACID CONDENSATE	DENITRATOR CONDENSER OFF-GAS	UO_3 PRODUCT
Carbon, kg/d																										
Thorium, kg/d																										
Uranium, kg/d		26.0					26.0												26.0		26.0					26.0
Al_2O_3, kg/d																										
Th^{++++}, M																										
UO_2^{++}, M		0.2108					0.0326												0.0653		2.0					
H^+, M	2.10	2.0		3.75		2.5	0.03	0.01							0.4				0.10	0.06	1.4			5.71		
Al^{+++}, M																										
Cd^{++}, M																										
NO_3^-, M	2.11	2.42		3.75		2.5	0.03	0.01							0.4	0.2			0.23	0.06	5.4			5.71		
F^-, M																										
Na^+, M														0.4		0.2										
HSO_3^-, M																										
FP's^{++}, M																										
CO_3^{--}, M														0.2												
Liters/day	368.5	528.5	105.5	423	3414$^{(2)}$	1057	3414$^{(2)}$	1707		3414$^{(2)}$	6812$^{(2)}$	Varies$^{(2)}$	6812$^{(2)}$	681	681	1362		Varies$^{(2)}$	1707	1651	55.7			52.7		
Gallons/day	97.4	139.6	27.9	111.8	902	279.3	902	451		910	1800	Varies	1800	180	180	360		Varies	451	436	14.7			13.9		
Air, scfm									Varies								Varies					3.95	3.95		3.95	
O_2, scfm																										
N_2, scfm																										
NO+NO_3+HNO_3, scfm																							0.175			
Water Vapor, scfm																							1.40			
CO_2, scfm																										
CO, scfm																										
Th, g/l																										
U, g/l		49.12																	15.21		466					
FP's, g/l																										

(2) 5% TBP in Amsco diluent

FIGURE 4-8
FLOWSHEET FOR SECOND EXTRACTION CYCLE FERTILE PROCESS

In the second solvent extraction cycle, thorium and uranium are partitioned from each other and the uranium receives an additional decontamination. The second cycle feed (1AF) is contacted in a pulsed column with an extractant containing five percent TBP in Amsco (1AX). By adjusting the relative 1AF and 1AX flow rates and by selecting a 2M HNO_3 scrub stream (1AS), virtually all of the thorium exits with the aqueous raffinate. In addition, the acid scrub stream (1AS) provides additional decontamination of the uranium bearing solvent stream (1AU). The uranium is stripped back into the aqueous stream by the stripping solution (1CX) in the 1C column. The 1C column product (1CU) is reduced in volume by evaporation in a similar manner to the HCP stream.

Because of the presence of Th-228 from decay of U-232, recovered and purified thorium from irradiated HTGR fuel elements has a significantly higher radiation level than naturally occurring thorium. Cost of natural thorium is low enough such that re-use of thorium in a fuel fabrication plant is not justified. After 15 years of storage, the Th-228 and daughters decay to levels comparable to natural thorium(22). Therefore, the recovered thorium in stream 1AT from the 1A column will be stored after being reduced in volume by evaporation to the limits of thorium solubility to minimize tankage requirements. To aid in reducing the nitric acid concentration of the evaporator bottoms (and increase the maximum thorium concentration), a portion of the HCP evaporator condensate is added to the 1AT evaporator. The 1AT overheads are condensed and routed to the intermediate level waste cell for nitric acid recovery and disposal. The concentrated thorium solution is subsequently sent to storage tanks.

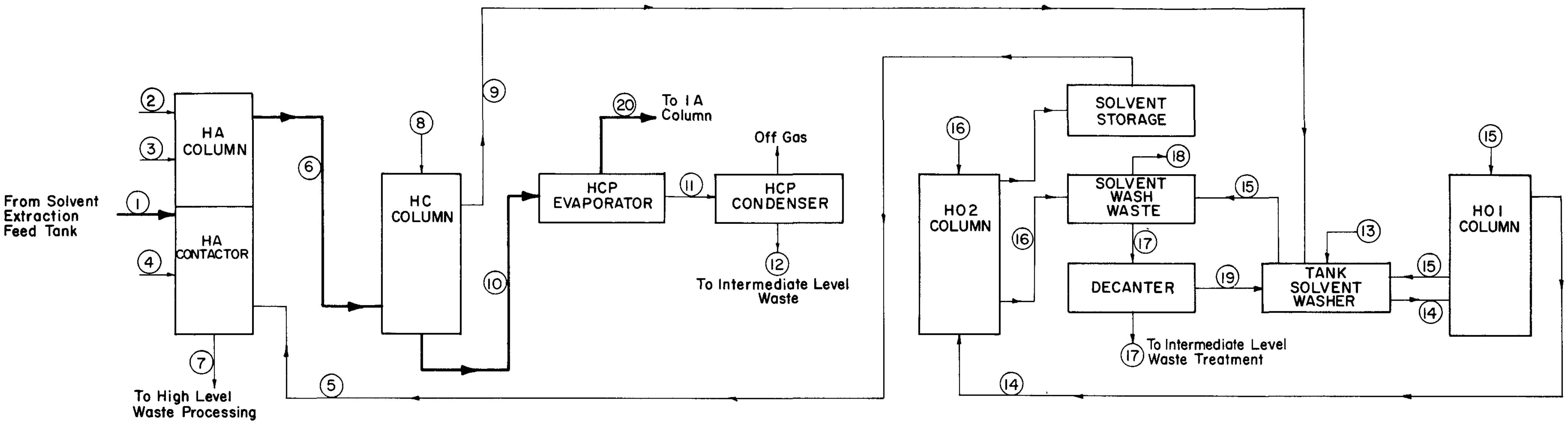
The third solvent extraction cycle is designed to give one additional uranium purification step. The product stream (evaporator bottoms) from the 1CU evaporator is adjusted by acid addition (2AA) to provide additional salting strength and better column operability. The uranium-bearing solvent is contacted countercurrently by dual scrub streams; a top scrub (2AS) of demineralized water minimizes both the nitric acid and chemical impurity content of the 2A column product (2AU), while a 3.75M HNO_3 intermediate scrub (2AIS) furnishes the remainder of the salting strength and improves decontamination. The 2A column waste is sent to the intermediate level waste collection tanks for processing. Uranium is returned to the aqueous phase in the 2C column by stripping and sent to an evaporator for adjustment of volume prior to being fed to the uranium product denitrator. The evaporator concentrates uranium to 2 molar in the 2CU evaporator bottoms stream.

Two solvent wash systems are provided to remove impurities formed by radiolytic and chemical degradation of TBP and paraffin hydrocarbons during contact of the solvent with fission products. Independent wash systems are required for the solvent containing 5 and 30 percent TBP. Removal of solvent degradation products is necessary for proper chemical and mechanical operation of the solvent extraction system. For example, dibutyl phosphate (DBP), one of the degradation products, combines with thorium to form a slimy precipitate. In both solvent wash systems, the solvent effluent from the strip column(s) is contacted with a dilute solution of sodium carbonate in a pulsed column (streams HOB and 20B). Spent sodium carbonate solution is continuously withdrawn from the H01 and 201 columns and solvent tank washer and sent to the solvent wash waste tank. The partially treated solvent cascades from the pulsed column to a packed column (H02 and 202) where it is countercurrently contacted with a dilute nitric acid scrub stream. The solvent effluent from this final treatment column overflows to the solvent storage tank for return to the extraction columns (HA or 1A and 2A). The acid effluent flows into the solvent wash waste tank where it is neutralized by the sodium carbonate. Periodically the wash waste is transferred through a decanter to the intermediate-level waste cell for disposal. When necessary, fresh makeup solvent may be added to one of the systems via its tank solvent washer.

After long processing periods, certain degradation products--not removed in the solvent washing system--build up in the extractant and form complexes with some fission products, namely, zirconium and niobium(23). Periodically as these degradation products build up in the solvent, the solvent must be discarded and replaced. For disposal, this degraded solvent is burned as a fuel in the waste calcining facility.

4.3 SOLVENT EXTRACTION OF FISSILE MATERIAL

Ideally, the solvent extraction flowsheet for separating fissile uranium-235 from fission products could utilize the Purex process, if the fissile material, per se, contained no thorium. However, the fissile particles from some fuels do contain thorium. Consequently, the solvent extraction flowsheet, shown in Figures 4-9, -10, and -11, for the fissile stream is identical in all major respects to the extraction scheme previously outlined for fertile meat.



STREAM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
DESCRIPTION	HAF	HAS	HAIS	HAA	HAX	HAP	HAW	HCX	HCR	HCP	HCP EVAPORATOR OFF-GAS	HCP EVAPORATOR CONDENSATE	SOLVENT MAKE-UP	HOF SOLVENT COLUMN FEED	HOB SCRUB	HOS SCRUB	HOW SOLVENT WASH WASTE	SOLVENT TREATMENT OFF-GAS	DECANTER SOLVENT	I AF
Carbon, kg/d																				
Thorium, kg/d	73.4(1)					73.2	0.02			73.2										73.2
Uranium kg/d	14.2(2)					14.2	0.004			14.2										14.2
FP's, kg/d	29.9					0.09	29.8			0.09										0.08
Al$_2$O$_3$, kg/d	-																			
Th^{++++}, M	1.15					0.164	0.00015			0.164										1.50
UO$_2^{++}$, M	0.221					0.0315	3x10^{-5}			0.0315										0.288
H$^+$, M	-0.27	0.009	5.0	13.0		0.10	2.02	0.01		0.10		0.03				0.4				0.67
Al^{+++}, M	0.63						0.27													
Cd^{++}, M	0.34						0.15													
NO$_3^-$, M	9.95		5.0	13.0		0.82	4.27	0.01		0.82		0.03				0.4	0.2			7.26
F$^-$, M	0.18						0.078													
Na$^+$, M	0.10						0.043								0.4		0.2			
HSO$_3^-$, M	0.10						0.043													
FP's^{+++}, M	0.937					0.0004	0.407			0.0004										0.0036
Fe^{++}, M		0.01					0.0035													
NH$_2$SO$_3^-$, M		0.02					0.007													
CO$_3^{=}$, M															0.2					
PO$_4^{---}$, M		0.003					0.001													
Liters/day	275	220	55	83	1925(3)	1925(3)	633	1925	1925(3)	1925		1715	Varies(3)	1925(3)	192	192	384		Varies(3)	210
Gallons/day	72.6	58.1	14.5	21.9	508.6(3)	508.6(3)	167	508.6	508.6(3)	508.6		453	Varies(3)	508.6(3)	50.9	50.9	101.8		Varies(3)	55.5
Air, scfm																		Varies		
O$_2$, scfm																				
N$_2$, scfm																				
NO+NO$_3$+HNO$_3$, scfm											Trace									
Water Vapor, scfm											55									
CO$_2$, scfm																				
CO, scfm																				
Th, g/l	267					38.0	0.03			38.0										348
U, g/l	51.8					7.39	0.007			7.39										67.6
FP's, g/l	29.9					0.05	47.3			0.05										0.4

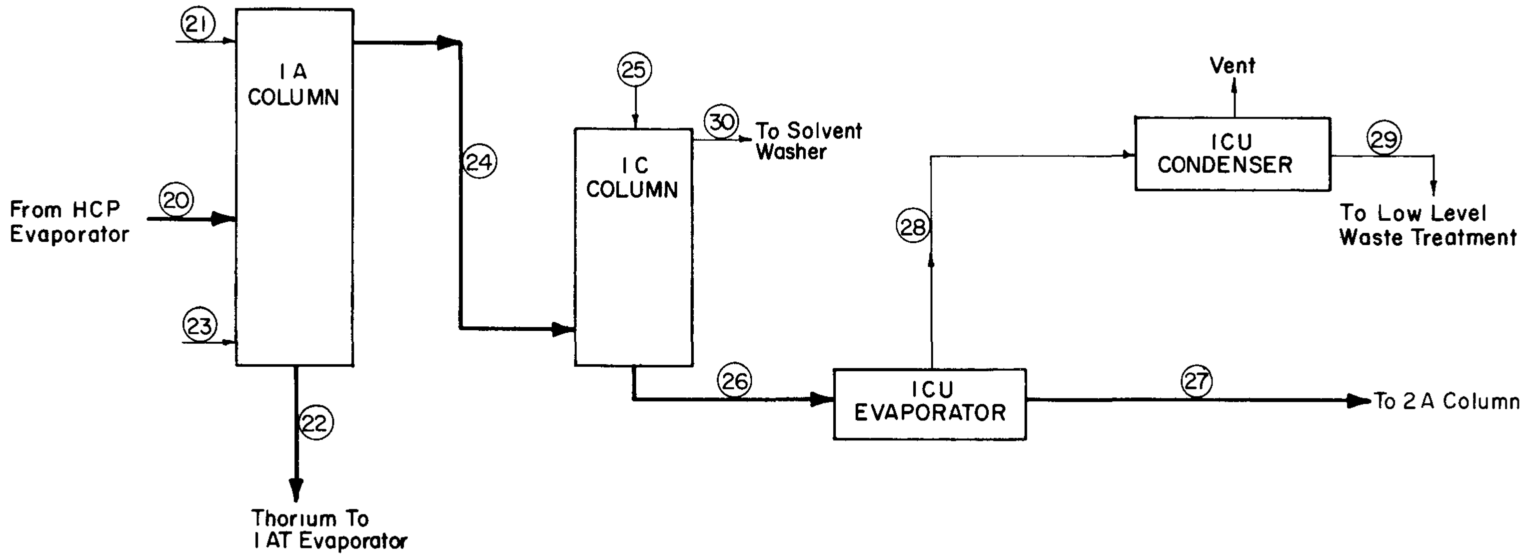
(1) Considers maximum Th carryover.

(2) Primarily U^{235} + some U^{233}.

(3) 30% TBP in Amsco.

(4) 5% TBP in Amsco.

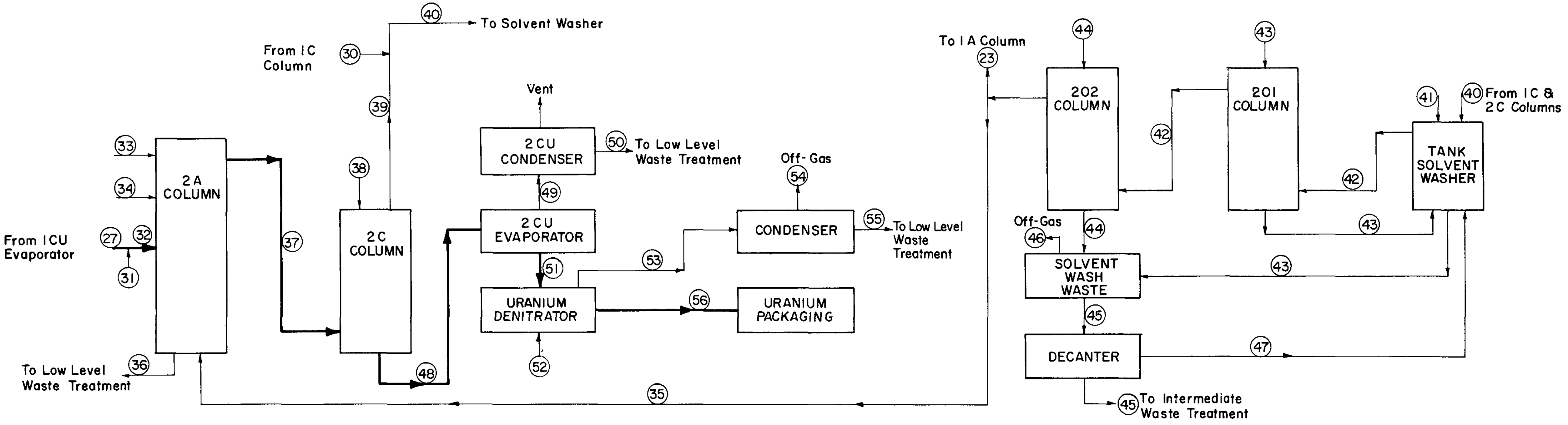
FIGURE 4-9
FLOWSHEET FOR H EXTRACTION CYCLE FISSILE PROCESS



STREAM	20	21	22	23	24	25	26	27	28	29	30
DESCRIPTION	IAF	IAS	IAT	IAX	IAU	ICX	ICU	ICU EVAPORATOR PRODUCT	ICU EVAPORATOR OFF-GAS	ICU EVAPORATOR CONDENSATE	ICW
Carbon, kg/d											
Thorium, kg/d	73.2		73.2								
Uranium, kg/d	14.2		0.026		14.2		14.2	14.2			
FP's, kg/d	0.08		0.08								
Al_2O_3, kg/d											
Th^{+++}, M	1.50		1.07								
UO_2^{+++}, M	0.288		<0.0004		0.0655		0.0655	0.301			
H^+, M	0.67	5.0	1.88		0.01	0.01	0.02	0.078		0.03	
Al^{+++}, M											
Cd^{+++}, M											
NO_3^-, M	7.26	5.0	6.17		0.14	0.01	0.14	0.62		0.03	
F^-, M											
Na^+, M											
HSO_3^-, M											
FP's^{++}, M	0.0036		0.0025								
Fe^{++}, M											
$NH_2SO_3^-$, M											
CO_3^{--}, M											
PO_4^{---}, M											
Liters/day	210	84	294	923(4)	923(4)	923	923	201		722	923(4)
Gallons/day	55.5	22.2	77.7	244(4)	244(4)	244	244	53.1		191	244(4)
Air, scfm											
O_2, scfm											
N_2, scfm											
NO + NO_3 + HNO_3, scfm									Trace		
Water Vapor, scfm									23.3		
CO_2, scfm											
CO, scfm											
Th, g/l	348		249								
U, g/l	67.6		0.09		15.4		15 4	70 6			
FP's, g/l	0.4		0.29								

