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INFORMAL AEC RESEARCH
AND DEVELOPMENT REPORT

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REPROCESSING HTGR HEX BLOCK FUELS AT
THE NUCLEAR FUEL SERVICES PLANT

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INTRODUCTION

The High-Temperature Gas-Cooled Reactor developed by General Atomic utilizes enriched uranium and thorium oxide or carbide fuel particles contained within graphite rods or hexagonal blocks. All the fuel particles are coated with pyrolytic carbon, and in some applications part or all of the particles may also be coated with silicon carbide. Most of the nuclear-powered generating stations now in operation, under construction, or in design in the United States are of the water-cooled type. The only existing commercial fuel reprocessing plant was designed to handle metallic-sheathed fuel elements from these water-cooled reactors. This commercial plant, Nuclear Fuel Services, West Valley, New York, employs a chop-leach head-end operation to prepare fuel elements for solvent extraction decontamination and recovery of fuel materials. This type of head-end operation cannot be used for the graphite-matrix HTGR fuels.

In 1964, a joint study was made by General Atomic and Nuclear Fuel Services (NFS)⁽¹⁾ to determine a feasible method for the head-end processing of HTGR fuels and to develop capital cost estimates for a processing facility to be coupled to the existing NFS plant. Operating costs for processing HTGR fuels were also determined.⁽²⁾ Since the completion of this study, the HTGR fuel element has been changed from a long rod to a short hexagonal block (hex block) with the fissile uranium contained in separate fuel particles. All the fuel particles have a pyrolytic carbon coating, and the fissile fuel particles may have an additional coating of silicon carbide. In addition, an increased reprocessing load has been projected. The effects of these changes on the feasibility and costs of reprocessing spent HTGR fuels at NFS have been investigated and are the subject of the present report.

SUMMARY

The changes made in the HTGR fuel element design since the initial study⁽¹⁾ on reprocessing HTGR fuels at the NFS plant was performed have necessitated some changes in the head-end auxiliary processes. However, the basic burn-leach process with two burn-leach lines considered in the previous study remains the same, subsequent development having confirmed it as the most attractive head-end process for HTGR-type fuels.

The inclusion of the silicon carbide coating on the fissile particles requires additional head-end process steps. During the fuel element burning operation, the silicon carbide coating is not removed. Therefore, a screening step is needed to separate the fissile particles from the burner ash. The separated fissile particles are placed in high integrity containers which are sealed by welding. These containers are then placed in a fissile particle storage vault sized to hold the entire fissile particle container yield from the entire assumed fuel processing period of 7.5 yr. For cost estimating purposes, it is assumed in the present study that, starting at the end of the processing period, the containers will be shipped to a salt mine repository for ultimate disposal. It is further assumed that such a repository will exist at that time. Since the residual uranium in the fissile particles is predominately U^{236} , reprocessing of the fissile particles for uranium recovery was not considered in this study. An economic assessment would be made to determine the value of the fissile particles before the fuel was shipped for ultimate disposal.

The change in fuel element geometry has only minor effects on fuel handling. Larger diameter fuel storage containers and larger crushers and crusher auxiliaries are needed.

It is assumed that the maximum reprocessing capacity for HTGR fuels at the NFS plant (500 kg of fertile particle actinides per day for 130 days each year) will be attained within a few years after the start of HTGR fuel reprocessing at NFS. As a result, the proposed initially installed HTGR head-end facility at NFS contains two burn-leach lines and is designed to match the solvent extraction capacity of the NFS plant for HTGR fuels. Equipment common to both burn-leach lines is used in off-gas treatment and in preparing the leacher product for solvent extraction. In addition, the assumption of early full capacity operation of the reprocessing plant eliminates the requirement for a large solvent extraction feed accumulation tank similar to that specified in the earlier study.

Based on the estimated reprocessing load (see Table 1), 540 process days are required at the NFS plant during the assumed 7.5-yr operating period. With the addition of 180 days for plant turnaround, the total number of NFS revenue days chargeable to HTGR fuels would be 720. Reprocessing costs for HTGR fuels are estimated to be \$51,077 per revenue day. The cost per kilogram of actinides in the unirradiated HTGR fuel is \$129. These costs include amortization charges for the HTGR head-end facility, which is estimated to cost \$9,480,000. The estimated NFS reprocessing charges for HTGR hex block fuels as made by General Atomic are lower than those previously estimated for HTGR rod-type fuels.⁽²⁾ This decrease in reprocessing cost is due to the increase in the estimated quantity of HTGR fuel available for reprocessing and the resultant increase in the number of revenue days over which the capital cost of the HTGR head-end facility is amortized.

Table 1
PROJECTED AVAILABILITY OF HTGR FUEL

<u>Year</u>	<u>Quantity of Fuel^a (kg/yr)</u>
1974	3,470
1975	10,500
1976	24,000
1977	37,800
1978	>65,000 ^b
1979	>65,000
1980	>65,000

^a Kilograms of actinides in the irradiated fertile particles.

^b Assuming that 130 processing days at 500 kg/day are available each year at NFS.

BASIS FOR STUDY

FUEL ELEMENT DESCRIPTION

The size and composition of the HTGR fuel element used in the present study are based on one of the current concepts. ⁽³⁾ This concept is described in Table 2.

Substitution of uranium carbide and/or thorium carbide for the respective oxides would have no significant effect on the reprocessing equipment discussed in this report. The 210-day cooling time is used to permit decay of Pa^{233} to U^{233} .

The fuel particles are bonded to the fuel block, and processing of the entire fuel block is considered necessary to recover the fuel values. The uranium in the irradiated fissile particles is U^{235} grossly contaminated with U^{236} . This uranium may be of little value for recycle. Irradiated fertile particles contain U^{233} , which has a high value as a reactor fuel. The silicon carbide coating on the fissile particles remains intact during the head-end processing, ^(4, 5) which makes it possible to separate the two types of fuel particles. In the present study, only the uranium (mostly U^{233}) and thorium in the fertile particles are considered for recovery. The separated fissile particles are placed in long-term storage.