(4) 5% TBP in Amsco diluent

FIGURE 4-10
FLOWSHEET FOR FIRST EXTPACTION CYCLE FISSILE PROCESS



STREAM	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
DESCRIPTION	2AA	2AF	2AS	2AIS	2AX	2AW	2AU	2CX	2CW	1CW & 2CW ORGANIC RAFFINATE	SOLVENT MAKE-UP	SOLVENT COLUMN FEED	2OB SCRUB	2OS SCRUB	2OW SOLVENT WASH WASTE	SOLVENT TREATMENT OFF-GAS	DECANTER SOLVENT	2CU	2CU EVAPORATOR OFF-GAS	2CU EVAPORATOR CONDENSATE	DENITRATOR FEED	FLUIDIZING AIR	DENITRATOR OFF-GAS	DENITRATOR CONDENSER OFF-GAS	ACID CONDENSATE	UO_3 PRODUCT
Carbon, kg/d																										
Thorium, kg/d																										
Uranium, kg/d		14.2				0.005	14.2											14.2			14.2					14.2$^{(3)}$
FP's, kg/d																										
Al_2O_3, kg/d																										
Th^{++++}, M																										
UO_2^{++}, M		0.25				4×10^{-5}	0.0433											0.0433			2.00					
H^+, M	11.7	2.05		3.5		2.5	0.01	0.01						0.4				0.02		0.01	0.33				4.3	
Al^{+++}, M																										
Cd^{++}, M																										
NO_3^-, M	11.7	2.55		3.5		2.5	0.10	0.01						0.4	0.2			0.1		0.01	4.33				4.3	
F^-, M																										
Na^+, M													0.4		0.2											
HSO_3^-, M																										
FP's^{++}, M																										
Fe^{++}, M																										
$NH_2SO_3^-$, M																										
CO_3^{--}, M													0.2													
PO_4^{---}, M																										
Liters/day	41	242	56	261	1397$^{(3)}$	559	1397$^{(3)}$	1397	1397$^{(3)}$	2320$^{(3)}$	Varies$^{(3)}$	2320$^{(3)}$	232	232	464		Varies$^{(3)}$	1397		1367	30.2				28.2	
Gallons/day	10.8	63.9	14.8	69.0	369.1$^{(3)}$	147.7	369.1$^{(3)}$	369.1	369.1$^{(3)}$	613$^{(3)}$	Varies$^{(3)}$	613$^{(3)}$	61.3	61.3	122.6		Varies$^{(3)}$	369.1		361.2	8.0				7.45	
Air, scfm																Varies						3.96	3.96	3.96		
O_2, scfm																										
N_2, scfm																										
$NO+NO_3+HNO_3$, scfm																			Trace				0.07	Varies		
Water Vapor, scfm																			44.1				0.79			
CO_2, scfm																										
CO, scfm																										
Th, g/l																										
U, g/l		58.7				0.009	10.1											10.2			470					
FP's, g/l																										

(3) 5% TBP in Amsco diluent.

(4) As UO_3

FIGURE 4-11
FLOWSHEET FOR SECOND EXTRACTION CYCLE FISSILE PROCESS

Two minor differences are apparent, aside from volume flow rates and total daily capacities. The first difference is in the thorium to uranium ratio in streams HAF, HAP, HCR, and 1AF. Proportionately more uranium is present in these streams on the fissile flowsheet. The second difference is one of stream numbering on the two flowsheets, beginning with stream 24 on the fissile flowsheet. In addition, the thorium-containing product (1AT) from the 1A column on the fissile flowsheet is routed to the thorium evaporator on the fertile flowsheet, since only one thorium evaporator (and product storage scheme) is necessary.

4.4 PRODUCT

The concentrated U-233 product could be routed directly from the 2CU evaporator receiver to the uranium loadout area for shipment directly to a fuel refabrication plant as a nitrate solution if the refabrication plant were adjacent to the processing plant. In the event that the refabrication plant is not located in the vicinity of the reprocessing facility (as is assumed in this report), denitration and conversion to solid uranium trioxide are desirable. Denitration of both the U-233 and U-235 product streams is accomplished in separate fluid-bed product denitrators to obtain final UO_3 products that are subsequently packaged for shipment to the AEC or the fuel refabricator.

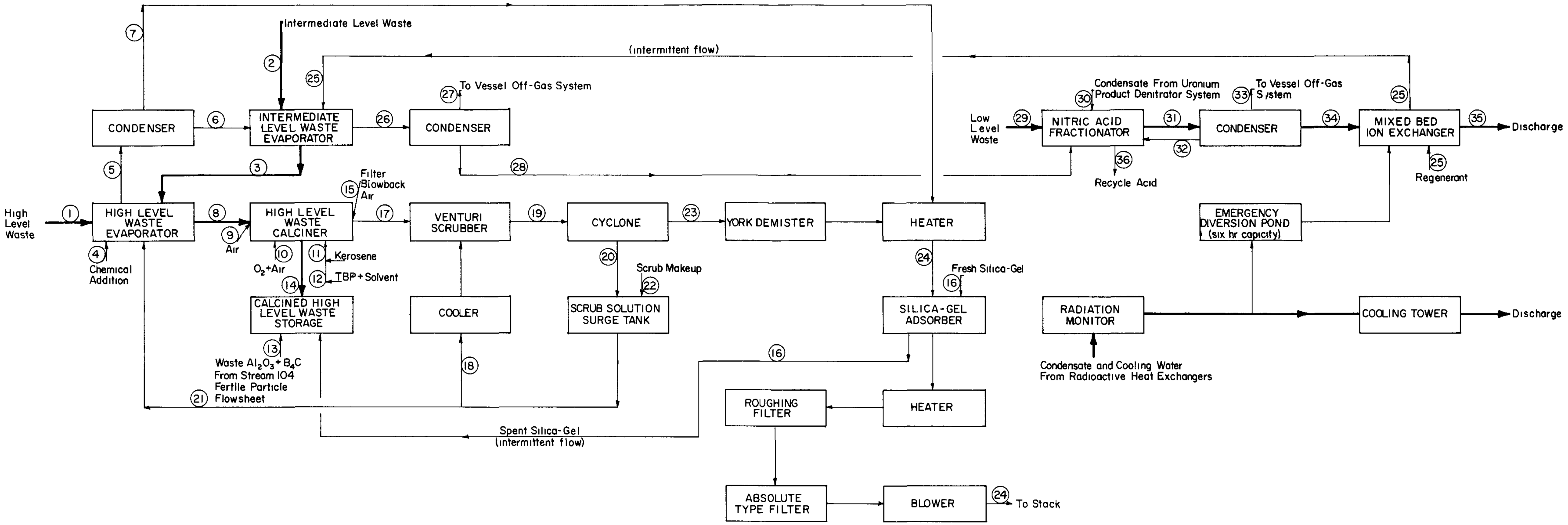
As described in Section 4.2, the thorium nitrate solution is stored for an indefinite period of time in stainless steel tanks. Product flowsheet information is shown with the solvent extraction flowsheets.

4.5 WASTE DISPOSAL

The bulk of the fission products along with nitric acid and various salts will be in the raffinate from both HA columns. The objective of the waste management scheme for the HTGR conceptual plant is to convert these fission products and salts to a solid form that can be stored indefinitely in a manner that precludes release of radioisotopes to the environment.

4.5.1 Liquid Wastes

In general, the liquid waste disposal flowsheet, shown in Figure 4-12, consists of three waste streams: high-, intermediate-, and low-level waste. Cooling water and condensate from radioactive heat exchangers are not normally defined as a low level liquid waste; although, this waste is monitored for radiation prior to



STREAM / DESCRIPTION	1 HIGH LEVEL WASTE (a)	2 INTERMEDIATE LEVEL WASTE (b)	3 EVAPORATOR BOTTOMS	4 CHEMICAL ADDITION	5 EVAPORATOR OFF-GAS	6 EVAPORATOR CONDENSATE	7 CONDENSER OFF-GAS	8 WASTE CALCINER FEED	9 FEED ATOMIZING AIR	10 FLUIDIZING OXYGEN	11 KEROSENE FUEL	12 SPENT TBP SOLVENT (c)	13 WASTE SOLIDS FROM HEADEND	14 CALCINED WASTE	15 BLOWBACK AIR	16 SILICA GEL MAKE UP	17 CALCINER OFF-GAS	18 SCRUB SOLUTION	19 OFF-GAS TO CYCLONE	20 SCRUB SOLUTION RETURN	21 SCRUB SOLUTION RECYCLE	22 SCRUB SOLUTION MAKE-UP	23 CYCLONE OFF-GAS	24 OFF-GAS	25 ION EXCHANGE REGENERANT	26 EVAPORATOR OFF-GAS	27 CONDENSER OFF-GAS	28 EVAPORATOR CONDENSATE	29 LOW LEVEL WASTE (e)	30 CONDENSATE FROM PRODUCT DENITRATORS	31 FRACTIONATOR OFF-GAS	32 FRACTIONATOR REFLUX	33 CONDENSER OFF-GAS	34 CONDENSATE	35 DISCHARGE WATER	36 13M ACID RECYCLE
Th, kg/d	2.58																																			
FP's, kg/d	65.4													65																						
Total Solids Calcined														218																						
Al_2O_3+SiC+B_4C kg/d													661																							
SiO_2, kg/d																Varies																				
Th^{++++}, M	0.0015							0.0042																												
H^+, M	1.94	0.196	2.23			0.25		6.30										4.0	4.0	4.0	Varies	13				0.12		0.12	0.23	5.2		0.01		0.01		13
Na^+, M	0.021	0.041	0.82	0.054				0.06																												
Al^{+++}, M	0.0651							0.186																												
Fe^{+++}, M	0.0037							0.011																												
Cd^{++}, M	0.0532							0.151																												
Ca^{++}, M				1.1				0.042																												
FP's^{+++}, M	0.0758							0.217													Varies															
NO_3^-, M	2.44	0.237	3.05	2.2		0.25		7.80										4.0	4.0	4.0	Varies	13				0.12		0.12	0.23	5.2		0.01		0.01		13
$SO_4^=$, M																																				
$PO_4^{\equiv}$, M	0.0035							0.01																												
$BO_3^{\equiv}$, M								0.004																												
$B_4O_7^=$, M				0.027																																
OH^-, M																																				
F^-, M	0.0276							0.077																												
HSO_3^-, M	0.021							0.06																												
$NH_2SO_3^-$, M	0.0075							0.021																												
Liters/day	7429	33,420	1671	100		6585		2615										14,500	14,500	14,500	Interm't	Varies			Interm't	38,335		38,300	8995	81		23,000		46,870	46,870	509
Gallons/day	1963	8830	441	26		1740		691			288	Varies						3,840	3,840	3,840	(d)					10,130		10,130	2376	21		6,077		12,380	12,380	134
Air, scfm							Varies		29						1												Varies						Varies			
O_2, scfm										55							14						14	14												
N_2, scfm																	23						23	23												
NO + NO_2 + HNO_3					0.96		Varies										Trace						Trace	Trace		3					Trace					
Water Vapor, scfm					210												117						117	117		1230					2255					
CO_2, scfm																	55						55	55												

(a) High Level Waste is from stream 7 on both the fertile and fissile solvent extraction flowsheets

(b) Intermediate Level Waste includes streams 17, 25, 27, 41, and 51 of the fertile flowsheet, 12, 17, 36, and 45 from the fissile flowsheets for solvent extraction, and 34 and 103 from the headend flowsheets

(c) Spent TBP-Solvent used as calciner fuel is available intermittently

(d) Scrub solution surge tank solution to WCF when FP conc warrants

(e) Includes low level waste from streams 35 and 55 from the fertile solvent extraction flowsheets, 29 and 50 from the fissile solvent extraction flowsheets, and 52 from the headend flowsheets

FIGURE 4-12
FLOWSHEET FOR AQUEOUS WASTE DISPOSAL

being discharged. If the radiation monitor indicates radioisotopes (indicative of faulty equipment), this stream can be diverted to a holding pond on an emergency basis and subsequently treated as a low-level waste.

The high-level waste includes the aqueous raffinate from both HA columns (both HAW streams), and the intermediate-level waste evaporator bottoms. This high-level waste is routed to the waste evaporator where it is mixed with calcium nitrate and sodium tetraborate Calcium is added to insure formation of solid calcium fluoride in subsequent calcination, while the presence of boron prevents the formation of alpha alumina During evaporation, the total nitrate concentration is limited to six molar; this serves as a precautionary step to prevent loss of ruthenium as ruthenium tetroxide (formed at higher nitrate concentrations). However, after the two headend burning steps, only small amounts of ruthenium may be present in the high-level waste. The condensate from the waste evaporator is fed to an intermediate-level waste evaporator for decontamination while the bottoms are transferred to the waste calcining facility for conversion to solids.

The concentrated high-level waste is fed into a fluidized bed calciner utilizing air as the atomizing gas. With the exception of calciner startup, the calcined waste is the fluidized bed media For startup, dolomite is added to form the initial bed During operation, bed particle growth by waste deposition is offset by particle attrition and by bed withdrawal so that a steady-state particle distribution develops in a relatively short time Calciner operating temperature is maintained by burning kerosene or spent TBP-Amsco solvent in the fluidized bed Combustion is initiated by preheating the bed with externally heated air to about 700°F.

At the calciner operating temperature of 900°F, with an in-bed combustion heating system nitrate salts of fission products and other cations decompose into nitrogen, oxygen, and oxide solids Fluorine is retained in the calcine as the stable calcium fluoride; both sulfate and any phosphates are also retained as stable salts. Prior to passing into the scrub system, most of the particulate matter entrained in the calciner off-gas is removed by sintered metal filters located at the top of the calciner. An air-pulsed blowback system periodically blows the solids off the sintered metal filters and returns them to the calciner. Additional removal of particulate matter occurs in the venturi scrubber where the cooled calciner off-gas is contacted with a $4\underline{M}$ HNO_3 scrub solution. Liquid droplets of nitric acid and dissolved solids are removed in the cyclone and demister downstream of the venturi, and sent to the scrub solution surge tank for recycle and periodic transfer to the high level waste evaporator.

Off-gas from the waste calcining facility joins the non-condensable off-gas stream from the high-level waste evaporator condenser. This off-gas stream is then circulated through a shell-and-tube-type heat exchanger to maintain a temperature higher than the dew point of the gas prior to entry into the ruthenium adsorbers. The ruthenium adsorbers consist of columns packed with silica-gel, which selectively adsorbs ruthenium tetroxide from the calciner off-gas. Additional heat is provided prior to the final cleanup of the off-gas--cleanup that is accomplished by remotely removable filter units installed in parallel. After this final cleanup, the off-gases are vented through the plant stack.

The solid calcine produced by decomposition of fission products and other cations is removed continuously from the waste calciner and transported pneumatically to underground storage containers where the calcine is mixed with other solid waste (primarily waste alumina and silicon carbide hulls). Periodically, silica-gel from the ruthenium adsorbers is also added to the underground storage facility.

Intermediate-level wastes have radioisotope concentrations low enough such that no thermal problems arise from fission product decay heat, but high enough to require treatment. Intermediate-level wastes arise primarily from the following sources:

1. Head-end stripper condensate
2. Solvent wash wastes from the three solvent treatment systems
3. Condensates from the HCP and thorium evaporators
4. Aqueous waste from the 2A columns (2AS streams)
5. Condensate from the high-level waste evaporator
6. Regenerant from periodic elution of the ion exchange columns
7. Streams resulting from periodic decontamination of process equipment.

Intermediate-level waste processing consists of concentrating the solution in a waste evaporator. The evaporator bottoms are sent to the high-level waste evaporator; the overheads are condensed and this condensate contains some nitric acid and enough fission products that it can not be discharged directly to the environment. For additional decontamination, therefore, the condensate is blended with the low-level waste stream for additional treatment.

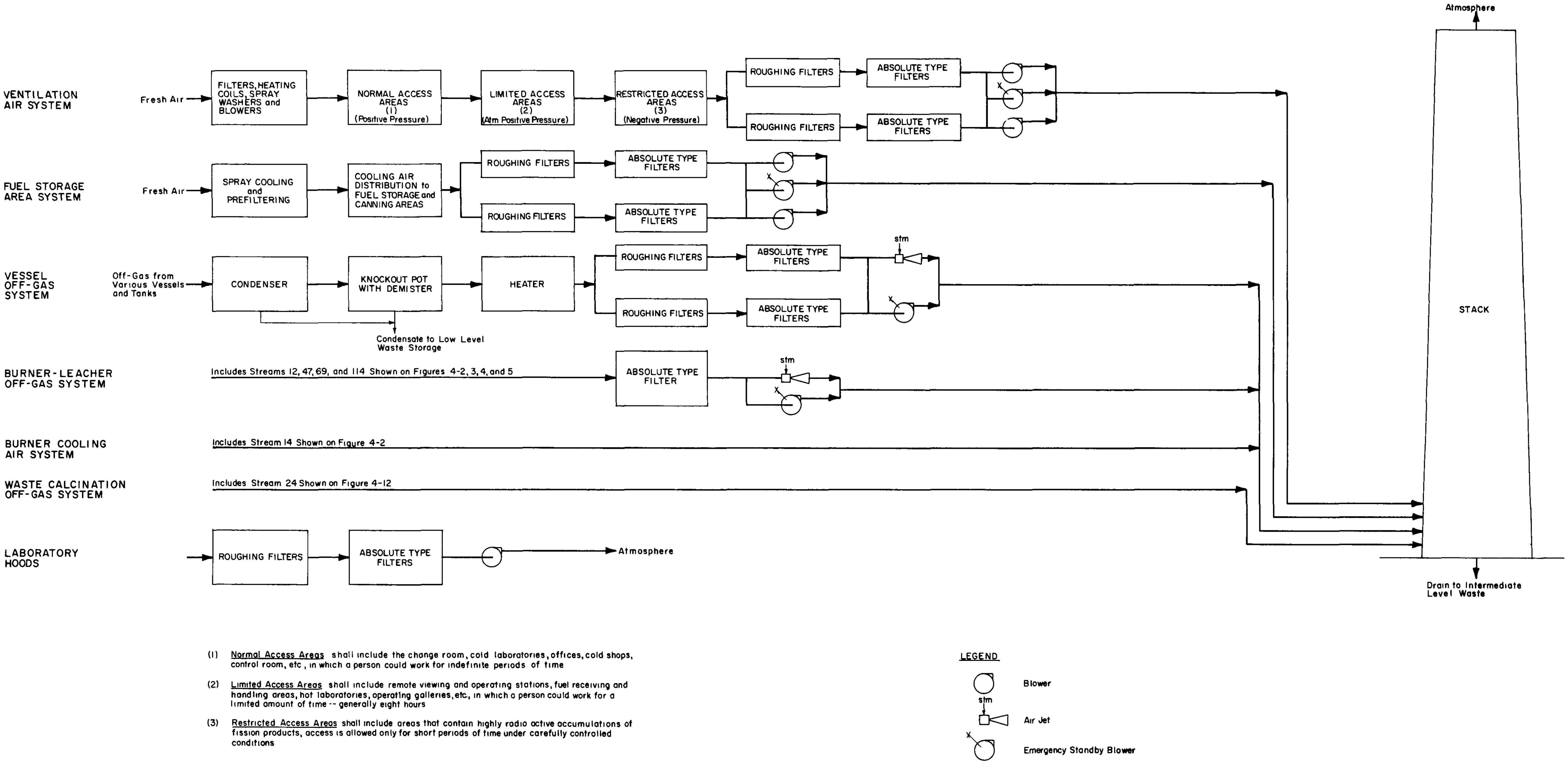
Low-level wastes originate primarily as condensed overhead vapors from the intermediate-level waste evaporator, from the 1CU and 2CU evaporators and the nitric acid from the uranium product denitrators. The high nitric acid concentration of low-level waste would lead to frequent regenerations of the anion exchange resin; consequently, the low-level waste is first fed to a nitric acid fractionator to remove and recover nitric acid. The concentrated acid contains the bulk of the fission products present in the low-level waste and is recycled to a process acid tank for reuse in the head-end leacher. The fractionator overheads are routed to the mixed-bed ion exchanger columns for final purification before being discharged to the environment

Final fission product removal occurs in the mixed-bed ion exchange columns. The sequence in which the waste effluent is treated is important, since at low pH values, cesium and strontium are not effectively removed from solution on the cation exchange resin Therefore, the low-level waste is first percolated over a strong-base anion exchange resin to remove residual nitric acid and traces of ruthenium that may be present in the waste. Following base exchange, the low-level stream is percolated over a strong-acid cation exchange resin to effectively remove cesium, strontium or other cation radionuclides. Caustic and nitric acid regeneration solutions are periodically pumped through the anion and cation exchange beds, respectively. The eluted streams containing fission products are cycled back to the intermediate level waste evaporator. After passage through the ion exchange columns, the low-level waste is either discharged to the environment after suitable monitoring or reused in the solvent extraction flowsheet.

Other potential sources of low-level wastes include the effluents from the radioactive service tank coils and the evaporator steam condensates. Normally, however, these secondary sources are free of contamination. However, as previously indicated, this stream is continuously monitored. The detection of activity in this stream requires immediate corrective action in the form of routing the stream into a diversion pond with a six-hour capacity to allow shutdown of process equipment or determination and correction of the defect. After shutdown, water in the diversion pond is processed through the ion exchange columns used for low-level waste.

4.5.2 Gaseous Waste

The gaseous waste disposal system is to consist of two main systems: (1) ventilation air and (2) process off-gas. The ventilation system is briefly described in Section 2; most of the process off-gas system, consisting of several subsystems, have been briefly described in prior portions of Section 4 and is shown in Figure 4-13. Combined effluent gas of the plant will be monitored and sampled at the stack.



(1) Normal Access Areas shall include the change room, cold laboratories, offices, cold shops, control room, etc, in which a person could work for indefinite periods of time

(2) Limited Access Areas shall include remote viewing and operating stations, fuel receiving and handling areas, hot laboratories, operating galleries, etc, in which a person could work for a limited amount of time -- generally eight hours

(3) Restricted Access Areas shall include areas that contain highly radio active accumulations of fission products, access is allowed only for short periods of time under carefully controlled conditions

FIGURE 4-13
FLOW DIAGRAM FOR GASEOUS WASTE DISPOSAL

The plant off-gas system is composed of the following subsystems:

1. Burner-Leacher Off-Gas (BLOG)
2. Vessel Off-Gas (VOG)
3. Waste Calcination Off-Gas
4. Ventilation Air System
5. Burner Cooling Air
6. Fuel Storage Area Cooling System
7. Laboratory Hood Ventilation System

Other off-gas originates in miscellaneous facilities; if non-radioactive, this gas can be discharged to the atmosphere directly, after suitable cleanup.

In general, fission products and particulate matter are to be removed by combinations of scrubbers, filters, condensers, and packed beds. The bulk of the contamination is to be removed near its source, so that it can be returned to the process system from which it originated. Final cleanup of the off-gas by roughing and absolute-type high efficiency filters is to be performed on the combined gas systems as shown in Figure 4-13.

4.5.3 Solid Waste

High-activity solid waste is produced mainly from the waste calciner; because of its high specific heat generation, it must be stored in cooled containers indefinitely in suitable underground vaults. Other solid waste, such as unfueled portions of fuel elements, that have a relatively low specific activity level will be placed in drums; the drums will be decontaminated prior to placement in a shielding cask or shipping container for transportation to an on-site burial ground. Other miscellaneous solid waste, such as spent ventilation filters and discarded equipment, will also be buried.

4.6 PROCESS ALTERNATIVES

The processing facilities thus far described are specifically for the HTGR reference fuel as described in Section 3, ie, for the situation where both the fissile and fertile particles are coated with silicon carbide. There is a possibility, however, that the fuel particles in some or all of the HTGR fuels will differ from those for the reference fuel. Such a possibility alters the process requirements and several alternatives must be considered as follow: (1) fertile particles uncoated, fissile particles coated; (2) all particles uncoated; and (3) more than a two particle system.

In addition, two alternatives exist with respect to processing objectives: (1) packaging and storing the fissile particles rather than reprocessing, and (2) shipping recovered U-233 as a nitrate solution rather than as the solid oxide.

Flow diagrams for these various alternatives are shown in Figure 4-14. All process changes for these alternatives can be accomplished in the head-end flowsheet with little or no change required to the solvent extraction process. A description of each of the alternatives follows.

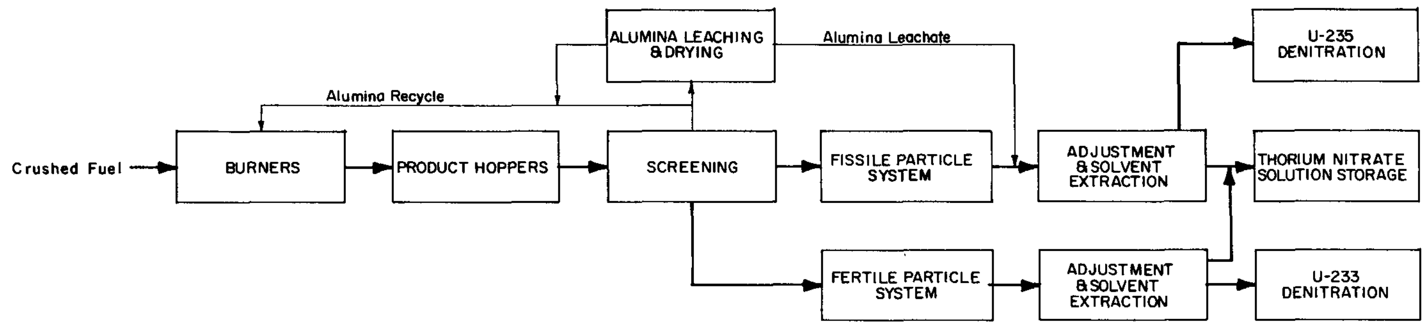
The Reference Process is that already described for the reference HTGR fuel and is presented here for comparative purposes. Equipment changes from the reference process are indicated in the process alternatives by cross-hatching.

Process Alternative 1 assumes the fissile particles will not be processed. This will eliminate the need for equipment for fissile particle crushing, burning, and leaching, but will require installation of a packaging facility and particle storage equipment in a water-filled canal. Other equipment in the reference process is unaffected.

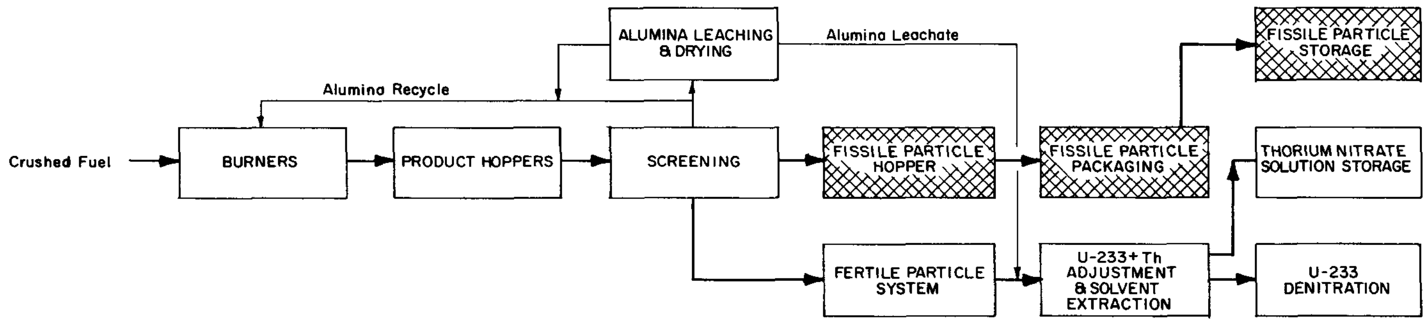
Process Alternative 2 requires no change in either the headend or solvent extraction portions of the process. The U-233 denitration step will be omitted and the U-233 will be packaged as a nitrate solution in polyethylene containers. The reasons for this procedure are discussed in Section 5.

Process Alternative 3 assumes the absence of silicon carbide coatings on both types of fuel particles. The particles are coated only with pyrolytic carbon; thus, all heavy metals and fission products will be exposed in the fluidized bed burner. For this alternative, the

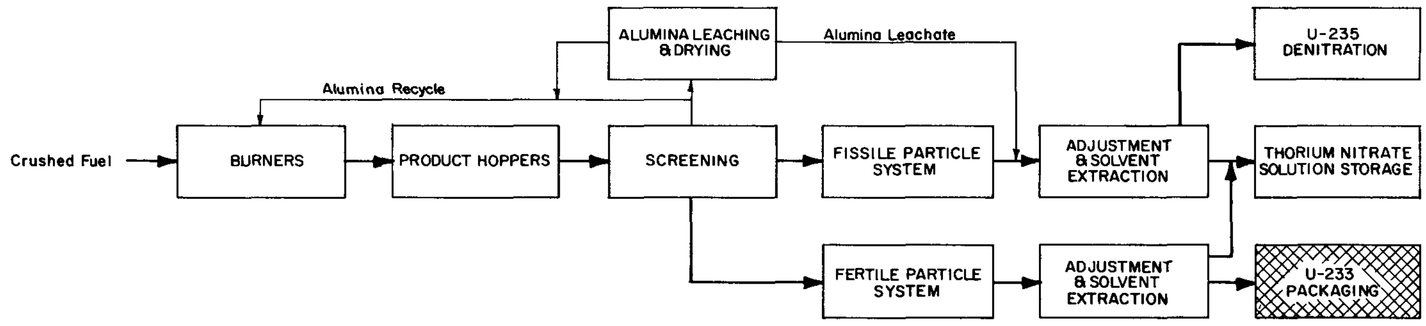
A. REFERENCE PROCESS (two types of SiC-coated particles)



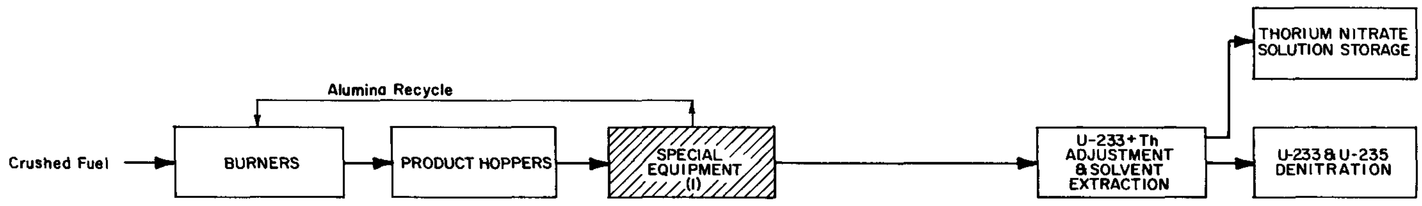
B. PROCESS ALTERNATIVE 1 (fissile particles packaged and stored)



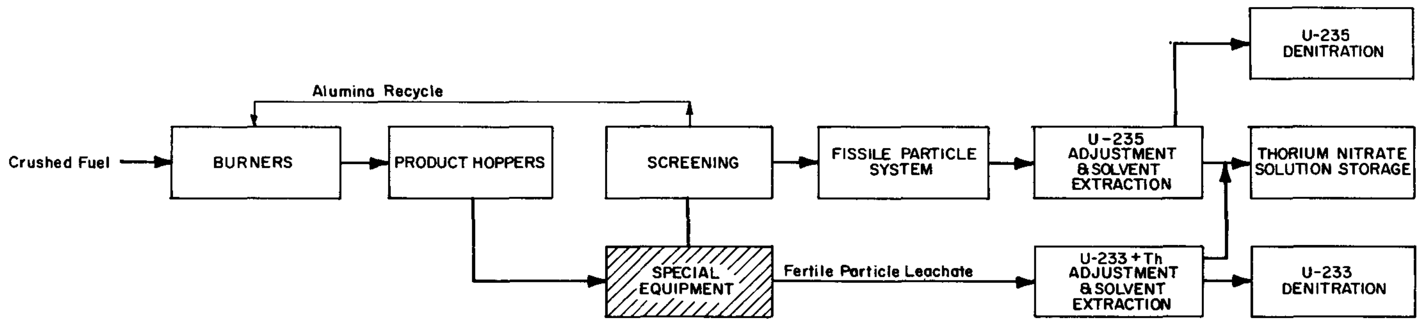
C. PROCESS ALTERNATIVE 2 (U-233 shipped as a nitrate solution)



D. PROCESS ALTERNATIVE 3 (all particles uncoated)



E. PROCESS ALTERNATIVE 4 (fertile particles uncoated, fissile particles SiC coated)



(1) The Special Equipment Consists Of The Following:

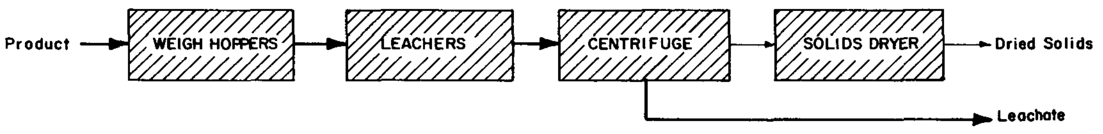


FIGURE 4-14
COMPARISON OF ALTERNATIVE CASES

screening equipment and both particle cycles are omitted; however, other equipment will be required as indicated by footnote. For this case, the entire contents of the bed would be transferred to a weigh hopper which feeds the process leacher. The operation of this leacher will be similar to that described for the alumina leacher in Section 4.1.2. Solids consisting mainly of alumina would be separated from the leachate, dried, and recycled to the burner. The leachate would be adjusted to 1.5M thorium and then fed to the solvent extraction process.

Process Alternative 4 assumes that only the fissile particles are coated. The reference fuel steps for fertile-particle crushing and burning can be eliminated. The new equipment required (indicated by footnote), must be capable of leaching the contents of the bed from the burner prior to removal of the fissile particles. The solids, mainly alumina and unbroken fissile particles are separated from the leachate in a centrifuge, dried, and screened The alumina is recycled to the burner, while the fissile particles either are transferred to storage or processed to recover U-235. The leachate passes through the feed adjustment system (nitric acid is stripped and sodium bisulfite is added) prior to being fed to the solvent extraction system.

The reference flowsheet or one of the Process Alternatives could be employed for essentially any graphite matrix fuel, even those containing more than two particles. That is, regardless of whether (1) the particles are coated, (2) only the fissile particles are coated, or (3) none of the particles are coated, one of the alternatives as already specified should be adequate to reprocess the spent fuel satisfactorily

5. CRITERIA FOR PROCESS EQUIPMENT

Criteria for designing the major pieces of processing equipment for the HTGR fuel reprocessing plant are presented in this section. Design of the other equipment should be based on the general design concepts presented in Section 2 and the chemical flowsheets in Section 4; facilities for fuel handling and storage are described in Section 6. Storage tanks are sized to maintain continuous equipment operation while allowing adequate time for process control and accountability samples and results.

5.1 HEADEND PROCESSING EQUIPMENT

5.1.1 General Considerations

Canned fuel will be remotely transferred from storage to the crusher cell for the headend step. Since the crusher cell will probably have a higher level of contamination than the fuel storage areas, the transfer system should be designed to minimize inter-cell contamination. Dusting will be a problem in all headend areas where dry solids are handled; consequently, this equipment must be specially designed (or off-the-shelf-items modified) accordingly.