FUEL ELEMENT AVAILABILITY

The assumed quantity of HTGR fuel available for reprocessing at NFS from 1974 through 1980 is shown in Table 1. The amounts of fuel listed were used in the design and cost estimate presented in this report.

NFS PLANT THROUGHPUT CAPABILITY

The throughput capability of the existing NFS plant for reprocessing HTGR fuels has been assumed to be limited by several factors:

1. Fuel elements from several different types of reactors are reprocessed at the NFS plant. As a result, the number of days available for reprocessing HTGR fuels is limited. The earlier study⁽¹⁾ established the time available for reprocessing HTGR fuels at 130 days/yr. For comparative purposes, the same time availability has been used in this study.

Table 2
FUEL ELEMENT CHARACTERISTICS

Length (in.)	31. 22
Width (in.)	14. 17 (across flats of hex block)
Fertile particles	
Diameter (μ)	
ThO ₂ kernel	350
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
Pyrolytic carbon and buffer carbon coatings	<u>10. 90</u> 23. 64
Fissile particles	
Diameter (μ)	
UO ₂ kernel (70% voids)	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	<u>2. 22</u> 3. 53
Graphite fuel block (kg/element)	97. 46
Carbon binder	4. 94
Total weight of fuel at discharge (kg/element)	129. 57
Cooling time (days)	
At reactor	90 (min)
At reprocessing plant	<u>120</u>
Total	210 (min)
Average burnup (MWD/tonne of actinides)	68, 000
Heat release (Btu/hr/element)	
90-day cooled	1700
210-day cooled	
Fissile particles	390
Fertile particles	<u>380</u>
Total	770

2. Solvent extraction column throughput capability and criticality considerations establish a production rate of ~500 kg/day of heavy metal from HTGR-type fuels.
3. The assumed life of the NFS plant is 15 yr. Since plant operation started around the beginning of 1966, continued operation until 1981 is anticipated.
4. A maximum of 12, 000 curies of Kr^{85} can be released to the atmosphere daily. Tritium release is not considered limiting.

Five hundred kilograms of heavy metals corresponds to approximately 45 fuel blocks. Coincidentally, the amount of Kr^{85} released from 45 fuel elements would be slightly below the NFS limit. The assumed HTGR fuel availability for NFS (see Table 2) coupled with the NFS processing capability yields a total of 540 processing days at NFS which could be utilized through 1980.

PROCESS DESCRIPTION

Basically, the head-end operation for reprocessing HTGR fuels utilizes the burn-leach process. This process was used as the basis for the earlier study⁽¹⁾ and still offers the most promising approach to HTGR fuel reprocessing. Burn-leach was conceived at Brookhaven National Laboratory⁽⁶⁾ and developed at both Brookhaven⁽⁷⁾ and Oak Ridge National Laboratory.⁽⁸⁾ Experimental work on burn-leach is also being performed at the Idaho National Reactor Testing Station.⁽⁹⁾

BURN-LEACH

The burn-leach process as applied to the hex block fuel is performed as follows:

1. Crush the fuel blocks to a size suitable for burner operation.
2. Burn the crushed blocks with oxygen and/or air in a fluidized bed reactor of alundum particles to aid in temperature control. The silicon-carbide-coated fissile particles will be unaffected by the burning operation,⁽⁴⁾ but the fertile particles will be exposed.
3. Leach the fertile particle components from the alundum and the fissile particles with nitric acid containing a trace of fluoride. The silicon-carbide-coated fissile particles will be unaffected⁽⁵⁾ by the leaching.
4. Render the leacher solution acid-deficient.
5. Separate and decontaminate the thorium and uranium by solvent extraction.
6. Ship the recovered uranium to a fuel refabrication facility.
7. Store the thorium as an acid solution for Th^{228} decay; then ship it to a fuel refabrication facility.
8. Screen the leacher solids to separate the fissile particles from the alundum, and recycle the alundum to the burner.
9. Package and store the fissile particles.

Block flow diagrams and the material balance for the burn-leach processing of hex block fuels are presented in Figs. 1, 2, and 3.

FUEL ELEMENT RECEIVING AND STORAGE

New fuel receiving and storage facilities are required for HTGR fuel elements. Existing NFS facilities, designed for metallic-sheathed fuels, utilize underwater cask unloading, storage, and transfer to the mechanical disassembly cell, whereas HTGR fuel requires dry receiving and storage. The proposed arrangement of the HTGR fuel head-end complex is shown in Figs. 4 through 8.

The receiving station accommodates the shipping of casks on railroad cars. If casks are received by truck, they are transferred to a captive railroad car with the existing 100-ton crane. Once the railroad car (captive or common carrier) with its cask in the unloading orientation is positioned in the unloading station, a shield is lowered onto the cask by a power-operated screw jack. The ventilation door on the shield is removed with the unloading station crane and hung on the wall. Then the shipping cask shield plug is lifted off and set aside, and the motorized shielding door to the storage vault is opened. The HTGR fuel elements are then removed from the cask and placed in the fuel storage vault. If uncanned, the individual elements would be lifted from the cask with a grapppler and placed into prepositioned cans in the storage vault. Each can would hold seven hex block elements. Lids would be placed on the cans and tightened with the vault crane, which would then move the cans to a position on the storage rack. The reuseable storage cans would simplify fuel handling and permit the use of air for cooling and ventilating the vault. If the fuel elements are shipped canned, the shipping can and the vault design could be made compatible so as to permit direct placement of the cans into storage. In this case, empty cans would replace those removed from the shipping cask. The cranes are remotely controlled, their operation being observed through viewing windows and television cameras.