Most of the headend equipment will need to be cooled because of fission product decay heat. This heat will be removed by air cooling where dry solids are handled and by water cooling where solutions are present. Solids contained in the various hoppers probably should be cooled by contact with air rather than being cooled through a heat transfer surface such as the vessel or tubing walls. Cooling air from the storage and feed hoppers will be filtered to remove particulate material and used as transport air whenever possible. Dust should be centrally collected and returned automatically to the process equipment from the crushing, cutting, grinding, and screening steps. The use of sintered metal filters with automatic pulse blowback systems in these processes is desirable. Equipment should be arranged to provide gravity feed wherever possible; when not possible, transport air systems should be used to minimize mechanical equipment in radioactive areas. Headend equipment should be designed to minimize the breakage of the SiC-coated fuel particles. Specific design criteria for the headend equipment are tabulated in Table 5-1 and discussed in the following paragraphs.

TABLE 5-1 (Continued)

Item	Number Required	Capacity (each)	Heat Duty (Btu/hr)	Diameter (inches)	Height (feet)	Operating Temperature (°F)	Operating Pressure (psig)	Materials of Construction
Acid Rinse Tank (Centrifuge)	1	25 gal				100	-1/4	304L SS
Composite Leachate Receiver Tank	1	180 gal	18,200			250	-1/4	304L SS
Composite Stripper Feed Tank	1	225 gal	23,400			250	-1/4	304L SS
Stripper	1	54 gal				275	-1/4	304L SS
Reboiler			1.5×10^5	18	1.7			
Tower		(Packed with 3/4" Raschig Rings)		8	10			
Sparger		35 lb/hr steam				328	100	304L SS
Cooler		2.1 gph	2.5×10^3			275	-1/4	304L SS
Condenser		15.6 gph	1.5×10^5			275	-1/4	304L SS
Stripper Receiver Tank	1	40 gal	18,200			200	-1/4	304L SS
Solvent Extraction Feed Tank	1	50 gal	23,000			200	-1/4	304L SS
Condensate Receiving Tank	1	700 gal				200	-1/4	304L SS
Evaporator	1	82 gph	4.0×10^5			250	-1/4	304L SS
Evaporator Condenser	1	41 gph	4.0×10^5			250	-1/4	304L SS
Recycle Acid Storage	1	600 gal				100	-1/4	304L SS
4. <u>ALUMINA CLEANUP SYSTEM</u>								
Alumina Hopper	1	3.7 ft^3	270	15	3	300	-1/4	304 SS
Alumina Weigh Hopper	1	2.0 ft^3	150	12	2.5	300	-1/4	304 SS
Leacher Acid Makeup Tank	1	8 gal				100	-1/4	304L SS
Leacher	1	29 gal				250	-1/4	309 SCb SS
Lower Section				15	1.4			
Upper Section				20	1.0			
Heat Exchanger - Recirculating Line			5×10^5					309 SCb SS
Heat Exchanger - Coils in Solution Reservoir			20,000					309 SCb SS
Condenser		2 gpm	1×10^6			250	-1/4	309 SCb SS
Centrifuge Acid Rinse Tank	1	2 gal				100	-1/4	304L SS
Centrifuge	1	7 gph solution 180 lb/hr solids 2 gph 13$\underline{M}$ HNO_3 Wash 2 gph H_2O Wash				200	-1/4	304L SS
Solids Drying Hopper	1	3.5 ft^3				200	-1/4	304L SS
Air Heater	1	2400 scfh Air	8,000			200	-1/4	304 SS
Off-Gas Condenser	1	5 lb/hr H_2O	13,000			200	-1/4	304L SS
Leachate Receiver Tank	1	12 gal	150			200	-1/4	304L SS

(1) All heat will be removed through the annulus.

TABLE 5-1

HEADEND PROCESSING EQUIPMENT

Item	Number Required	Capacity (each)	Heat Duty (Btu/hr)	Diameter (inches)	Height (feet)	Operating Temperature (°F)	Operating Pressure (psig)	Material of Construction
1. BURNER SYSTEM								
Saw	1	See Section 5.1						304 SS
Crushers, Jaw Type	2	6.5 tons/day	1400			300	-1/4	304 SS
Crushed Fuel Hoppers	4	64 ft^3	8400	42	6	300	-1/4	304 SS
Feeders, Airlock Type	4	1 ft^3	135			300	-1 to +10	304 SS
Burners	4	300 ft^3	3.2×10^6			1380		310 SS
Fluidized Bed Section				42	8			
De-entrainment Section				72	8		-1	
Heaters, Electrical	2 banks		30 kW					
Gas Preheater		167 scfm	265,000			1380	5	304 SS
Helix exhaust gas cooler	150 feet	166 scfm	30,000	1		1380	-1	304L SS
Burner Cooling Air Compressors	2 (min)	18,000scfm/Burner				100	10	304 SS
Burner Product Hopper	1	77 ft^3	33,400	42	8	300	-1/4	304 SS
Screen Separator	1	8 tons/day	2800			300	-1/4	304 SS
Burner Bed Dump Hopper	1	40 ft^3	2800	36	6	300	-1/4	304 SS
2 FERTILE PARTICLE SYSTEM								
Fertile Particle Hopper	1	15 ft^3	17,000	30	3	300	-1/4	304 SS
Crusher, Double-Roll	1	3500 lb/day	17,000			300	-1/4	304 SS
Crushed Particle Hopper	1	15 ft^3	17,000	30	3	300	-1/4	304 SS
Weigh Hopper	1	15 ft^3	17,000	30	3	300	-1/4	304 SS
Crushed-Particle Burner	1	15 ft^3	300,000	30	3	1380	-1/4	310 SS
Heaters, Electrical	2 banks		25 kW					
Gas Preheater	1	28 scfm O_2-Air	45,000			1380		
Cooling Tubes	50	326 scfm	50,000	1	3	1380	10	
Condenser	1	28 scfm	50,000			1380	-1/4	
Leacher Feed Hopper	1	15 ft^3	17,000	30	3	300	-1/4	304 SS
Leacher	1	1000 gal			13	250	-1/4	309 SCb SS
Lower Section				30				
Upper Section				48				
Heat - Recirculating Line			1.0×10^6					309 SCb SS
Exchanger - Solution Coils			1.5×10^6					309 SCb SS
Condenser			2 0 x 10^6					309 SCb SS
Leacher Acid Makeup Tank	1	580 gal				100	-1/4	304L SS
Centrifuge	1	350 lb solids- 525 gal solution/hr 262 gph HNO_3 Wash 262 gph H_2O Wash				100	-1/4	304L SS

TABLE 5-1 (Continued)

Item	Number Required	Capacity (each)	Heat Duty (Btu/hr)	Diameter (Inches)	Height (feet)	Operating Temperature (^oF)	Operating Pressure (psig)	Material of Construction
Leachate Receiver Tank	1	900 gal	17,000			200	-1/4	304L SS
Solids Drying Hopper	1	14 ft^3				200	-1/4	304L SS
Air Heater	1	4000 scfh	8,000			200		304L SS
Off-Gas Condenser	1	20 lb/hr H_2O	30,000			200	-1/4	304L SS
Stripper Feed Tank	1	1200 gal	26,000			200	-1/4	304L SS
Stripper	1	210 gal				275	-1/4	304L SS
Reboiler			6.4×10^5	40	3.3			
Tower		(Packed with 3/4" Rashcig Rings)		17	10			
Sparger		170 lb/hr steam						
Cooler			5.0×10^4			275	-1/4	304L SS
Condenser			1.0×10^6			275	-1/4	304L SS
Stripper Receiver Tank	1	400 gal	18,000			200	-1/4	304L SS
Solvent Extraction Feed Tank	1	500 gal	22,500			200	-1/4	304L SS
3. FISSILE PARTICLE SYSTEM								
Fissile Particle Hopper	1	6 ft^3	17,200	24	2	300	-1/4	304 SS
Crusher, Double-Roll	1	0.54 tons/day	1,500			300	-1/4	304 SS
Crushed Particle Hopper	1	6 ft^3	17,200	24	2	300	-1/4	304 SS
Weigh Hopper	1	6 ft^3	17,200	24	2	300	-1/4	304 SS
Crushed Particle Burner(1)	1	6 ft^3	84,000	24	2	1380	-1/4	310 SS
Heaters, Electrical	2 banks		20 kW					
Gas Preheater	1	6.3 scfm O_2-Air	1×10^4			1380		
Condenser	1	6.3 scfm	1×10^4					
Leacher Feed Hopper	1	6 ft^3	17,200	24	2	300	-1/4	304 SS
Leacher Acid Makeup Tank	1	125 gal				100	-1/4	304L SS
Leacher	1	300 gal			8	250	-1/4	309 SCb SS
Lower Section				24	2			
Upper Section				36	4			
Heat - Recirculating Line			1×10^6					309 SCb SS
Exchanger - Coils in Solution Reservoir			1.5×10^5					309 SCb SS
Condenser		2 gpm H_2O	2×10^6			250	-1/4	309 SCb SS
Centrifuge	1	125 gph solution 470 lb/hr solids 25 gph HNO_3 Wash 25 gph H_2O Wash				200	-1/4	304L SS

5.1.2 Bulk Fuel System

Fuel element cutting equipment, consisting of a remotely-operated saw and feed mechanism, will be provided to remove non-fueled sections, such as the graphite reflector sections from the Peach Bottom fuel elements, and to reduce the size of non-standard fuel elements. The facility will also be used to remove the canisters used for storage at the reactor site from the Peach Bottom fuel elements. The size and shape of future HTGR fuel elements may differ from those assumed in this report. Therefore, the cutting facility should have the capability for handling various sized elements in the future with minimum modification and expense.

The graphite fuel blocks and elements will be crushed into small pieces (less than one inch in diameter so that they can be fed to the burners) by two jaw-type crushers, each serving two burners Reference-type fuel possibly could be fed to the crushers directly from the fuel storage containers. A storage container could be oriented vertically, the lid removed, the container sealed to the crusher, and then tilted to the horizontal position for gravity feed to the crusher. The crushed fuel elements will be collected in four crushed-fuel hoppers, each sized to hold enough material for approximately 12 hours of burner operation at the design rate. One hopper will serve each burner. Crushed fuel from the hoppers will be automatically charged to the burners at ten-minute intervals by airlock feeders.

Each of the four burners will be an air-cooled vessel containing a bed of fluidized alumina, graphite lumps, and fuel particles. A diagram of the burner is shown in Figure 5-1. The crushed fuel, added through a top entry line, and the alumina bed, added through a side entry nozzle, are supported by an internal grid During startup, the alumina bed in the burner will be heated to operating temperature by a combination of (1) remotely-replaceable electrical heaters installed on the vessel wall inside the annulus, (2) preheating the fluidizing air, and (3) introducing low-ignition-temperature carbon to the bed During operation, a mixture of oxygen and air (80 v/o O_2 - 20 v/o N_2) will be metered, preheated, and introduced into the fluidized bed through a plenum chamber and distributor plate. The rate of oxygen addition controls the burning rate. If a sintered-metal distributor plate is used, the oxygen and air must be specially filtered to remove essentially all particulate matter and oil to prevent pluggage of the distributor plate with particles or carbon. If a bubble-cap-type distributor plate is used, no special precautions need be taken.

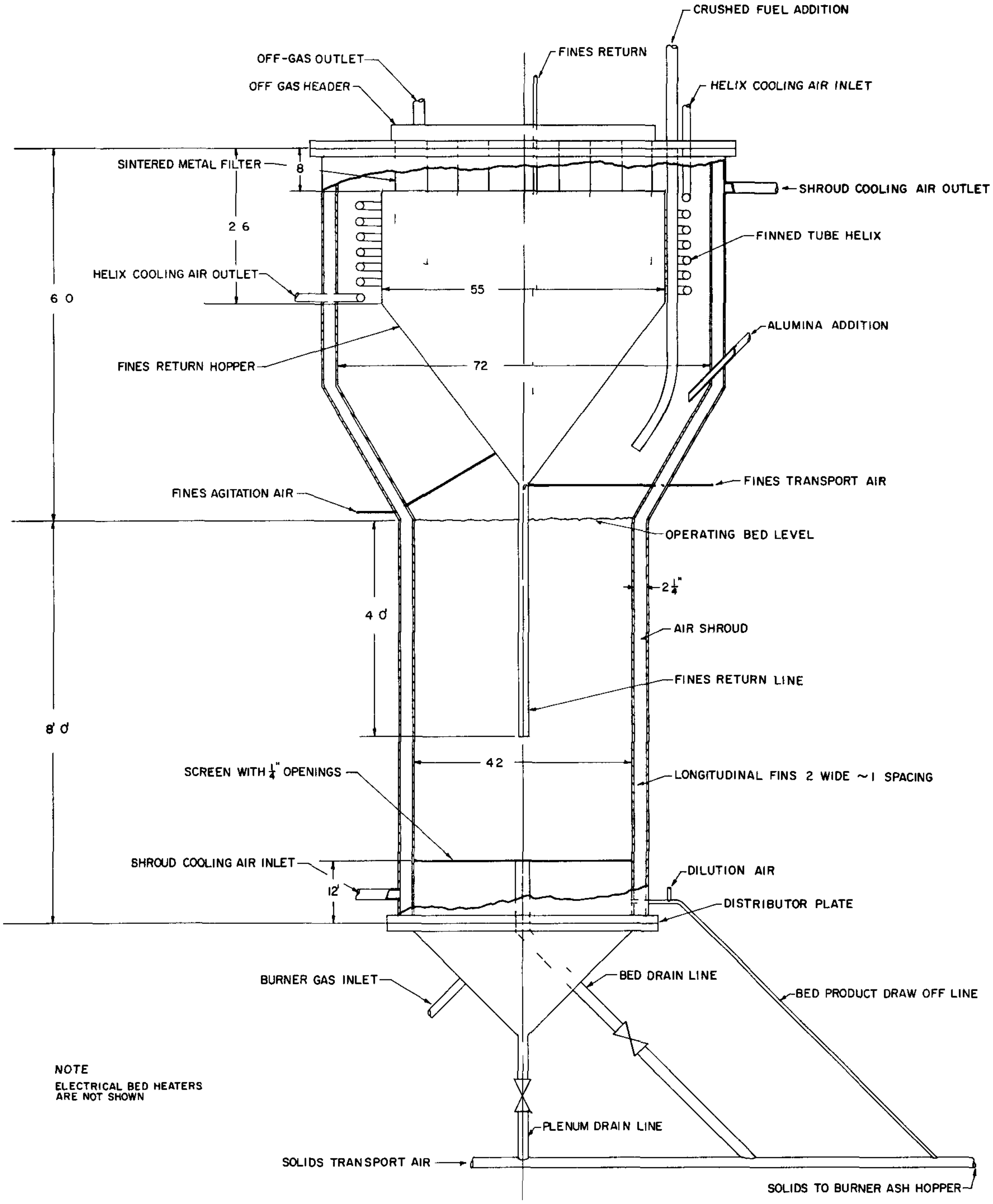


Figure 5-1

Conceptual Fluidized Bed Burner

Fluidizing and combustion gases, primarily CO_2, will be cooled to about 550°F and filtered through sintered metal (stainless steel) filters to retain particulate matter in the burner. A finned-tube (16 fins/inch) exchanger, located near the top of the de-entrainment section, cools the combustion gases before they pass through the sintered metal filters. A pulse blowback system incorporated with the sintered metal filters periodically returns a portion of the collected particulates on the filters to the fluidized bed by way of a fines return hopper in the de-entrainment section. An air line in the bottom section of the hopper transports the fines into the fluidized bed while an air line near the bottom of the hopper agitates the fines to prevent plugging of the fines return line.

The normal load of 18,000 scfm of cooling air (at 10 psig) to each burner will be supplied by a minimum of two compressors for the four burners. The heat from the exothermic reaction of carbon and oxygen will be removed by cooling air passing through the annular space surrounding the vessel. Longitudinal fins welded to the exterior wall of the burner increase the area for transferring heat to the cooling air passing through the annulus.

A dump hopper, sized to hold the beds from two burners, will be used to contain the contents from the burners when a burner needs maintenance. It is assumed that the four required burners will be contained in two cells, two burners per cell, if the burners are to be repaired by contact maintenance. If remotely replaceable, all can be placed in one cell.

The burner product, a mixture of alumina and fuel particles, will be continually removed from the bottom of the burners and pneumatically transported to a burner product hopper. The hopper is sized to hold the product from 12 hours operation of the four burners Product from the burners will be received in the hopper and fed to a screen separator where the alumina, fertile, and fissile particles will be separated by mechanical screening. Particle diameters for the silicon-carbide-coated fissile particles of the reference fuel will be 280 ± 80 microns, for the fertile particles 430 ± 100 microns, and for the alumina particles greater than 600 microns; other size ranges are possible so the screens should be remotely replaceable. Any broken or undersized alumina particles would follow the fuel particle streams. The screen separator should be capable of separating essentially all of the fuel from the alumina recycle stream and of separating the fertile and fissile particles with a maximum of ten-percent stream intermixing including particle breakage.

After screen separation, the three particle streams will be processed separately, as described in the following subsections.

5.1.3 Fertile Particle System

The fertile particles from the screen separator will be collected in a fertile particle hopper sized to provide a 12-hour surge storage. The fertile particles from the hopper will be fed to a double-roll crusher where the silicon carbide will be broken to expose the buffer carbon for burning and the fuel meat for leaching. Since quantitative recovery of uranium and thorium from coated-particle fuels requires that the coating of every fuel particle be broken prior to leaching, the following features not incorporated in commercially available units should be designed into the roll crusher (24): (1) a preloading mechanism between shafts which minimizes undesirable deflections between rolls during operation, (2) rolls hardened to Rockwell 60 (C scale) for maximum resistance to abrasion and indentation, (3) a clearance of 0.003 inch between the ends of the rolls and the heavy side plates to ensure that the material fed to the crusher will not bypass the roll, (4) a pivoting yoke that supports one roll to permit rapid and precise adjustment of the roll-to-roll spacing, and (5) horizontal gage rods (riding on the shaft of the adjustable roll) to provide a means of continuously monitoring the shaft position and to detect translational movement that would indicate a change in the preset roll-to-roll spacing under load.

The crusher product will be collected in a hopper sized to hold material from twelve hours of crusher operation. This hopper will feed a weigh hopper used to feed a weighed charge of crushed particles to a crushed particle burner; the material will be manually charged to the burner through remote-actuated valves. In the burner, the buffer carbon in the crushed fertile particles (from twelve hours of processing) will be oxidized. Remotely replaceable electrical heaters on the outside wall of the burner will be used to maintain the operating temperature since there will be insufficient carbon present in the burner to maintain the temperature by the heat of reaction during much of the six-hour burning time. Off-gases will pass through sintered metal filters to remove particulate material, be cooled to 150°F in a condenser, and flow through a silica gel adsorber to remove ruthenium and cesium before discharge to the stack through the burner-leacher off-gas system.

During normal operation a mixture of oxygen and air (50 v/o O_2 - 50 v/o air) will be preheated and metered into the burner through a plenum chamber and distributor plate. Cooling for the burner will be provided by 2,000 scfm of air flowing through both a one-inch annulus surrounding the burner vessel and a bank of vertical tubes evenly spaced inside the vessel. Burner ash will be removed from the bottom of the burner and collected in a leacher feed hopper. A feeder incorporated on the hopper will continuously feed the entire contents of the hopper to the leacher in approximately two hours during the initial part of each 12-hour leach cycle.

The leacher, shown in Figure 5-2, will be a dual-diameter vessel; the lower section is sized to contain a charge of burner product while the upper section serves as a solution reservoir An air lift and head pot system is used to recirculate the leachate through the burner ash. A heat exchanger in the recirculation line maintains the leaching acid at the boiling temperature. Coils in the solution reservoir aid in the initial heatup and post leaching cooldown. Cadmium nitrate will be added to the leacher solution to provide criticality protection An air sparger is included for mixing. A water-cooled downdraft condenser returns the condensable overhead vapors to the leacher. A steam jet will be used to transfer the resulting slurry from the leacher.

The undissolved solids, primarily alumina and silicon carbide, will be separated from the leacher solution in a centrifuge equipped with a dual-wash system using 4M HNO_3 and water. The entire contents of the leacher will be centrifuged within one hour. The wash solutions will be combined with the leachate and transported to a leachate receiver tank for material accountability and then to a stripper feed tank. The solids, with a three-percent maximum liquid carryover, will be dried in a hopper and then pneumatically transported to solids storage.

The leachate will be made acid deficient by a combination of evaporation and steam sparging in a continuous stripper consisting of a reboiler surmounted by a packed de-entrainment tower. In the stripper, the excess nitric acid and water will be vaporized leaving a concentrated solution containing thorium and uranium nitrates. A continuous steam sparge will be used to reduce the operating temperature to about 275°F thereby reducing corrosion rates. Steam and nitric acid vapors that pass through the de-entrainment tower will condense in the stripper condenser for eventual recovery and recycle of the HNO_3. The concentrated stripper product will be cooled to 200°F while passing through a water-cooled heat exchanger before

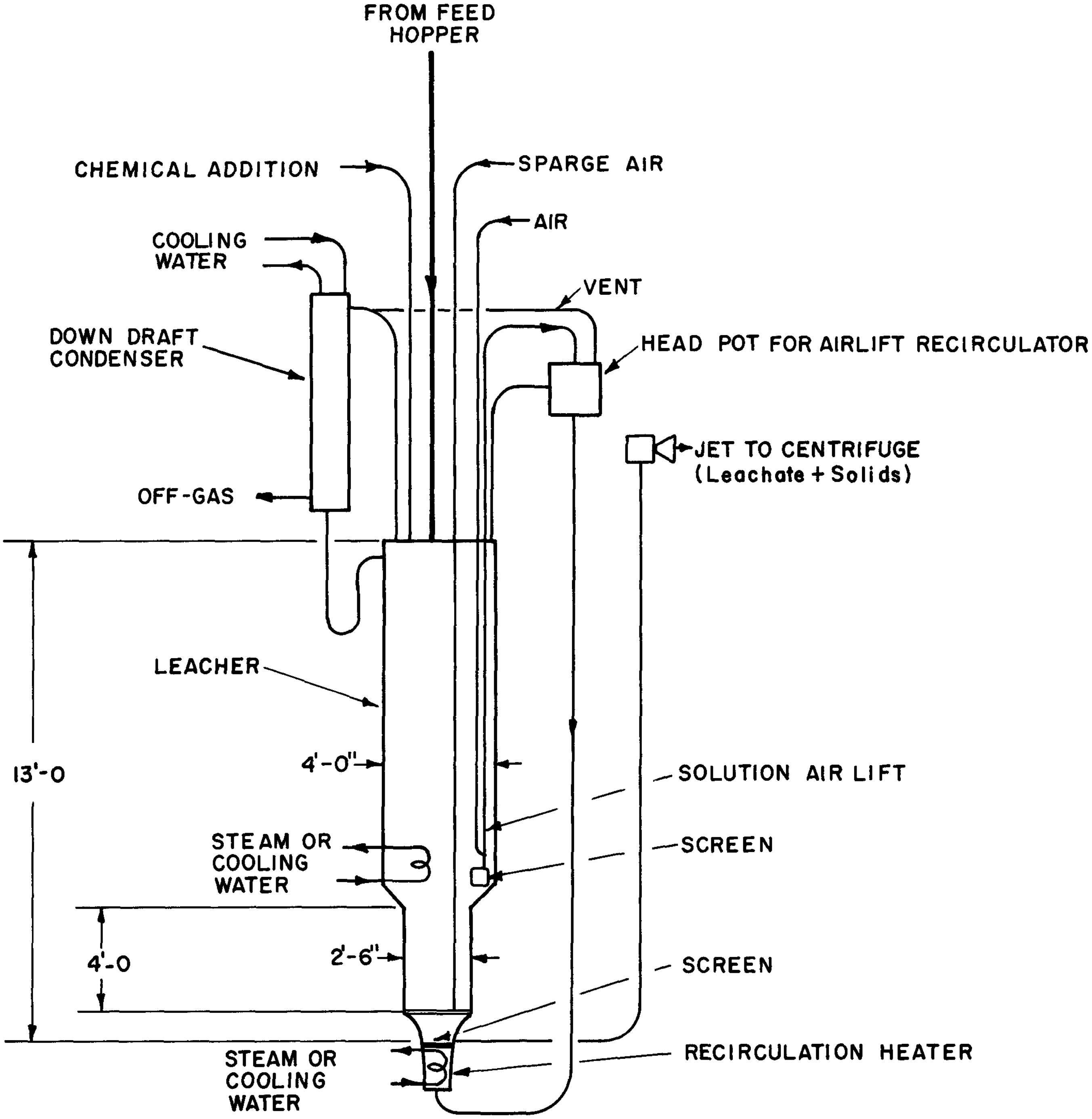


Figure 5-2

Conceptual Leacher Vessel

storage in the stripper receiver tank.

An aqueous solution containing sodium bisulfite will be added to the product stream in the stripper product tank to aid in the decontamination of ruthenium during solvent extraction. After accountability and process control analysis, the solution will be jetted to the solvent extraction feed tank sized to hold the solution from the stripper receiver tank plus an additional six hours of process solution.

5.1.4 Fissile Particle System

The fissile particles are processed in the same type of equipment as the fertile particles; however, the amount of material processed will be about one-third that of the fissile stream; consequently the equipment can be smaller. Design criteria for fissile equipment are tabulated in Table 5-1, and process criteria flowsheets are given in Section 4. For preparing the flowsheets, it was assumed that up to ten percent of the fissile and fertile particles will be broken in the block crushing, burning, and separation processes and the 80 percent of the broken fertile particles will follow the fissile particle stream.

Leacher solution from the alumina cleanup system (Section 5.1.3) will be blended with the fissile particle leacher stream in the leachate receiver tank. The combined streams will be stripped of nitric acid for feed to the solvent extraction system.

The overhead vapor from both the fertile particle stripper and the fissile particle-alumina cleanup stripper will be combined in the condensate receiver tank for evaporation to 13<u>M</u> HNO_3; the acid will be recycled to the leachers for reuse.

The fissile particle equipment will be essentially the same as the fertile particle processing equipment, except for capacity and heat duty.

5.1.5 Alumina Cleanup System

Most of the alumina bed material will normally be recycled to the burners; however, one-thirtieth of the alumina recycle stream will be diverted to a hold tank and then leached of heavy metals that build up on the alumina due to particle breakage. The alumina particles for recycle back to the burner will be collected in an <u>alumina hopper</u> sized to hold the cooled alumina from 24 hours of processing. A <u>weigh hopper</u> will receive alumina from the alumina hopper and feed a weighed charge (based on alumina from 12 hours of processing) to the leacher in approximately two hours during the initial part of each 12-hour leach cycle.

The alumina leacher will be constructed similar to the fertile particle leacher shown in Figure 5-2, except for dimensions. The steam jet used to remove the slurry from the leacher should be sized to handle the increased solids load or be replaced with an air lift. The undissolved solids from the leacher, primarily alumina, will be separated from the leachate and washed in a centrifuge equipped with a dual-wash system. The liquids from the centrifuge will be combined and transported to a hold tank then blended with the fissile particle leacher solution in the leachate receiver tank. The solids, with a three-percent maximum liquid carryover, will be dried in a hopper and recycled to the burners. Liquid from drying the alumina will be condensed and discharged to the intermediate-level waste storage tanks. Off-gases will pass through a heater, silica gel adsorber, and roughing filter before being discharged through the burner-leacher off-gas system. Specific design criteria for the alumina cleanup process equipment are given in Table 5-1.

5.2 SOLVENT EXTRACTION EQUIPMENT

A modified acid thorex solvent extraction process will be used to separate and purify the uranium and thorium from the headend processing steps. Two separate but similar extraction systems will be used; one for the heavy metals from the fertile fuel particles and one for the heavy metals from the fissile fuel particles. A six-stage centrifugal contactor similar in design to that developed at the Savannah River Laboratory(25,26,27), will be used for first cycle extraction to minimize solvent degradation. Pulsed column solvent extraction units, similar to those used in most of the nuclear fuel reprocessing plants, will be used for the remaining solvent extraction and the solvent treatment process with the exception of the H02 and 202 solvent treatment columns. The required pulsing action for the pulse columns will be produced by an air pulse generator capable of producing a pulse amplitude ranging from 0.5 to 1.0 inch at frequencies of 50 to 120 cycles per minute. The pulsed columns will contain sieve plates with 1/8-inch diameter holes on 1/4-inch triangular centers and spaced at 2-inch intervals. The H02 and 202 solvent treatment columns will contain Raschig-ring packing in place of sieve plates and will not be pulsed. Equipment sizes are tabulated in Table 5-2.

The columns and auxiliary equipment should be instrumented to maintain the

TABLE 5-2

SOLVENT EXTRACTION EQUIPMENT

Item	Number Required	Capacity (Each)	Heat Duty (Btu/hr)	Diameter (inches)	Height (feet)	Operating Temp. (°F)
1. FERTILE FUEL						
HA Contactors	6	5.6 gpm				100
HA Scrub Column	1	334 gph			18	100
Plate Section				9	13	
Top Disengaging				15	3	
Bottom Disengaging				15	2	
HAW Waste Tanks	2	600 gal	13,000			200
HC Column	1	520 gph			26	100
Plate Section				11	22	
Top Disengaging				24	2	
Bottom Disengaging				24	2	
HCP Evaporator, Thermosyphon	1	2100 lb/hr H_2O overhead	2.5×10^6			300
Condenser			2.5×10^6			300
Condensate Receiver Tanks	2	2500 gal				200
1A Column Feed Tank	1	250 gal				100
1A Column	1	75 gph			28	100
Plate Section				5	26	
Top Disengaging				27(a)	1.0	
Bottom Disengaging				27(a)	1.0	
1AT Evaporator, Pot-type	1	230 lb/hr H_2O overhead	2.3×10^5			300
Condenser		230 lb/hr H_2O	2.3×10^5			300
Thorium Product Tanks	2	180 gal				200
1C Column	1	56 gph			28	100
Plate Section				4	26.5	
Top Disengaging				27(a)	1.0	
Bottom Disengaging				27(a)	0.5	

TABLE 5-2 cont'd

Item	Number Required	Capacity (each)	Heat Duty (Btu/hr)	Diameter (inches)	Height (feet)	Operating Temp. (°F)
1CU Evaporator, Thermosyphon	1	160 lb/hr H_2O overhead				300
Evaporator Body				4.5 (max)		
Heat Exchanger			192,000	4.5 (max)		
Vapor Head		(4 Boron SS plates equally spaced in head) upper 8" packed with ½" x ½" x 16 ga. SS rings.		12 (max)		
Condenser	1	160 lb/hr H_2O	192,000			300
2AF Feed Tank	1	5 gal		4.5	6	100
2A Column	1	44 gph			31	100
Plate Section				4	29	
Top Disengaging				$27^{(a)}$	1.0	
Bottom Disengaging				4.5	1	
2AW Waste Tank	2	100 gal				100
2C Column	1	56 gph			28	100
Plate Section				4	26.5	
Top Disengaging				$27^{(1)}$	1.0	
Bottom Disengaging				$27^{(1)}$	0.5	
2CU Evaporator, Thermosyphon	1	160 lb/hr H_2O overhead				300
Evaporator Body				4.5 (max)		
Heat Exchanger			192,000	4.5 (max)		
Vapor Head		(4 Boron SS plates equally spaced in head) upper 8" packed with ½" x ½" x 16 ga. SS rings.		12 (max)		
Condenser	1	160 lb/hr H_2O	192,000			300
HC Column Solvent Wash Tank	1	510 gal				140
Mixing Section (with turbomixers)		255 gal	60,000			
Settler Section		255 gal				
Wash Waste Tank	1	250 gal		40	4	140

TABLE 5-2 cont'd

Item	Number Required	Capacity (each)	Heat Duty (Btu/hr)	Diameter (inches)	Height (feet)	Operating Temp. (°F)
HO1 Column, Pulsed	1	285 gph			23	140
Plate Section				10	20	
Top Disengaging				24	2	
Bottom Disengaging				12	1	
HO2 Column, Packed	1	285 gph			11	140
Plate Section		(¼" x ¼" Raschig Ring Packing)		10	8	
Top Disengaging				24	2	
Bottom Disengaging				12	1	
HAX Solvent Storage Tank	1	1100 gal				140
Decanter	1	50 gal		16	5	140
HO Solvent Wash Waste Tank	2	670 gal				140
1C and 2C Column Solvent Wash Tank	1	126 gal				140
Mixing Section (with turbomixers		63 gal	12,000			
Settler Section		63 gal				
Wash Waste Tank	1	75 gal		24	3	140
201 Column, pulsed	1	82.5 gal			22	140
Plate Section				5	20	
Top Disengaging				15	1	
Bottom Disengaging				7	1	
202 Column, Packed	1	82.5 gph			10	140
Plate Section		(¼" x ¼" Raschig Ring Packing)		6	8	
Top Disengaging				15	1	
Bottom Disengaging				7	1	
Decanter	1	7.4 gal		3	5	140
1C and 2C Solvent Wash Waste Tank		(Same tanks as HO Column Wash Waste				
1AX and 2AX Solvent Storage Tank	1	300 gal				140
2. FISSILE FUEL						
HA Contactors	6	0.5 gpm				100

TABLE 5-2 cont'd

Item	Number Required	Capacity (each)	Heat Duty (Btu/hr)	Diameter (inches)	Height (feet)	Operating Temp. (^{o}F)
HA Scrub Column	1	28.2 gph			17	100
Plate Section				3	13	
Top Disengaging				6	3	
Bottom Disengaging				6	1	
HAW Waste Tank	2	70 gal	14,000			200
HC Column	1	42.4 gph			24	100
Plate Section				3	22	
Top Disengaging				9	1	
Bottom Disengaging				9	1	
HCP Evaporator, Thermosyphon	1	200 lb/hr H_2O overhead	2.2×10^5			300
Condenser	1	200 lb/hr H_2O	2.2×10^5			300
Condensate Receiver Tanks	2	350 gal				100
1A Column Feed Tank	1	20 gal				100
1A Column	1	13.4 gph			29	100
Plate Section				3	26.5	
Top Disengaging				5	2	
Bottom Disengaging				5	0.5	
1C Column	1	20.4 gph			30	100
Plate Section				3	26	
Top Disengaging				5	2	
Bottom Disengaging				5	2	
1CU Evaporator, Thermosyphon	1	70 lb/hr H_2O overhead				300
Evaporator Body				4.5	3.5	
Heat Exchanger			80,000	3	4.0	
Vapor Head	(4 Boron SS plates equally spaced in head) upper 8" packed with ½" x ½" x 16 ga. SS rings.			9	3.0	
Condenser	1	70 lb/hr H_2O	80,000			300

TABLE 5-2 cont'd

Item	Number Required	Capacity (each)	Heat Duty (Btu/hr)	Diameter (inches)	Height (feet)	Operating Temp. (°F)
2AF Feed Tank	1	5 gal		4.5	6	100
2A Column	1	21.6 gph			34	100
Plate Section				3	29	
Top Disengaging				4.5	3	
Bottom Disengaging				4.5	2	
2AW Waste Tank	2	50 gal				100
2C Column	1	30.8 gph			30	100
Plate Section				3	26	
Top Disengaging				6	2	
Bottom Disengaging				6	2	
2CU Evaporator, Thermosyphon	1	140 lb/hr H_2O overhead				300
Evaporator Body				5.0 (max)	as required	
Heat Exchanger			154,000	5.0 (max)		
Vapor Head	(4 Boron SS plates equally spaced in head) upper 8" packed with ½" x ½" x 16 ga. SS rings					
Condenser	1	140 lb/hr H_2O	154,000			300
HC Column Solvent Wash Tank	1	36 gal				140
Mixing Section (with turbomixer)		18 gal	5,000			
Settler Section		18 gal				
Wash Waste Tank		20 gal		15	2.2	140
HO1 Column, Pulsed	1	23.3 gph			24	140
Plate Section				3	20	
Top Disengaging				6	3	
Bottom Disengaging				3	1	
HO2 Column, Packed	1	23.3 gph			12	140
Plate Section	(¼" x ¼" Raschig Ring Packing)			3	8	
Top Disengaging				6	3	
Bottom Disengaging				3	1	
HAX Solvent Storage Tank	1	90 gal				140

TABLE 5-2 cont'd

Item	Number Required	Capacity (each)	Heat Duty (Btu/hr)	Diameter (inches)	Height (feet)	Operating Temp. (°F)
Decanter	1	5 gal				140
1C and 2C Column Solvent Wash Tank	1	50 gal				140
Mixing Section (with turbomixer)		25 gal	6000			
Settler Section		25 gal				
Wash Waste Tank	1	30 gal		15	2.8	140
201 Column, Pulsed	1	28 gph			24	140
Plate Section				4	20	
Top Disengaging				6	3	
Bottom Disengaging				4	1	
202 Column, Packed	1	28 gph			12	140
Plate Section		(¼" x ¼" Raschig Ring Packing)		4	8	
Top Disengaging				6	3	
Bottom Disengaging				4	1	
Decanter	1	5 gal				140
1AX and 2AX Solvent Storage Tank	1	110 gal				140
Waste Rework Hold Tanks	2	600				100
Waste Rework Evaporator, Thermosyphon	1	210 lb/hr H_2O overhead	250,000			300
Condenser	1	210 lb/hr H_2O	250,000			300
Evaporator Bottoms Receiver Tanks	2	600				100

(a) Annular disengaging section--27 inch diameter section filled with a 24-inch diameter concrete core providing a 1-½-inch annulus.