When the number of irradiated fuel elements to be processed approaches the available reprocessing capacity of NFS for HTGR fuels, it will be necessary to receive only large shipping casks capable of holding more than 40 elements or so. This requirement is due to the relatively large number of elements processed annually. At design capacity (5850 elements per year), an average of 15 to 20 elements per day will be received. If only small, seven-element casks were used, it would be necessary to receive and unload an average of two to three casks daily. This would require multiple unloading stations at an increase in capital cost.

Fig. 2. Block flow diagram for HTGR hex block reprocessing - II. Extraction and partition

I HEAD END

[illegible]

II EXTRACTION É PARTITION

[illegible]

Fig. 3. Material balance for HTGR hex block reprocessing

SECTION A-A

Fig. 4. Layout Study I. Head-end reprocessing facility for HTGR hex block fuel

Fig. 5. Layout Study I. Plan above El. 160'-0

Fig. 6. Layout Study I. Plan above El. 115'-0

Fig. 7. Layout Study I. Plan above El. 94'-0

Fig. 8. Layout Study I. Ventilation filter and plot plan

The fuel storage cans are 18 in. in diameter and 20 ft long, have integral flanges, and hold seven hex block fuel elements. The cans are hung vertically in planar arrays from a support grid in the fuel storage vault. No criticality problem exists with the canned fuel elements, analysis having indicated that an infinite array of 18-in. -diameter cans containing a stack of hex block fuel elements would be subcritical in either the dry or water-flooded condition. (10) Aisles on both sides of the storage area would provide multiple access to the arrays.

The storage vault is sized to contain enough fuel elements for 24 days of operation at the maximum processing rate of 45 elements per day (1085 elements, or 155 seven-element cans). Since the cans are stored in rows accessible only from the ends, two extra rows are provided for receiving and emptying cans. The shortest operating period with the minimum charges for turnaround time is 24 days. An operating period longer than 24 days is possible if sufficiently aged (210-day minimum) fuel elements are received during the period. As the number of irradiated HTGR fuel elements available for processing at NFS increases, and the time interval between operating periods decreases, it will be necessary to keep the fuels longer in storage at the reactors or elsewhere in order to allow them to cool for 210 days prior to being processed. Eventually, because of storage limitations fuel elements which have been cooled a minimum of 140 days will be received at NFS.

Air is used to ventilate the storage vault and cool the cans of stored elements. With fuel elements ranging in cooling time from 90 to 210 days, the fuel vault requires 10,000 cfm of air to preclude excessive heating.

When not in use, the storage vault crane is parked in a shielded crane maintenance area. A water-filled shield door provides crane access between the vault and the maintenance area. Before this door is opened, the water is drained from it.

Since off-gases from the head-end process equipment could have relatively high concentrations of radioactive particulates, filters are provided for trapping the particulate matter. These filters, located in the fuel storage vault, must be periodically replaced with spares. Simple manipulators, observed by means of crane-mounted television cameras, are used to disconnect the filters. The vault crane is then used to move the filters to an adjacent storage area or to place them in a shielded burial box in the cask unloading area. The process filter area is enclosed within a ventilation barrier with suitable access hatches.

FUEL ELEMENT CRUSHING

Two roll-type crushers, one serving each burner, are used to reduce the hex block fuel elements to a size (~ 1 in.) compatible with the burner feeder and with efficient burner operation. The crushers are located in the storage vault and discharge into the burners, which lie below them, via an air lock feeder. During operation, the vault crane removes the lid from a storage can and positions the can, which contains seven fuel elements, in a horizontal cradle. The can flange is clamped to a mating flange on a crusher, and the cradle is raised to a vertical position, allowing the fuel blocks to fall into the crusher hopper. The crusher is operated intermittently, with the fuel fragments falling into the air lock. A collimated radiation detector indicates when a charge of crushed fuel has accumulated in the air lock and shuts down the crusher. A charge is added to a burner in 30-min to 1-hr intervals, a seven-element can supplying a burner for 7 to 8 hr.

To minimize dusting in the cell, the crushers are enclosed in a purge box. Vault air is drawn into the box, is passed first through sintered metal filter elements equipped with an automatic pulse blowback system and then through glass fiber filters, and is finally discharged into the building ventilation exhaust system. Fines blown off the sintered metal filters are charged to the burner along with the crushed fuel.

FUEL ELEMENT BURNING

Oxygen is used to burn the graphite matrix, the carbon binder, and the pyrolytic carbon particle coatings to carbon dioxide. (Any carbides in the fuel particles would be converted to oxides.) The burning operation is highly exothermic. Therefore, burning is done in a fluidized bed reactor to maintain proper temperature control and prevent clinkering of the fuel. Burning of graphite fuels has been successfully demonstrated on a pilot plant scale. (7-9, 11) Thirty-mesh, fused alundum bed material is fluidized with the oxygen and the carbon dioxide reaction product. A large-mesh alundum is used to permit subsequent separation of the fissile particles.

Burning proceeds at reasonable rates with a bed temperature of 700° to 750°C . Combustion rates of 15 kg of carbon per square foot of burner cross sectional area have been demonstrated in pilot plant studies. Air is blown through a burner jacket and through internal tubes to remove the heat of combustion and to partially cool the off-gases prior to filtration. Temperature control is maintained through control of the cooling air flow rate or the burner oxygen flow rate. Approximately 90% of the oxygen is consumed in the combustion reaction. The burner off-gas consists primarily of carbon dioxide with up to 10% carbon monoxide and 10% oxygen.

Metallic filters are used to remove entrained particles from the off-gas. Effective fission product removal was demonstrated in laboratory studies⁽⁸⁾ by cooling the off-gas prior to filtration. Fines accumulated on the filters are periodically removed with a pulse blowback system and returned to the burner via dip leg into the fluidized bed.