Note: All process vessels to be fabricated of 304L SS, operating pressure-¼ psig.

proper flow, temperature, and pressure of the various streams and to detect abnormal conditions. Provisions should be made for sampling the process streams and effluent tanks for accountability and process control. Process waste in the raffinate hold tanks will be sampled for uranium and thorium before being discharged to waste storage tanks. If uranium or thorium losses to the waste are large (due to upsets in the extraction system), the waste will be recycled back through the extraction system to reclaim the heavy metals.

Several evaporators are required with the solvent extraction process. These evaporators will be used to concentrate the column feed between cycles, the thorium product for storage, and the uranium product solution for denitration. To minimize liquid entrainment in the evaporator vapors, the upper nine inches of the vapor disengaging heads will be packed with 3/4-inch Raschig rings. Nuclear criticality can be a problem in the 1CU and 2CU evaporators because of the uranium content of the solution; thus the de-entrainment heads in these evaporators will contain the equivalent of four 10-gauge boron stainless steel plates evenly spaced and extending vertically the height of the disengaging section. The ends of the plates should be 1/2-inch from the wall. Since thorium solutions will be evaporated to a high concentration, a relatively large solution holdup will be needed to prevent over-concentration during process fluctuations. The thorium product evaporator will be a simple pot-type reboiler surmounted by a packed tower for de-entrainment; all other evaporators will use a thermosyphon design.

The organic solvent (30% TBP in Amsco) from the first extraction cycle will flow to a solvent treatment system to remove fission products and TBP decomposition products; the solvent from the second and third cycles (5% TBP in Amsco) will be treated together in a separate system. The solvent from the HC columns will flow to solvent wash tanks which will be divided into two sections--a mixer section and a settler section. Heating coils in the mixing section will keep the solution at 140°F. The mixer sections will be provided with turbomixer(s), similar in design to those used in AEC reprocessing plants(28) for mechanically mixing the solvent with a sodium carbonate solution and discharging the mixture to the settling sections where the two phases disengage. Clear solvent will overflow to a reservoir and be air lifted to a head pot feeding the bottom of the HO1 columns. The aqueous carbonate solution from the washer will be transported to wash waste tanks.

The solvent will be scrubbed with an aqueous carbonate solution in the HO1 pulse columns, with nitric acid in the packed H02 columns and then stored in the HA column feed tanks.

The residual solvent in the nitrate and carbonate wastes will be separated from the waste by decanters. The aqueous wastes from all the solvent treatment systems will flow to one of two interim storage tanks for accountability measurements before storage in the larger waste tanks.

Solvent from the 1C and 2C columns will be treated in a system similar to the HC column solvent. Specific design criteria for the solvent extraction and solvent treatment equipment, based on normal operating conditions and capacities, are tabulated in Table 5-2.

Process wastes, spills, and leaks containing excess uranium or thorium will be transferred to hold tanks, evaporated, and recycled through the solvent extraction system. The capacity of the two hold tanks will be large enough to contain solution from the largest process tank. The evaporator will be sized to evaporate one-half the liquid from one of the tanks within a 24-hour period. Two additional tanks will hold the evaporator bottoms for recycle to solvent extraction. The overhead vapors will be condensed and transferred to the condensate receiver tanks.

5.3 PRODUCT

Uranium from the solvent extraction systems will be denitrated to a granular UO_3 product in a fluidized bed, packaged in steel cans, and shipped in Y-12 Foamglas-type shipping containers. Thorium, as an acidic nitrate solution, will be stored for an indefinite period of time in large underground storage tanks fabricated of stainless steel. Specific design criteria for the product denitration and packaging equipment are tabulated in Table 5-3 and discussed in the following paragraphs.

The fertile and fissile particle uranium will be processed in separate, but similar, denitration systems. One system is described in general here with specific design details given in Table 5-3 for both systems. The uranyl nitrate solutions will be converted to solid UO_3 in a hot fluidized-bed denitration vessel. Heat will be supplied by replaceable electrical heaters attached to the exterior vessel walls and located on the lower one foot of the vessel--from the distributor plate to four inches above the feed nozzle. The vessel will be insulated with a non-adsorbant insulation which will be replaceable around the heating section.

TABLE 5-3

PRODUCT PROCESSING EQUIPMENT

Item	Number Required	Capacity (each)	Heat Duty (Btu/hr)	Diameter (inches)	Height (feet)	Temperature (°F)	Pressure (psig)	Material of Construction
1. FERTILE URANIUM (U-233)								
Denitrator Run Tanks	2	3.5 gal		4.5	4.3	200	-1/4	304L SS
Denitrator	1	7 gal/d (1048 g U/l)		4.5	2.5	580	-1/4	304L SS
Heaters, Electrical	1 bank		(5.0kW)					
Condenser	1	1.2 scfm air & steam	2,500			580	-1/4	304L SS
Superheater	1	0.52 scfm air	100			150	-1/4	304L SS
Product Collection Vessel	1	2.6 gal	154	4	4	580	-1/4	304L SS
Glove Box and Associated Equipment	1	(described in Section 5.3)					-1/4	
Tall #3 Cans	1370/yr	0.43 gal		4.25	0.58			Tinned Steel
Model FD Foamglas Shipping Containers	175/yr			22.5	1.83			cs and Foamglas
2. FISSILE URANIUM (U-235)								
Denitrator Run Tanks	2	4 gal		4.5	5	200	-1/4	304L SS
Denitrator	1	8 gal/d (470 g U/l)		4.5	2.5	580	-1/4	304L SS
Heaters, Electrical	1 bank		(10.0kW)					
Condenser	1	4.9 scfm air & steam	4,500			580	-1/4	304L SS
Superheater	1	4 scfm air	300			150	-1/4	304L SS
Product Collection Vessel	1	1.5 gal		4	2.1	580	-1/4	304L SS
Glove Box and Associated Equipment	1	(Same as Fertile Uranium Process)						
#12 Cans	440/yr	1.0 gal		6-3/16	0.73			Tinned Steel
Model FD Foamglas Shipping Containers	55/yr			22.5	1.83			cs and Foamglas
3. THORIUM STORAGE								
(See Section 5.3)								

Fluidizing air will be metered into the fluidized bed through a plenum chamber and a distributor plate. The uranyl nitrate solution will be fed to the denitrator by one or more two-fluid atomizing nozzles equipped with plunger pins; the nozzles will be located eight inches above the distributor plate. A baffle consisting of horizontal louvers and located approximately 18 inches above the feed nozzle de-entrains solids in the off-gas stream to the filters. Sintered metal filters, equipped with a pulse blowback system and mounted in the calciner vessel above the baffle, remove particulate matter from the off-gas and return it to the denitrator. A bed addition funnel will be incorporated in the vessel to add starting-bed material to the denitrator. The funnel will have a cone angle of 90° and a maximum diameter of four inches. A standpipe-type product take-off line with a take-off angle of 45° and with the inlet located nine inches above the bottom of the bed will be provided for removal of the UO_3 product.

Prior to packaging in a glove box, the product will be collected and cooled in a fluidized-bed collection vessel with a cone-shaped bottom. The cooling/fluidizing air will be vented to the denitrator off-gas system. The vessel should contain a product inlet line and a baffle for fines removal from the off-gas. The baffle design is to be the same as the denitrator baffle.

The collection vessel will be located above a glove box equipped with removable roughing and high-efficiency filters and ventilated with air to give three volume changes per minute. The interior of the glove box will be kept under a negative pressure of ¼ inch of water. The glove box should have Plexiglas viewing windows, eight-inch diameter glove ports, an eight-inch diameter bag port, a four-inch diameter bag port for transfer of sealed product cans and sample bottles, and a bag sealer and a mechanical can sealer should be contained inside the glove box. The bag sealer should make at least two separate seals across the diameter of the bag and cut the bag between the seals in one operation. The mechanical can sealer shall be an automatic motorized-type for sealing a tall tinned steel can in which the UO_3 product will be packaged. Ventilation air will pass through roughing and high-efficiency filters before discharge to the building ventilation system.

The off-gas from the denitrator flows through a condenser, a superheater, and roughing and high-efficiency filters before discharge to the stack via the vessel off-gas system. The condensate will be routed to the condensate receiver tanks.

The UO_3 product will be stored and shipped in Model FD Foamglas shipping containers. The containers are 16-gauge carbon steel drums filled with foamed borosilicate glass; the center of the Foamglas is hollowed out to form a cavity for the product can. An eight-inch high plug of Foamglas over the product can is held in place by a drum lid with a bolted ring clamp. The lid will be gasketed with a neoprene O-ring gasket.

The partially decontaminated thorium product solution will be stored for a period of 10 to 15 years to allow the Th-228 and its daughters to decay to levels permitting direct refabrication techniques for nuclear fuel. Thorium storage vaults and tanks should be designed according to the following criteria: (1) double containment, (2) at least one empty tank having a capacity of the largest thorium tank, (3) a minimum total working freeboard volume within the other thorium tanks equivalent to a years operating requirement for thorium solution, (4) three feet of concrete and four feet of earth shielding. A sump and jet in the vault(s) would be used to pump any leakage to the spare tank. The tanks are to be vented to the vessel off-gas system; the vault, to the atmosphere.

When the radioisotopes have decayed sufficiently, the thorium nitrate solution, if needed, would be pumped from the tanks to the solvent extraction facilities for purification.

5.4 RADIOACTIVE WASTE DISPOSAL

Radioactive contaminants in various waste streams must be removed to permit safe environmental release of the waste, or the waste must be stored in a safe, high-integrity confinement system. Thus, all waste streams will be decontaminated to the maximum extent practicable before discharge; activity content will not exceed the recommended AEC plant release limits(30). Criteria for design of radioactive waste facilities are given in Table 5-4 and in the following paragraphs.

5.4.1 Liquid Wastes

Low-level liquid wastes containing nitric acid will be fed to a nitric acid fractionator to remove the acid and passed through an ion exchange column to remove final traces of fission products, prior to discharge to the environment. The nitric acid will be removed for recycle to the headend process and to increase the time period between regenerations of the ion exchange resin.

The nitric acid fractionator consists of a tower packed with Raschig rings, a thermosyphon reboiler, a solution reservoir, a condenser, and a reflux metering system. Condensed evaporator overheads are to be metered from the feed tank of the nitric acid fractionator to a distribution plate at the midpoint of the fractionator tower. A portion of the condensed fractionator overheads will be refluxed to a distributor plate at the top of the column. The tower height and operating conditions will be designed to produce a concentrated fractionator product of 60-percent acid. The concentrated acid will contain the bulk of the fission products present in the low-level waste stream and will be recycled to a process acid tank for reuse in the headend leacher. The fractionator overheads will be routed to the ion exchange columns for final purification before being discharged to the environment.

Cooling water and condensate used for cooling and heating in radioactive process heat exchangers will be monitored for radioactivity, cooled in a cooling tower, and discharged to the environment. The cooling tower will be capable of lowering the temperature of the water to that approaching ambient conditions before discharge. A diversion pond, with a capacity equivalent to six hours of process usage, will provide storage should radioactivity be inadvertently released through leaks in the heat exchangers. This storage capacity is sufficient to allow time to determine the source of radioactivity in a stream and correct the problem or shut down processing equipment. As necessary, the contents of the diversion pond can be processed through the ion exchange columns for decontamination before discharge to the environment.

TABLE 5-4

WASTE DISPOSAL PROCESS EQUIPMENT

Item	Number Required	Capacity (each)	Heat Duty (But/hr)	Diameter (inches)	Height (feet)	Temperature (°F)	Pressure (psig)	Material of Construction
HLW Accumulator Tanks	2	30,000 gal	$1.0x10^6$			150	-1/4	304L SS
HLW Evaporator, Thermosyphon	1	670 lb/hr H_2O overhead	$8.0x10^5$			300	-1/4	304L SS
Condenser	1	670 lb/hr H_2O	$8.0x10^5$			300	-1/4	304L SS
Off-gas Heater (#1)	1	210 scfm	$5x10^4$			150	-1/4	304L SS
Off-gas Heater (#2)	1	210 scfm	$2.5x10^4$			150	-1/4	304L SS
HLW Calciner	1	30 gph (feed) 26 lb/hr (solids)	$5x10^5$	24	8	900	-1/4	310 SS
Venturi Scrubber	1	210 scfm gas						
		160 gph scrub sln.				900	-1/4	310 SS
Calciner Off-gas Cyclone	1	(Same as Solids Storage Cyclone (Sec. 5.5.3 plus capability for 160 gph scrub solution)						
Scrub Solution Surge Tank	1	640 gal				150	-1/4	304L SS
Silica Gel Adsorber	4	221 gal (Vertical Cone Bottom)				150	-1/4	304L SS
Scrub Solution Cooler	1	160 gph	$1.5x10^5$			150	-1/4	304L SS
ILW Accumulator Tanks	1	20,000 gal				150	-1/4	304L SS
ILW Evaporator, Thermosyphon	1	3800 lb/hr H_2O overhead	$5x10^6$			300	-1/4	304L SS
Condenser	1	3800 lb/hr H_2O	$5x10^6$			300	-1/4	304L SS
Nitric Acid Fractionator (Packed Tower, Thermosyphon Evaporator)	1	575 gph-0.15$\underline{M}$ (Feed) 5.6 gph-13$\underline{M}$ (Product)	$6x10^6$			300		304L SS
Condenser	1	4500 lb/hr H_2O	$6x10^6$			300		304L SS
Anion Exchange Column	1	450 ft^3				100	-1/4	304L SS
Cation Exchange Column	1	50 ft^3				100	-1/4	304L SS
Diversion Pond	1	6 hr usage				ambient	ambient	Plastic lined pond
Cooling Tower	1	As Required						
Spent TBP-Amsco Storage	1	4500 gal				100	-1/4	304 SS

High- and intermediate-level wastes will be reduced in volume by evaporation, calcined to convert the radionuclides to solids, then stored in underground storage bins. The calciner will consist of a vessel containing a bed of fluidized waste solids. Sintered metal filters located in the upper portion of the vessel will remove the bulk of the solids from the off-gas stream. Fluidizing gas, a mixture of air and oxygen will be introduced through a gas distributor plate below the fluidized bed. Concentrated wastes will be fed to the calciner through three two-fluid atomizing nozzles located near the top of the bed. The nozzles will be equipped with air-actuated plungers to free nozzle plugs. Kerosene or spent solvent waste (TBP + kerosene) will be sprayed into the bed to provide the necessary heat by in-bed combustion(31). Calcined solids will be continuously removed through a bed overflow line, located two to three feet above the distributor plate, and pneumatically transported to solids storage. The solids removal and transport system will be designed similar to that of the headend-burner product removal and transport system.

During startup, dolomite will be used in the vessel as the initial bed. The bed will be preheated to operating temperature by the fluidizing air.

5.4.2 Gaseous Wastes

Gaseous wastes from the reprocessing plant will be filtered to remove particulate material. For any streams containing large quantities of solids, sintered metal filters will be used The sintered metal filters should be equipped with automatic pulse blowback systems to return the solids back to the process. Glass fiber roughing filters will be used to remove particulate matter from streams containing moderate to low concentrations of solids and as backup filters for the sintered metal filters Final filtration of the streams will be accomplished by high-efficiency filters; each high-efficiency filter will be immediately preceded by a roughing filter The filters should be designed according to AEC specifications(32). Ruthenium in the off-gas streams will be removed by adsorption on silica gel.

5.4.3 Solid Wastes

Solid waste from the calciner and the headend processes will be combined and stored in underground storage bins contained in concrete vaults. Design criteria for the solids storage bins are: (1) maximum bin wall temperature could be 550°F, but will be considerably lower depending on the thermal conductivity of the solids and bin cooling system; (2) centerline temperature of calcine in bins of 1290°F; (3) natural convection of air over the bin surface for cooling;

(4) material of construction will be Type 304 stainless steel; (5) storage capacity for 8,000 ft^3 solids per year (which includes silicon and boron carbides from fuel particles); and (6) solids heat generation rate of 2,400 Btu/hr-ft^3.