The fuel does not ignite until a temperature of about 650°C is reached. For initial operation it is necessary to preheat the bed to the ignition temperature. This is accomplished by passing air or nitrogen preheated to 700° to 750°C through the bed and then changing to oxygen when the proper bed temperature is attained. Electrical heaters located in the operating area are used as preheaters. Although preheating of the oxygen is not necessary during normal operation, oxygen preheating is necessary at the termination of a run to complete burning of the pyrolytic carbon coatings.

Burner ash is continuously withdrawn through a control valve at the bottom of the burner and pneumatically transported to an ash storage hopper. The burner ash consists of the alundum bed and up to 30% heavy metal oxides. Only trace quantities of carbon are expected to be present in the ash.

Two burners are needed for the required processing rate of 45 hex block fuel elements per day. Each burner (see Fig. 9) is about 18 ft high and has a 40-in. ID in the fluidized bed portion and a 66-in. ID in the upper deentrainment-cooling portion. An internal grid within the fluidized bed supports the fuel fragments. About 10,000 cfm of cooling air is needed to remove the heat of combustion. This air flows through a jacket on the burner and through bayonet tubes within the reactor. The outside of the type 310 stainless steel burner and the upper portion of the internal tubes are finned to increase heat transfer rates. A 500-hp blower supplies the cooling air. The effluent air is cooled, filtered, and discharged to the atmosphere through the plant stack. Pressures of -0.1 to 6 psig within the burner and 9 psig in the cooling air passages are anticipated.

The metallic off-gas filters are contained in a separate filter unit. Fines blown off the filters are returned to the burner through a line terminating within the fluidized bed. A separate filter unit is used rather than elements within the burner in order to facilitate filter assembly replacement should a filter element fail and to reduce the overall burner height. From the metallic filters, the burner off-gases pass first through a cooler, then through a silica gel adsorber for removing any volatilized ruthenium, and finally through filters before being discharged through the plant stack. The silica gel adsorber and final filtration system are common to both burners. Two stages of final filtration are used. In the first stage, the gases are passed through a deep bed glass fiber filter located in the process filter area in the fuel storage vault. In the second stage, the gases

Fig. 9. Burner

are combined with the building ventilation air and then passed through absolute filters prior to atmospheric discharge. An ejector located in the process filter area maintains the burner off-gas train at a slightly sub-atmospheric pressure to minimize contamination from minor leakage. The silica gel adsorber, located in the utility cell, is regenerated periodically with dilute nitric acid.

During operation, the burner ash is continuously accumulated in the ash hopper. Periodically, the ash hopper contents are pneumatically transported to a weigh hopper which is instrumented to measure the weight and volume it contains. When sufficient ash has accumulated in the ash hopper, the ash is gravity-discharged into the leacher.

Alundum is periodically added to the burner from the recycle alundum hopper. Most of the alundum added is recycled from the leacher cell. The alundum undergoes some degradation in the burner and leacher, which results in a reduction in the size of the alundum particles. When an alundum particle degrades until it is comparable to a fissile particle in size, it follows the fissile particle during the screening operation for packaging and storing. Degradation is assumed to amount to about 10% of the alundum throughput. Make-up alundum is added to the recycle alundum hopper from the operating area. An air lock is used for contamination control.

LEACHING

Strong dissolving reagents are required to effect thorium oxide dissolution in a reasonable time. In pilot plant studies, ⁽⁸⁾ boiling 13M HNO_3 , 0.05M HF dissolved thorium oxide microspheres in an alundum bed in 6 hr. Aluminum nitrate is added to the dissolver solution to minimize leacher corrosion, and cadmium nitrate is added to facilitate criticality control. The dissolution reaction is easily controlled since very little heat is evolved. Silicon carbide is not attacked by the leaching solution, so the fissile particles are not affected. ⁽⁵⁾

A separate 4-ft-diameter, 8-ft-high, type 309 stainless steel leacher (see Fig. 10) is used for each burner. Auxiliaries include an array of poison plates within the leacher for criticality control, a jacket and/or coil for heating and cooling, an air sparger, a jet-out line with a filter at the suction inlet, a pneumatic transport system for removal of the leached ash, and off-gas treatment equipment. Leacher off-gases pass successively through a water-cooled reflux condenser, a scrubber for decontaminating the off-gases and removing residual nitric acid vapors, a silica gel adsorber for removing volatilized ruthenium, and filters. The scrubber is common to both leachers. The silica gel adsorber and the filters are also common to the burner off-gas system.

Fig. 10. Leacher

A leacher operating cycle requires about 18 hr and consists of the following:

1. Charging the leacher with burner ash from the weigh hopper.
2. Adding the leaching solution from a make-up tank in the operating gallery.
3. Heating to boiling while air sparging.
4. Digesting for 6 hr at the boiling point.
5. Cooling while air sparging.
6. Transferring the dissolver solution to a receiver tank.
7. Rinsing the alundum and fissile particles with a dilute solution of cadmium nitrate, the rinse being combined with the dissolver solution in the receiver tank.
8. Pneumatically transporting the alundum and fissile particles to a storage hopper.

SOLVENT EXTRACTION FEED PREPARATION

To achieve adequate solvent extraction decontamination of thorium, the feed solution to the first extraction column must be acid-deficient; i. e. , the free nitric acid concentration must have a negative value. Since the leacher product solution has a high nitric acid content, a denitration step is necessary. Denitration is achieved in a nitric acid stripper by evaporating the leacher solution to a high salt content and sparging with steam. This drives off the excess nitric acid as a vapor, which is condensed, collected, and routed to the existing NFS nitric acid recovery system. A simple, continuously operated stripper system serves both leachers.

The stripper (see Fig. 11) consists of a 30-in. -diameter, 3-ft-high pot surmounted by an 8-in. -diameter, 12-ft-high deentrainment tower. Type 309 stainless steel is the material of construction. Poison plates in the stripper pot and the cadmium nitrate in the stripper feed provide criticality control. The concentrated solution overflows to a water-cooled pot. Water is continuously added to the overflow pot to effect dilution to the solvent extraction feed concentration. An air lift continuously transfers the diluted solution to the solvent extraction feed storage tank. Off-gases from the stripper condenser are combined with those from the leacher condensers for treatment.

Fig. 11. Stripper

A 1000-gal storage tank is provided to hold approximately a 2-day supply of solvent extraction feed. The type 304L stainless steel storage tank is equipped with a cooling coil for removing fission product decay heat, an air sparger for agitation, and poison plates for criticality control. From the tank, the solution is transferred in batches to the solvent extraction facilities.

SOLVENT EXTRACTION

The existing NFS solvent extraction equipment is used to decontaminate and separate the uranium and thorium. The solvent extraction block flow diagrams and material balances are presented in Figs. 2 and 3. Pulse columns 4-C1 through 4-C4 code-contaminate the uranium and thorium by extracting these heavy metals from the aqueous feed with 20% tributyl phosphate (TBP) in a hydrocarbon diluent, scrubbing with acid, and stripping with dilute acid. The resultant thorium-uranium product containing a trace of fission products is acidified and fed to column 4-C9, where only the uranium is extracted with a 5% TBP solvent. The thorium-bearing aqueous stream from this column is concentrated by evaporation and stored as an acidic solution. Decontamination of the uranium is completed in the solvent extraction columns, 4-C10 through 4-C12. After evaporation, the purified uranium product is packaged and shipped as the nitrate.

Some equipment must be added to the NFS solvent extraction facilities for thorium recovery. For the acid addition to the lower section of column 4-C1, a head tank, a flow control system, and both "hot" and "cold" piping are required. In addition, a thorium product concentration system is needed to minimize the thorium solution storage requirements.

The thorium product concentration system consists of a continuously operated thermosyphon evaporator, a condenser, and condensate and product receiver tanks, all constructed of type 304L stainless steel (see Fig. 12). An 18-in. -diameter, 6-ft-high reboiler is connected to a 30-in. -diameter solution reservoir and deentrainment tower. The overall height of this unit is 18 ft. The concentrated thorium solution continuously overflows to a small water-cooled pot and then is transferred to the product receiver tank. Periodically, the thorium is transferred from the product receiver to the thorium storage tanks. Since the evaporator feed solution has a relatively high acid content, it is fed directly to the reboiler rather than to the evaporator tower for steam stripping of entrained and dissolver solvent. This feed point permits a large fraction of the excess nitric acid to be boiled off, thus reducing the product nitric acid contents and, as a result, allowing a higher terminal thorium concentration and minimum storage requirements. Because the evaporator is fed from a solvent extraction system, the reboiler steam pressure is limited to 30 psig to preclude

Fig. 12. Thorium evaporator

solvent-nitric acid or solvent-thorium nitrate reactions. Evaporator overhead vapors are condensed, collected, and routed to the existing NFS waste-handling system. The evaporator and receiver tanks are vented to the existing NFS vent systems.

THORIUM STORAGE

The thorium product solution contains the active isotopes Th^{228} and Th^{234} . This precludes recycling of the thorium product to a contact-operated fuel refabrication plant until the active isotopes have decayed to low levels. A decay period of 10 to 15 yr is required. Thus, all the thorium nitrate solution processed through 1980 (150,000 gal) requires storage. Uncooled stainless steel underground storage tanks are used for this purpose. Spare tanks, one for up to five active tanks, are also required. An economic evaluation indicates that using three tanks of 100,000-gal capacity each results in a minimum total cost.

Since the thorium product must be stored for an extended period, only one solvent extraction cycle is performed for decontamination of the thorium. The residual fission products decay to low levels during the storage period. Sufficient fission product removal is achieved in one decontamination cycle to eliminate the problem of decay heat.

SCREENING

The silicon-carbide-coated fissile particles are not affected by the burning and leaching operations; as a result, the leacher residue is a mixture of alundum and fissile particles. Separation of the leacher residue components is necessary to permit reuse of the alundum and to minimize the space requirements for fissile particle storage. Since the alundum particles are larger in diameter than the fissile particles, mechanical separation by screening is possible.

After leaching, the burner ash is rinsed with water and pneumatically transported to a hopper. This hopper has a false bottom of sintered metal or wire mesh through which heated air is blown to dry the particles. The humidified air passes through a condenser, an off-gas heater, and a glass fiber filter before being combined with the building ventilation air. Drying is carried out in the hopper rather than in the leacher in order to reduce the leaching time cycle and consequently the size of the leaching equipment. The dried particles are fed at a controlled rate to a vibrating screen. The fissile particles and any physically degraded alundum particles pass through the screen and into a fissile particle hopper. Another hopper receives the larger alundum particles. This alundum is pneumatically

transported to the recycle alundum hopper for reuse in the burner, and the fissile particles are pneumatically transported to a weigh hopper in the fissile particle storage vault. A separate screening system is used for each leacher, but the weigh hopper is common to both lines.

FISSILE PARTICLE PACKAGING AND STORAGE

At the high burnups obtainable from HTGR-type fuels, most of the U^{235} initially contained in the fissile particles undergoes fission. In addition, a significant portion of the residual fissile particle uranium is U^{236} . In the present study, it is assumed that the uranium remaining in irradiated fissile particles has little economic value for recycle to HTGRs and is not recovered. The fissile particles are packaged along with the degraded alundum and placed in an air-cooled vault for long-term storage. The packaged fissile particles can be treated the same as calcined high level waste. The ultimate disposal techniques eventually developed for calcined high level waste could also be utilized for the fissile particles. Should it prove economically desirable, the fissile particles could be retrieved and processed at any time prior to ultimate disposal.