Cooling air from the atmosphere is to be transported through an inlet filter and then through duct work to the bottom of the vault. Air will pass over the bin surfaces and discharge through a stack installed on top of the vault. An automatic shut-off valve in the cooling air inlet and high-efficiency filters in the exhaust air are to be part of the cooling system. An on-line constant-air monitor is to be installed for continuously measuring the activity of the exhaust air.

The storage vaults will be constructed of 4000-lb reinforced concrete. The vault walls will be two feet thick. A concrete sump on the vault floor is to be provided to collect and remove any ground or rain water which may enter the vault. The vaults are to be designed such that they will not float in the unlikely event of site flooding. During filling, solids will be pneumatically transported to a cyclone located above the bins in the vault. The solids will drop from the bottom of the cyclone into the solids distributor pipe and thence flow by gravity through pipes radiating from a central distributor into the bins. Transport air leaving the cyclones will be returned to the calciner.

The gravity-flow lines from the central solids distributor are to be inclined downward at a minimum angle of 45° to insure solids flow. Cleanout stubs, free of bends and extending to the top of the vault for access, are to be provided for unplugging the cyclone, the distributor pipe, and the fill lines.

Each bin will have a six-inch, Schedule 40, flanged pipe extending from the top of the bin, upward, through the vault roof, and into a concrete lid. This will permit installation of a solids-measuring device and will provide for installation of any future solids removal system

The solids cyclone separator will be constructed of Type 304 stainless steel plate and designed for full vacuum and 30 psig at 930°F, for a pressure drop of four inches of water at 15 scfm, and for a maximum solids loading of 150 lbs/hr. Design efficiency should be 98 percent for solids having a size distribution of 99.8 percent greater than 100 Tyler mesh screen

5.5 NON-RADIOACTIVE STORAGE AND PROCESS TANKS

A large number of tanks are required for storing, mixing, and feeding the various non-radioactive chemicals used in the process. These tanks and their auxiliary equipment, except for a solution transfer method, are listed in Table 5-5. The solutions should be metered and transferred to the various processes either by pumps or by a gravity system; provisions should be made for sampling all the makeup solutions before transfer to the run tanks. All the tanks will operate at atmospheric pressure and room temperature. The tanks will be vented to the stack through the building off-gas system.

The solvent extraction scrub, strip, and chemical addition solutions are the same for both fertile and fissile fuel processing; consequently the same makeup tanks can be used for both processes. The capacity of the makeup tanks are based on quantities used during one day. The run tank capacities are based on quantities used during 32 hours; this provides an extra 8 hours capacity so that no tank will be empty while fresh solutions are made up. Nitric acid storage capacity is based on quantities used during two weeks of processing. Hydrofluoric and phosphoric acid (capacity based on two weeks usage) will be stored in the shipping containers and will be transferred directly to the makeup tanks. Amsco and TBP will also be stored in the shipping containers; however, storage capacity for these materials is based on the volume in the process system and on usage for two weeks.

A decontamination solution makeup tank will be provided for use when any portion of the process system needs decontaminating. The solutions from the decontamination tank will flow through a series of headers to any process equipment requiring cleanup.

TABLE 5-5

NON-RADIOACTIVE STORAGE AND PROCESS TANKS

Tank	Capacity (gallons)	Auxiliaries(a)	Materials of Construction
1. Storage and Makeup Tanks			
Oxygen Storage(b)	1050 Tons/mo. (570 scfm)		
Nitric Acid Storage	14,000		304 SS
Alumina Makeup Hopper	105	S,C	304 SS
30% TBP Makeup	400	A	CS
5% TBP Makeup	150	A	CS
Venturi Acid Scrub Makeup	200	A	347 SS
HF Makeup (0.17M)	250	A	Plioweld Type LS 580 Lined Carbon Steel
Phosphoric Acid Makeup (0.027M)	275	A	316 SS
Decontamination Makeup	1,000	A,S,C	347 SS
HAS Makeup	750	A,S	347 SS
HAIS Makeup	225	A	347 SS
HAA Makeup	225	A	347 SS
HCX-1CX-2CX Makeup	9,000	A	347 SS
1AS Makeup	250	A	347 SS
2AIS Makeup	200	A	347 SS
2AA Makeup	120	A	347 SS
HOB-2OB Makeup	950	A,S	CS
HOS-2OS Makeup	950	A,C	347 SS
Adjustment Solution Makeup (Fissile-Alumina Stripper Product)	50	A,S	347 SS
Adjustment Solution Makeup (Fertile Stripper Product)	250	A,S	347 SS
Centrifuge Acid Wash Makeup (Fertile Stream)	300	A	347 SS
Chemical Addition Makeup (Waste Calciner)	30	A,S	304 SS
Ion Exhcnage Regenerant Makeup (HNO_3)	800	A	347 SS
Ion Exchange Regenerant Makeup (NaOH)	3,000	A	347 SS
2. Run Tanks--Fertile Fuel Stream			
HAS	800		347 SS
HAIS	250		347 SS
HAA	250		347 SS
HCX	7,000		347 SS
IAS	250		347 SS
1CX	500		347 SS
2AIS	125		347 SS
2AA	125		347 SS
2CX	500		347 SS

(a) A = agitator; C = heating coil; S = solids addition port

(b) The oxygen storage capacity is large enough to warrant construction of an oxygen plant.

TABLE 5-5
(cont.)

Tank	Capacity (gallons)	Auxiliaries[a]	Materials of Construction
HOB	700		347 SS
HOS	700		347 SS
2OB	200		347 SS
2OS	200		347 SS
HO Solvent Makeup	300		304 SS
2O Solvent Makeup	2,000		304 SS
Adjustment Solution	300		347 SS
Centrifuge Acid Wash	150		347 SS
3. Run Tanks--Fissile Fuel Stream			
HAS	70		347 SS
HAIS	20		347 SS
HAA	25		347 SS
HCX	575		347 SS
1AS	25		347 SS
1CX	275		347 SS
2AIS	80		347 SS
2AA	15		347 SS
2CX	400		347 SS
HOB	60		347 SS
HOS	60		347 SS
2OB	70		347 SS
2OS	70		347 SS
HO Solvent Makeup	575		304 SS
2O Solvent Makeup	700		304 SS
Adjustment Solution	50		347 SS
4. Run Tanks--Waste Calciner			
Chemical Addition	40		304 SS

5.6 PROCESS ALTERNATIVES

The various process alternatives, described in Section 4-6, will require some additional and/or different sized equipment depending on the flowsheet modifications. Capital costs for these options are needed to generate cost data for the alternate processes. Design criteria for equipment associated with the process alternatives are given in Table 5-6 and discussed in the following paragraphs.

5.6.1 Alternative 1--Fissile Particles Packaged and Stored

If the fissile particles are not processed, they will be packaged and stored. Criteria for disposal containers for the fissile particles are: (1) reliable containment of the radionuclides, (2) retrievability of the particles, and (3) adequate dissipation of the fission product decay heat. To meet this criteria, the fissile particles would be packaged in high-integrity stainless steel containers and stored in a water-filled storage basin.

Fissile particles from the particle hopper would be pneumatically transferred to a weigh hopper where a predetermined weight of fissile particles would be dropped into the storage container. A plug would be seal-welded on the container. The containers would be stored in the storage basin with a 12-inch minimum distance between containers.

5.6.2 Alternative 2--U-233 Shipped as a Nitrate Solution

Depending on the location of a fuel fabrication plant and the lapsed time before the U-233 is refabricated into fuel, it may be desirable to return U-233 as a nitrate solution instead of a granular UO_3 solid. If returned as a solution, the concentrated uranyl nitrate product from the solvent extraction system would be loaded into plastic product-containers from the denitrator run tanks. The loadout operation would be conducted manually in glove boxes to protect operating personnel against alpha contamination. The plastic containers would be placed in a protective stainless steel container, surrounded by a steel framework to guarantee a nuclear safe geometry. The frame would then be placed in a steel drum; the drum would be filled with loose vermiculite and then sealed.

5.6.3 Alternative 3--All Particles Uncoated

For fuel systems where none of the particles are coated with silicon carbide or other non-oxidizible coating, the contents of the burner would be leached from the alumina in the same vessel with no separation of fertile and fissile fuel. Burner product, consisting of fertile particle uranium and thorium, fissile particle uranium, fission products, and alumina bed material would be continuously removed

TABLE 5-6

ALTERNATIVE PROCESS EQUIPMENT

Item	Number Required	Capacity (each)	Heat Duty (Btu/hr)	Diameter (inches)	Height (feet)	Operating Temperature (°F)	Operating Pressure (psig)	Material of Construction
1. Alternative 1								
Fissile Particle Hopper	1	6 ft^3	17,200	24	2	300	-1/4	304 SS
Weigh Hopper	1	3.5 ft^3	11,500	8	10	300	-1/4	304 SS
Product Containers	822/yr	3.5 ft^3	11,500	8	10	500	0	304L SS
Storage Canal (based on 5 yr. storage)	1	12,500 ft^2	4.7×10^7		25	70	0	Concrete
2. Alternative 2								
Product Containers (0.1 in. Wall)	770/yr	10.8 l		4.5	4.2	70	0	Polyethlene
Shipping Containers	100	11 l		4.5	4.2	70	0	cs
Glove Box	1	as required					-1/4	304 SS
3. Alternative 3								
Weigh Hopper	1	75 ft^3	33,400	42	8	300	-1/4	304 SS
Leacher	2	1000 gal			13	250	-1/4	309 SCb SS
Lower Section				36	5			
Upper Section				48	7			
Heat- (Recirculating Line)			1.5×10^6					309 SCb SS
Exchanger (Solution Coils)			1.0×10^6					309 SCb SS
Condenser			1.5×10^6			250	-1/4	309 SCb SS
Centrifuge	2	3000 lb Solids 320 gal Sol'n/hr				100	-1/4	304L SS
HNO_3 Wash		160 gph						
H_2O Wash		160 gph						
Solids Drying Hopper	1	110 ft^3				200	-1/4	304L SS
Air Heater		230 scfm Air	35,000			200	-1/4	304L SS
4. Alternative 4								
Weigh Hopper	1	75 ft^3	33,400	42	8	300	-1/4	304 SS
Leacher	2	1000 gal			13	250	-1/4	309 SCb SS
Lower Section				36	5			
Upper Section				48	7			
Heat- (Recirculating Line)			1.5×10^6					309 SCb SS
Exchanger (Solution Coils)			1.0×10^6					309 SCb SS
Condenser			1.5×10^6					309 SCb SS
Centrifuge	2	3000 lb Solids 320 gal Sol'n/hr						
HNO_3 Wash		160 gph						
H_2O Wash		160 gph						
Solids Drying Hopper	1	110 ft^3				200	-1/4	304L SS
Air Heater		230 scfm Air	35,000			200	-1/4	304L SS

and transported to a product hopper. A weigh hopper would transfer a charge of burner product to a leacher where the material from the fuel particles would be leached from the alumina. Following the leaching, the alumina would be separated from the leachate in a centrifuge, the alumina dried and recycled, and the leachate processed through the solvent extraction system.

5.6.4 Alternative 4--Fertile Particle Uncoated, Fissile Particle Coated

The processing equipment for fuel with only the fissile particles coated with a silicon carbide-type coating would differ from the reference fuel process in that: (1) both fissile and fertile particles would be leached together; (2) the uncoated fertile particles would dissolve in the leacher while the coated fertile particles would not--thus providing a mode of separation; (3) the two streams would be separated by centrifugation; and (4) the fissile particles and alumina would be dried in a hopper. Starting with the screening step, the process would be that of the reference fuel process.

6. CRITERIA FOR SITE, BUILDINGS, AND SERVICE FACILITIES

Bases to be used in determining the cost of the site, various facilities, and services follow.

6.1 PLANT SITE

It is assumed that the location for the conceptual reference plant will be similar to that at the National Reactor Testing Station, Idaho, in an area of low population density. The site will be relatively level, but adequate drainage should be provided. The type of soil shall preclude any unusual or elaborate foundation requirements. The site will have adequate underground water available. Ready access to the site by both railroad and highway is assumed for delivery of construction supplies and fuel element shipping casks.

Most of the plant facilities will be contained within a small security area located in the center of a 500-acre undeveloped area owned by the plant-operating corporation. The 500-acre area will measure approximately 1-1/4 miles long and 3/4 miles wide and will be fenced. The long axis of the site should be aligned in the direction of the prevailing wind. The security area will be enclosed by a chain link fence and will be lighted. Access to this area will be through a guard gate house. A parking area will be provided for approximately 200 cars outside of the security area adjacent to the gate house. Paved roads will be extended from the main highway to the plant site and will connect all buildings within the security area. Truck loading and unloading facilities will be provided at some of the buildings and small areas provided for parking at most of the plant buildings. A railroad spur track will be extended from the main rail lines in the area to service the fuel storage facility.

6.2 GENERAL BUILDING DESIGN

All buildings will be designed to provide adequate shelter and working conditions for a climate similar to that at the NRTS. Buildings will be constructed of reinforced concrete, pumice block, and/or insulated pre-cast concrete wall panels; in the case of warehouses, bottle storage, etc., prefabricated metal might be applicable. Buildings shall be designed to withstand wind loads of 30 psf, snow roof loadings of 30 psf, and earthquake loads for earthquake-zone 2 as defined in the Uniform Building Code, Pacific Coast Building Officials Conference. Foundations shall be reinforced concrete carried five feet below grade to set below frost line. Design for heating and ventilating equipment shall be based on an interior temperature of 70°F and an outside temperature of -20°F with a 15 mph wind. Walls shall have a "U" factor of approximately 0.18; roofs, 0.14. Roofs shall meet Class I construction as defined by the Factory Mutual Handbook.

6.3 MAIN PROCESS BUILDING

The main process building shall be located at the center of the 500-acre plant site. Maintenance shops, miscellaneous offices, change rooms, analytical laboratories, fuel storage, decontamination room area, and other desirable facilities, can be a part of or attached to the main process building. In general, offices should be located adjacent to the respective work areas.

6.3.1 Fuel Receiving and Storage

Spent fuel, canned or uncanned, will be received in large shipping casks at a receiving facility integral with the fuel storage facility. The receiving facility will be constructed to receive shipments by either rail or truck, although the bulk of the shipments will be by rail. The economical upper limit for reference-type fuel shipments by rail is about 50 elements per cask, while the most economical truck shipment is 3 elements per cask(29). The estimated height of the conceptual 50-element cask in the unloading position is 22 ft, and the cask and fuel would weigh an estimated 125 tons; if the fuel were packaged, it would be in ten containers of a type suitable for use in the dry fuel storage area. Each container could be approximately 1.5 ft. O.D. x 15 ft. long and could hold either five reference fuel elements or nine Peach Bottom elements. The Peach Bottom fuel comprises about 0.3 percent of the total fuel load to be processed in the plant. The balance of the load will be the reference fuel type.

The fuel receiving facility is to be designed to handle approximately 130 uncanned reference fuel elements per day. Uncanned fuel elements will be remotely placed in containers to minimize contamination of the storage area, to minimize off-gas cleanup problems, and also to facilitate transfer of the fuel to the fuel processing area. Placement in containers must be done in a cell or cave separate from the fuel storage area, and special precautions must be taken in the design of the fuel handling equipment to prevent contamination of the trucks or rail cars. Suitable roughing and high-efficiency particulate filters should be used to cleanup the air from the cave in which the fuel is placed in containers. Decontamination equipment for the rail cars, trucks, casks, and the cave must be provided.

Filled containers shall be moved remotely from the cave to the dry storage area and hung vertically in planar arrays from a support grid sized to provide at least 30-inch center-to-center spacing between containers. Additional center-to-center space may be required so that fuel can be transferred freely from cave to storage to processing area The fuel storage area is to provide a surge capacity equivalent to 60 days of processing Thus, room for about 1050 containers must be provided. Well-distributed cooling air at a flow rate of about 70,000 scfm will be required to dissipate decay heat. This air must also be filtered through roughing and high-efficiency particulate filters and monitored prior to release to the atmosphere through the plant stack.

Operations within the handling and storage areas are to be performed by operators using master-slave manipulators and remotely operated bridge cranes; suitable lead-glass windows must be provided for observing the fuel handling operations. The crane is to be equipped to remotely replace lamps within the storage agea. The crane should be a type that is easily maintainable, either remotely or by direct maintenance.

A remote method of moving about 18 containers of fuel per day from the storage area to the headend process must be provided, as well as an air lock for separating these two areas.

6.3.2 Process

The main process building shall consist of an operating corridor or control room, office area, shielded processing areas, chemical makeup area, etc Areas in which fuel is handled or processed are to be shielded with either high density or normal reinforced concrete. The walls and ceiling must be of sufficient thickness to adequately shield personnel from the radiation emanating from the fuel elements or fuel solutions within the cells, as described in the detailed design criteria of Section 5 and in Section 2.2.7.

Areas in which mechanical operations, such as crushing, grinding, screening, and fuel handling, are performed with irradiated fuel shall be equipped such that mechanical parts or complete units can be replaced remotely. All overhead cranes and mechanical lifting equipment in radioactive service shall be capable or remote servicing or removal to a shielded cubicle or cubicles where maintenance or repair can be performed directly.

6.3.3 Maintenance

Maintenance shops, adequately equipped to perform routine maintenance operations on equipment, instruments and electrical items and routine fabrication of parts and components needed for emergency repair, are to be an integral part of the facility complex. The machine, instrumentation and electrical shops are to be separated from the other craft shops either by location or by a barrier to prevent grinding dust, weld smoke and other contaminants from interfering with machining and repair operations.

Office space, with sufficient room for plant maintenance records and for planning and scheduling activities, shall be included as a part of the shop area.