Packaging is carried out within the fissile particle storage vault. The vault overhead crane places an empty 6-in. -diameter, 20-ft-long cylindrical container in the filling station near the fissile particle weigh hopper. A manipulator is used to connect a flexible line from the hopper to a filling spout on the container. A predetermined quantity of fissile particles is dropped into the container through a valve on the hopper outlet. To minimize dusting problems, vault air is drawn up through the open end of the fill line and exhausted through a filter. After a container has been filled, it is disconnected and moved by the crane to a welding station, where a cap is positioned by a manipulator and welded in place by a remote welder. Windows are provided for operational viewing. The vault crane then moves the containers into storage. Head room limitations require the floor in the packaging area to be recessed. Empty containers and caps are brought into the vault from the small access gallery below. The vault crane is used to lift the containers into the vault through a shielding door in the floor. This access is also used for replacing packaging equipment.

The storage vault is sized to store all the fissile particles processed through 1980. During head-end operations, about 1.5 fissile particle containers are filled daily. For the assumed 540 processing days, approximately 800 containers will be filled. The containers are stored vertically in planar arrays, with support members on the upper end of the containers mating into a positioning grid. Because of criticality considerations, the storage area is divided by concrete walls into eight bays, each of which can accommodate eight rows of containers.

Ventilation air is used to remove the fissile particle decay heat. When the vault is full at the termination of the HTGR fuel processing in 1980, the fission product decay heat generation rate will be 3.2×10^6 Btu/hr. An air flow rate of 15,000 scfm will then be required to prevent overheating of the vault. The centerline temperature of a can containing fissile particles cooled for 210 days will be about 800°F.

VENTILATION

A reliable ventilation system is needed to assure confinement of radioactive particles and gases and to remove the fission product decay heat from the fuel and fissile particle storage vaults. A ventilation supply system on the roof of the fissile particle storage vault serves the entire HTGR head-end building. Two parallel blower systems are used, each supplying half of the 40,000 cfm of air required. The air flow pattern is from the "cold" areas to the contaminated areas.

The cell and vault air is filtered prior to atmospheric discharge by two banks of absolute filters in series contained in an underground structure. Two underground filter units will be installed initially, with one unit serving as a spare. Should it become necessary to abandon a filter unit because of filter pluggage or breakage, a gate on the inlet air duct to the spare unit will be removed and installed on the inlet to the failed unit. Provisions are included for installing additional filter units as needed.

The highly radioactive areas are maintained at a slightly subatmospheric pressure by means of exhaust blowers on the filter outlet. Two parallel blowers, each rated at 50% of the ventilation capacity, are used for normal operation. In addition, a third 50% capacity blower, with both a normal and an emergency power supply, is installed as a spare. The blowers discharge to a 200-ft-high exhaust stack provided for the dispersion of radioactive gases.

The primary source of particulate matter is the process equipment. To maximize the life of the building ventilation absolute filters, several process filters are used on the various equipment vent systems. Most of these process filters are deep beds of glass fibers which have high dust-loading capacities. The filtered process gases are discharged to the building ventilation filters for final cleanup. The process filters are located in the fuel storage vault as described previously. Air ejectors on the individual vent systems are also located in the process filter area. The installed vent systems include the following:

1. Vessel vent.
2. Pneumatic transport vent.
3. Silica gel vent.
4. Crusher and packaging vent.
5. Dryer condenser vent.

COSTS

Charges for reprocessing HTGR fuels at the NFS plant can be divided into three categories: (1) standard NFS reprocessing charges, (2) amortization of the HTGR fuel head-end facility, and (3) special charges for surveillance and disposal of the thorium nitrate solution and the canned fissile particles. Reprocessing charges quoted by NFS are based on a revenue day. A revenue day consists of the actual processing time for a lot of fuel elements plus turnaround time for plant cleanout and preparation for the next fuel lot. The turnaround time is computed as one-third the processing time, with a minimum charge of 8 days. Since the HTGR fuel storage vault is sized to accumulate fuels for a 24-day processing period, an 8-day turnaround time will be one-third the number of processing days. The total number of process days based on the HTGR spent fuel load considered here and NFS processing limitations is 540. The number of turnaround days is 180, yielding a total of 720 revenue days.

STANDARD NFS CHARGES

Standard charges made by NFS include operating costs, amortization of the original NFS facility, funds for long-term radioactive waste surveillance, contingency reserve, and profit. These standard charges for reprocessing HTGR hex blocks were estimated from the 1964 study on reprocessing HTGR rod-type fuels.^(1,2) The estimated standard charge is \$29,265 per revenue day for HTGR-type fuels. In addition, a \$500 per revenue day allowance is made for preoperational testing of the HTGR head-end facility. These costs are summarized in Table 3.

CAPITAL COST

A capital cost estimate for the HTGR hex block head-end facility building and equipment was made by General Atomic on the basis of the drawings contained in this report. The original capital cost estimate for the HTGR rod-type fuel element head-end facility was made by Bechtel Corporation, which also designed and built the existing NFS plant. In order to minimize any differences in the two cost estimates, General Atomic also made a cost estimate of the HTGR rod-type fuel head-end facility described in the 1964 study.⁽¹⁾ A ratio of the two cost estimates for the rod-type fuel facility was then applied to the current General Atomic cost estimate for

Table 3
SUMMARY OF REPROCESSING COSTS

	Cost per Revenue Day
Standard NFS charge ^{a, b}	\$29,265
Depreciation (head-end facility) ^c	13,180
Interest (head-end facility) ^d	3,540
Preoperational testing (head-end facility) ^a	500
Thorium storage ^a	1,910
Thorium surveillance ^a	955
Fissile particle containers ^e	1,045
Fissile particle disposal ^f	682
	<u>\$51,077</u>
 Cost per kilogram ^g	 \$129

^a Based on previous NFS cost study. (2)

^b Includes allowance for contingency reserve and profit.

^c Based on \$9,480,000 capital cost and 720 revenue days.

^d At 6% interest for 7.5 yr.

^e \$940 per container.

^f From Table 4.

^g Based on 540 process days at 45 fuel elements per day,

11.76 kg of actinides per unirradiated fuel element, and 720 revenue days.

the hex block facility. The resultant cost estimate for the HTGR hex block head-end facility is \$9,480,000, or \$13,180 per revenue day. This estimate is based on current construction costs with no allowance for escalation or for process and equipment development. The interest charge on the capital facility was assessed at 6% from 1974 through 1980, or \$3540 per revenue day. This interest charge is comparable to that used by NFS in their earlier study. (2) It does not include interest charges on capital employed during construction.

The cost of providing special storage tanks for the recovered thorium nitrate solution was taken from the previous cost study. (2) The cost of the three 100,000-gal, uncooled storage tanks required is \$1,374,000, or \$1910 per revenue day.

FISSILE PARTICLE AND THORIUM NITRATE SURVEILLANCE AND DISPOSAL

To establish a cost estimate for the ultimate disposal of the fissile particles, cost studies and disposal techniques described by Oak Ridge National Laboratory for the ultimate disposal of calcined high level waste were employed. (12, 13) The disposal steps considered are:

1. Packaging the fissile particles in high integrity stainless steel containers.
2. Accumulating the canned fissile particles in the fissile particle vault through 1980.
3. Shipping the canned fissile particles to a calcined waste salt mine repository starting in 1981. It is assumed that a repository of this type will exist at that time.

It is assumed that the fissile particle containers will be shipped to the salt mines in the same order and at the same rate as they were filled. All the containers shipped would thus have the same cooling time. Vault surveillance is required until all the fissile particle containers have been removed.

The cost of fissile particle disposal is \$682 per revenue day. A breakdown of total costs is given in Table 4. The cost of the high integrity containers is not included in the standard NFS charge. Each container is estimated to cost \$940, which results in a charge of \$1045 per revenue day. Surveillance charges for the thorium nitrate solution are 50% of the cost of the thorium nitrate tankage, or \$955 per revenue day. This percentage was used in the previous study. (2) No credit is taken for the recovered thorium nitrate.

REPROCESSING CHARGES

The total charge for reprocessing HTGR hex block fuels at the NFS plant is estimated to be \$51,077 per revenue day. A summary of reprocessing costs is presented in Table 3. The cost per kilogram is \$129, based on the total actinide content of the reference fuel. Reprocessing costs in terms of mills per kilowatt-hour of electrical power are plotted in Fig. 13 as a function of fuel burnup.

Table 4
FISSILE PARTICLE DISPOSAL

	<u>Total Cost</u>
Vault surveillance ^a	\$352,000
Shipping ^b	267,500
Salt mine storage ^c	<u>139,500</u>
	\$759,000 ^d

^aAssuming an incremental surveillance manpower need for four men for 8 yr at \$11,000 per man-year (including overhead costs).

^bAssuming a 76-ton cask, 21 containers per shipment, and a salt mine located 1000 miles from the plant site. Cost based on Ref. 12.

^cAssuming that waste is aged 8 yr prior to storage. Cost based on interpolation of cost data in Ref. 13.

^dBased on uniform accumulation of funds during HTGR fuel reprocessing period, uniform expenditure during the subsequent disposal period, and investment of funds at 6% interest, the total funds needed are only \$491,000, or \$682 per revenue day.

Fig. 13. NFS reprocessing costs for HTGR hex block fuel elements as a function of fuel burnup (40% reactor conversion efficiency)

PROCESS ALTERNATES

Several alternates to the burn-leach fuel processing methods and their limitations were considered in the earlier study.⁽¹⁾ These alternates will not be discussed here, since development work subsequent to the previous study has confirmed burn-leach as the most attractive head-end method of preparing graphite fuels for solvent extraction. The individual processing steps involved in the burn-leach method that are described in this report were chosen on the basis of proven technology, economic feasibility, and compatibility with the existing NFS plant. However, variations of individual processing steps may offer economic advantages.

Studies on leaching of burner ash have been confined to the development of a batch process. The use of a continuous leacher, for example, one similar in design to a moving bed ion exchange contactor, would potentially reduce the size of the process equipment and the process cell. However, the development of a continuous leacher would entail considerable effort.

The need for a stripper could be eliminated if chemical denitration of the leacher solution were employed. Most of the excess nitric acid could be destroyed by adding sugar to a heated leacher solution in a storage tank. With this technique, the solution could not be made acid-deficient, and the addition of some caustic would be necessary. An increased volume of high level waste from solvent extraction would result. The increased cost of waste storage would therefore have to be balanced against the capital cost advantage to be gained from not using a stripper. A small amount of laboratory development work would be needed for sugar denitration flowsheet optimization. Sugar denitration is routinely used in some radiochemical processing plants.

A flowsheet alternate considered in the previous study was the disposal of the thorium with the high level waste. Cost studies showed that the potential savings in processing and equipment costs were offset by increased waste storage costs. Because the solvent extraction, waste storage, and thorium storage aspects of the two studies are very similar, the relative costs of the two flowsheet alternates should also be similar. Only the thorium recovery alternate is considered here.