6.3.4 Analytical

Analytical facilities adequately equipped to conduct all chemical analyses required for plant operation are to be incorporated into the plant. The laboratory space requirements and major equipment costs are listed in Table 6-1. Approximately 10,000 ft^2 of laboratory space and major equipment costing about $600,000 (based on FY-1969 costs) are required. As indicated in Table 6-1, only certain laboratories can be combined.

The shielded analytical facility is to be comprised of ten shielded operating positions, as follows:

7 work positions
1 sample storage position
1 sample loading and waste disposal station
1 maintenance and decontamination station

Each position will be provided with a shielded viewing window, suitable manipulators and a sample transfer system. The basic shielding is to be three feet of high density concrete or the equivalvent. Auxiliary equipment, such as a ventilation system, hoods, and glove boxes for handling low-activity-level sample aliquots, should also be provided.

6.3.5 Offices

The main processing building should have 8 single-occupancy and 20 double-occupancy offices, plus one conference room capable of holding about 50 persons. The offices would be used by operations, health physics, safety, analytical, and engineering personnel. Restroom facilities built in accordance with AEC Standard Health and Safety Requirements shall be included.

TABLE 6-1

MAJOR SPACE AND EQUIPMENT REQUIREMENTS
FOR ANALYTICAL LABORATORIES

Laboratory and Major Equipment	Laboratory Floor Area,(a) ft^2	Estimated Major Laboratory Equipment Cost, dollars
Mass Spectrometer(b)	380	$163,000
Mass Spectrometer Preparation(b)	170	8,000
Emmission Spectrograph(b)	550	60,000
Spectrographic Preparation(b)	450	4,000
Atomic Absorption(b)	200	12,000
Dark Room	64	1,000
X-Ray	300	56,000
Balance Room(c)	150	3,000
Instrument Room	120	32,000
Routine Analytical Chemistry(d)	1800	19,000
Sample Receiving(d)	180	10,000
Shielded Analytical Facility	3500	140,000(e)
Counting Room(c)	288	56,000
Radiochemical	1224	23,000
Standards	180	6,000
	9556 ft^2	$593,000

(a) Corridors, offices, and vent systems are not included in the estimated floor space with the exception of the shielded analytical facility.

(b) These five laboratories could be combined into one area.

(c) These rooms must be located on the ground floor.

(d) This laboratory and room could be combined into one area.

(e) The major laboratory equipment costs for the shielded facility include development and installation costs. Installation costs for such items as fume hoods and bench space are not included for the other laboratories. None of the costs include ventilating equipment, sinks, utilities, and miscellaneous equipment.

6.3.6 Decontamination Room

A decontamination area shall be a part of or attached to the main process building, and, depending on the building layout, perhaps it should be accessible from the processing areas so that contaminated equipment can be readily decontaminated. The facility shall be divided into three major areas: (1) a "hot" receiving area, (2) a decontamination area, and (3) a "clean" storage area. A two-ton capacity overhead crane, designated as a "hot area" crane, will service the "hot" storage area and the decontamination area. A second two-ton capacity overhead crane, designated as a "clean area" crane, will operate between the decontamination area and the clean area. The decontamination facility should cover approximately 1600 ft^2 and should be constructed of reinforced concrete. The floor of the facility shall be completely covered with a stainless steel lining to protect against chemical corrosion from nitric acid and various decontaminating reagents. The floor should slope so that all fluids drain to the center. Included in the decontamination area shall be stainless steel decontamination vats recessed into the floor. Also included in this area shall be a cubicle for use when decontamination is done with high pressure spray. The walls of the cubicle to a height of eight feet shall be lined with stainless steel. Stainless steel grating over stainless steel lined pits make up the floor of the cubicle which is to be equipped with high pressure air and high pressure steam-water decontamination sprays.

6.3.7 Safety

Proper safety and fire protection is to be provided in all buildings. The National Fire Codes can be used to establish design criteria for (1) handling flammable liquids and gases; (2) handling combustible solids, dusts and chemicals; (3) fire protection requirements in building construction; (4) exit requirements; and (5) electrical safety. Piping systems and equipment physical-hazards will be safety color coded.

Safety equipment for personnel at the plant should include face masks, various types of portable breathing apparatus, acid hoods, safety glasses, gloves for use with acids, etc. Plant safety equipment should include a fire water system, fire alarms, emergency power and lighting, and various types of portable fire extinguishers.

6.3.8 Health Physics

The Health Physics (HP) facilities at the processing plant shall consist of a field office, an issue room, clothing change room, showers, and storage, in addition to the administration office described in Section 6.3.5. The field office shall contain approximately 1000 sq. ft. of floor space and be divided into two areas or rooms; one room is used for HP lab work and as a counting room; the second room is used for routine HP activities connected with plant operation.

The main processing building, as well as some of the other buildings in which personnel routinely work, shall have three radiation monitoring systems. These systems are: (1) constant air monitors, (CAM's) (2) area radiation monitors, and (3) portal personnel monitors. Areas normally occupied such as operating and instrument areas, the maintenance shops, stockroom, and analytical area, are to be monitored by CAM's. This system shall consist of portable air monitors of commercial design; each monitor is to be supplied with an integrally mounted recorder which provides a continuous record of air activity and shall be equipped with alarm circuitry which gives a visual and audible signal when high air activity occurs. The area radiation monitors shall each consist of a sensing unit, a built-in calibration source, a control and readout unit, and a remote readout unit. The system shall give a direct reading of mainly gamma radiation for plant areas normally occupied by operating personnel. The portal radiation monitors serve to detect radioactive contamination transported by personnel and prevent its spread. Portal monitors shall be installed on the main doorways connecting areas of different activity level and equipped with audible and visual alarms. Some of these monitors should alarm in the HP field office.

Other HP equipment shall include hand and foot counters for alpha and gamma activity, film dosimeters, portable survey radiation meters for alpha, beta, and gamma radiation, and laboratory-type equipment for counting smear samples.

The clothing change room should contain about 200 lockers and a shower area for about 25 plant operating personnel. The clothing issue room is to be located adjacent to the change room and is to contain shelf and storage space for clean clothing, respirators, safety equipment, and other protective clothing and equipment common to a radioactive area. HP supplies should include shoe covers, coveralls, laboratory coats, rubber boots, and surgical gloves for radiactive areas, etc. Storage space for contaminated clothing, and contaminated equipment such as respirators, shall be provided as part of this area of the plant.

6.3.9 Communications

The plant is to be provided with telephone service and a signal system activated by telephone dialing for key persons; the code call system should connect all buildings and outside areas. Fire and evacuation alarms (sirens) should also be provided in all buildings and outside areas.

6.3.10 Laundry

A room and equipment for laundering shoe covers, lab coats, coveralls, etc., are to be provided. Facilities will also be included for monitoring the waste water for radioactivity before it is discharged into the sanitary waste disposal system.

6.3.11 Chemical Technology Laboratory

A combination chemistry and engineering laboratory for technical plant support type work is to be provided in the main process building. The laboratory should have an area of about 1500 ft^2 and a floor-to-ceiling height of at least 20 ft. It should include a walk-in hood, laboratory bench with a sink and utilities, and an area for pilot plant work. The pilot plant area should have suitable drains in a stainless-steel-lined and coved floor, a special ventilation system, a glove box, and miscellaneous instrumentation.

6.3.12 Supply Room

A suitable central supply room is to be provided in the main building; a self-service philosophy will be used. A special restricted area is to be reserved for sensitive items. Integral with the supply room could be the shipping and receiving areas.

6.4 AUXILIARIES BUILDING

The auxiliaries building can contain equipment for steam generation, water conditioning and purification, and air compression and treatment. It can also contain electrical switch and distribution gear, a warehouse, and the emergency electrical generator, if desirable. The building is to be constructed of pumice block. Storage tanks for compressed air, water, condensate, oil, etc., can be located outside or underground if suitable precautions are taken to prevent freezing.

Four different water systems are required: (1) untreated fire water; (2) treated water for coolers and condensers; (3) potable water; and (4) demineralized water. Pumps, including one standby, will be provided to supply water to the plant. In addition, these pumps will supply a 100,000 gallon overhead storage tank to serve as a fire water reservoir. Plant fire protection will include a network of fire hydrants located throughout the plant area, in addition to sprinklers and fire hose cabinets within some or all buildings.

A portion of the water from the supply pumps will be treated to meet cooling water requirements. Used cooling water may be recycled through a cooling tower if economically advisable. Some of the water will also be treated to meet standards for potable water which shall be chlorinated, stored in a 1000-gallon tank, and distributed as required throughout the plant. Hot potable water will be supplied from water heaters provided in each building where needed. Demineralized water will be required for some process chemical make-up and boiler-feed water make-up. These needs will be met by diverting a portion of the supply water through a demineralizer unit, into a storage tank, and from there to various plant areas in stainless steel pipe. All water system equipment, except water heaters and various storage tanks, can be located in the steam plant.

Both compressed and instrument air will be required. Compressed air shall be supplied by two identical compressors at 115psig. A portion of the compressed air will be passed through a dryer and filter unit to provide dry, clean air at 15 psig suitable for instrument air use.

Steam will be provided by at least two boilers. Steam will leave the boilers at 200 psig and be reduced to 100 and 15 psig for use in low pressure systems. Condensate from non-radioactive uses will be returned to condensate storage tanks adjacent to the steam plant.

Electrical power requirements will be provided by normal commercial means through a plant substation and distribution panels in various buildings. Power will be distributed from the substation to the buildings by underground conduits encased in concrete. Emergency power shall be provided for critical equipment items and some lighting by an on-site diesel-driven generator. The diesel unit will be instrumented to start automatically should the normal power source fail.

6.5 ADMINISTRATION BUILDING

The administration building will house a reception area, corporate management offices, a design and drafting area, dispensary, mailroom, library, conference room, miscellaneous accounting and personnel offices, a lunch room, as well as several rooms for miscellaneous functions. The building can be constructed of pumice block and should contain about eight single-occupancy offices, eight double-occupancy offices, and two large offices--each suitable for up to ten clerical personnel. The design drafting room should accomodate up to four draftsmen plus drawing storage and a machine for reproducing engineering drawings. The lunch room should accomodate about 75 persons. Food preparation facilities will not be furnished, but an area should be provided for machines to dispense food, beverages, cigarettes, and candy. The conference room should accomodate about 25 persons; for larger meetings, the lunch room can be used. Miscellaneous functions shall include a small storage area, duplicating area, restrooms, and janitorial supplies.

6.6 MISCELLANEOUS FACILITIES

Other miscellaneous facilities should be provided for storage, security and sewage. Storage for large machinery and bulky supplies is to be provided; it could possibly be part of the auxiliaries building or a separate Butler-type building of metal construction.

A security guard house is to be situated at the main entrance gate of the plant. This facility will include an electrically operated vehicle gate, pedestrian entrances and exits through the guard house, a portal radiation monitor (see Section 6.3.8) and a small restroom.

Sanitary waste will be collected in underground sewers and treated in an on-site sewage plant. Liquid effluent will be chlorinated and disposed of through a disposal field. Sludge will be dried and then trucked away for burial or incineration.

7. REQUIRED INFORMATION

The capital cost estimate for the HTGR Reference Plant shall be a study-type conceptual estimate aimed at ± 20 percent of the true cost of such a plant. Along with the capital cost estimate, a brief report should be prepared by the A-E describing significant design and engineering concepts of the plant (not to duplicate this report), and appropriate drawings are desired so that the conceptual design and costs can be evaluated. This information will permit personnel of Idaho Nuclear Corporation to make a good estimate of the required number of operating and maintenance personnel. Preliminary drawings specifying construction, arrangement, and elevations of the main buildings, as well as the general arrangement of equipment, piping, tank farms, and other items that would affect the operation and maintenance of the plant should be included with the estimate; section drawings of building elevations should be supplied as necessary to show the building construction and equipment arrangement features. Preliminary or scoping type flowsheets and drawings should be prepared for utilities. Lists of piping, insulation, instrumentation, and electrical requirements should be assembled, but they should not be transmitted in the report.

The capital costs should be shown in the report by the A-E as direct and indirect costs similar to the guide given in Table 7-1. The direct costs shall be the installed costs for buildings and equipment and the cost of improvements to the plant site, such as clearing, grading, excavation, site drainage, roads, and railroad spurs. Process equipment costs should be the installed cost and shall include appurtenances such as piping, fittings, hangers, insulation, instrumentation, electrical, pumps, blowers, jets, motors, etc. Miscellaneous equipment costs are to be divided into three categories: (1) utilities equipment shall include items for the production of steam, water treatment and storage, electrical substations, sanitary waste disposal, storm sewers, plant air, and the necessary distribution systems ; (2) service equipment shall include items such as plumbing, heating, ventilating, sprinkling, lighting, communications, and painting; (3) nonprocess equipment shall include equipment such as office furniture, personal lockers, fire extinguishers, dosimeters, and radiation meters, as well as equipment for medical, shop, laboratory, stockroom, and housekeeping purposes.

The indirect engineering design and inspection costs shall cover the A-E

TABLE 7-1

DESIRED DIVISION OF THE CAPITAL COSTS
for the
REFERENCE PROCESS

	Cost ($1000)
I. Direct Costs	
A. Structures and Improvements	
1. Site Improvements	
2. Main Process Building	
a. Fuel Storage	
b. Headend Cells	
(1) Fuel cutting	
(2) Fuel crushing and burning	
(3) Screening	
(4) Alumina recycle process	
(5) Fissile particle process	
(6) Fertile particle process	
c. Solvent Extraction Cells	
(1) U-233 process	
(2) U-235 process	
d. Product Cells	
(1) U-233	
(2) Thorium Storage Vaults	
(3) U-235	
e. Waste Disposal Cells	
(1) Aqueous storage vault	
(2) Evaporation, calcination, and ion exchange	
(3) Calcined Solids Storage	
(4) Off-gas cleanup	
f. Miscellaneous	
3. Utilities Building	
4. Administrative Building	
5. Other	
B. Process Equipment	
1. Fuel Unloading and Storage	
2. Headend	
a. Fuel cutting	
b. Fuel crushing and burning	
c. Screening	
d. Alumina Recycle Process	
e. Fissile Particle Process	
f. Fertile Particle Process	

Cost ($1000)

3. Solvent Extraction

a. U-233 Process
(1) H Cycle
(2) First Cycle
(3) Second Cycle

b. U-235 Process
(1) H Cycle
(2) First Cycle
(3) Second Cycle

4. Product

a. U-233

b. Thorium Storage Tanks, etc.

c. U-235

5. Waste Disposal Equipment

a. Aqueous waste storage tanks

b. Evaporation, calcination, and ion exchange

c. Calcined solids storage

d. Off-gas cleanup

6. Remote Manipulators, Shielded Windows, and Cranes

7. Chemical Storage and Makeup

C. Miscellaneous Equipment

1. Utilities

2. Services

3. Non-Process

II. Indirect Costs

A. Engineering Design and Inspection

B. Miscellaneous Construction

C. Contingency

D. Spare Parts

E. Non-Installed Equipment Spares

III. Alternatives

	Cost of Equipment and Building Space ($1000)	
	Of deleted items	Of replacement items
A. Fissile Particles Packaged		
B. U-233 Solution Shipped		
C. All Particles Uncoated		
D. Only Fissile Particles Coated		

services required for the detailed design, construction, and inspection of the plant. Miscellaneous construction costs shall cover the cost of temporary construction buildings, construction equipment rental, and other similar costs that would be incurred by the constructor. Contingency costs shall cover the allowances that must be made in anticipation of design changes, additions to systems and structures after construction has advanced significantly, and other similar items. Spare parts costs shall cover spare items that are not generally included under operating and maintenance supplies. Major non-installed equipment spares shall include such items as a spare crusher or screener, if these would be carried as spares. Other indirect costs, such as owner's general and administrative, startup, training, licensing and public relations, and land and land rights, should not be estimated by the A-E unless they are affected by the design and construction costs.

Because of the possible fuel variations, capital costs must be given in detail as suggested in Table 7-1 to allow identification of incremental capital costs associated with the following alternatives which are shown schematically in Figure 4-14 of Section 4:

1. Fissile Particles Packaged and Stored
2. U-233 Shipped as a Nitrate Solution
3. All Particles Uncoated
4. Fertile Particles Uncoated, Fissile Particles Coated

Process alternative 1 -- Fissile Particles Packaged and Stored -- involves the deletion of processing area and equipment required in the reference process for (1) fissile particle processing, (2) U-235 solvent extraction, (3) U-235 denitration, and (4) U-235 packaging and shipment. Replacement equipment would include a collection hopper, packaging, handling, and storage equipment. Design details of this equipment are given in Section 5.

Process alternative 2 -- U-233 Shipped as a Nitrate Solution -- involves the omission of space and equipment for the denitration, packaging, and shipment of U-233; replacement equipment includes a hold tank, bottling and weigh station, bottles, and transfer containers.

Process alternative 3 -- All Particles Uncoated -- involves the omission of considerable equipment and space for the following facilities: (1) alumina leaching and drying, (2) screening, (3) fissile particle processing, (4) fissile solvent extraction, (5) fissile denitration, and (6) fertile particle facilities. Alternative 3 would then require the addition of replacement equipment and area for the following special equipment: (1) burner product weigh hoppers, (2) leachers, (3) centrifuge, and (4) solids drier. This special equipment is described in Section 5.

Process alternative 4 -- Fertile Particles Uncoated, Fissile Particles Coated-- involves the omission of the following facilities: (1) alumina leaching and drying and (2) fertile particle processing. This alternative would require the addition of the same replacement equipment as given in alternative 3.

In addition to the above information, an estimate of the time and capital distribution required to construct a plant similar to the conceptual project is desired; ie, the number of months required from start to end for the construction project, and the time distribution of construction funds (assuming annual funds are available at the first of each fiscal year) shall be reported. Any assumptions made for the conceptual design or the cost estimate shall be presented in the final report on the project. All costs should be in terms of 1969 dollars.

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