FUEL ALTERNATES

CARBIDE FUELS

The HTGR fuel elements considered in the present study contain uranium and thorium oxide fuel particles. However, elements with uranium and thorium carbide fuel particles could be processed in the equipment if minor flowsheet adjustments were made. In pilot plant burner studies conducted at Oak Ridge, (8) carbide fuel particles were converted to fine oxide particles. These dust particles were easily removed from the off-gas with the metal filters. A slight adjustment in the burner oxygen requirements would be necessary. Because burning thorium carbide fuels results in very small thorium oxide particles, a less aggressive leachant could be used. At Oak Ridge, carbide fuel burner ash was successfully leached with 4M HNO_3 , 0.05M HF. This dilute leachant would require a slight modification of the leaching and denitration steps.

SILICON-CARBIDE-COATED FERTILE PARTICLES

The head-end facility described in this report is based on HTGR fuels having silicon carbide coatings on the fissile particles and only pyrolytic carbon coatings on the fertile particles. With the addition of another process cell, the head-end facility could be modified to accommodate HTGR fuels in which both particle types (fissile and fertile) have silicon carbide coatings. Separate process steps would be needed to penetrate a silicon carbide coating on the fertile particles because such a coating would not be removed by burning or leaching processes developed to date. A modified head-end process to prepare silicon-carbide-coated fertile particles for solvent extraction is as follows:

1. Crush the fuel blocks.
2. Burn the crushed fuel blocks.
3. Screen the burner ash into three fractions: alundum, fissile particles, and fertile particles.
4. Package and store the fissile particles and recycle the alundum to the burner.
5. Grind the fertile particles to a -140 mesh size.

6. Burn the ground fertile particles to remove the remaining carbon coating.
7. Leach the second burner ash with a HNO_3 -HF solution.
8. Centrifuge the leacher solution to remove the silicon carbide hulls.
9. Slurry the hulls from the centrifuge and combine with the high level waste from the solvent extraction process.
10. Prepare the leacher solution for solvent extraction by stripping it of excess nitric acid.

With the exception of the grinding, second burning, and centrifuging steps, the process is the same as that described in this report.

A cursory cost analysis of the additional facilities and operations required to penetrate a silicon carbide coating on the fertile particles indicates a cost increase for reprocessing at the NFS plant of \$3500 per revenue day, or \$9 per kilogram.

DEVELOPMENT NEEDS

Development studies on the burn-leach process have been conducted with relatively small-scale equipment. The pilot plant burners used in studies at Brookhaven National Laboratory, Oak Ridge National Laboratory, and Idaho Chemical Processing Plant were only 4 in. in diameter. Operation of a larger burner is necessary to assess scale-up factors. To permit separation of the fissile and alundum particles, a larger-mesh alundum than that used in the pilot plant studies is required, and operational verification of the larger-mesh bed is needed. Studies to optimize the crusher-burner system are also needed, as are additional leacher studies with emphasis on equipment scale-up. Long-term studies on alundum degradation during repeated burner-leacher operational cycles should be performed to establish degradation rates and the storage requirements for the combined fissile particle and waste alundum. Since alundum is an abrasive material, erosion problems in alundum-handling equipment must also be considered.

Extensive design verification work is needed for various mechanical items, such as crushers, weigh hoppers, solids level indicators for radioactive service, and screens.

APPENDIX

EQUIPMENT REQUIREMENTS FOR HTGR HEX
BLOCK REPROCESSING AT NFS

PROCESS EQUIPMENT

Item No	Item	No Req'd	Capacity	Duty	Diam (in)	Height (ft)	Length (ft)	Area (ft ²)	Temp (°C)	Pressure (psig)	Material
1	Liquid oxygen storage tank	1	20 000 gal			(17.5-ft-diam sphere)					
2	Burner gas preheater	2		50 kW	8x15		3		750	8	Inconel elements 304 SS
3	Recycle alundum hopper	2	9000 lb, 75 ft ³		48	5 (cylinder) 3 (cone)			200	-0.5	304L SS
4	Burner	2	22.5 elements/day	3.5x10 ⁶ Btu/hr	72 (top) 48 (bottom)	18			750	-1 to 6	310 SS
5	Burner off-gas filter	2	160 scfm		36	8			400	-0.5	304L SS
6	Burner off-gas cooler	2		1x10 ⁵ Btu/hr	10	6		80	400	-0.1	304L SS
7	Cooling air blower	2	10,000 scfm	500 hp					50	9	CI
8	Air cooler	2	10,000 scfm	3x10 ⁶ Btu/hr	48		10	1500	200	-0.1	CS
9	Cooling air filters	2	10,000 scfm			10	5		50	-0.1	CS
10	Crusher	2	5 tons/day						200		SS
11	Ash hopper	2	6000 lb, 50 ft ³		42	7			700	-0.1 to 6	304L SS
12	Ash weigh hopper	2	4000 lb		36	6			300	-0.1	304L SS
13	Leacher	2	100 ft ³		54	8		125	150	-0.1	309 SS
14	Leacher condenser	2		1.2x10 ⁵ Btu/hr	12	4		55	150	-0.1	309 SS
15	Scrubber	1			6 (tower) 24 (pot)	10 2			150	-0.1	304L SS
16	Scrubber off-gas heater	1		10 ⁴ Btu/hr	8	4			100	-0.1	304L SS
17	Leacher solution receiver tank	2	75 ft ³		48	6		20	150	-0.1	309 SS
18	Stripper	1		3x10 ⁵ Btu/hr	8 (tower) 30 (pot)	12 3		35	150	-0.1	309 SS
19	Stripper condenser	1		3x10 ⁵ Btu/hr	24	4		25	150	-0.1	309 SS
20	Stripper condensate receiver	1	75 ft ³		48	6			50	-0.1	304L SS
21	Utility waste tank	1	75 ft ³		48	6			50	-0.1	304L SS
22	Fissile particle & alundum hopper	2	50 ft ³		48	6			150	0.1	304L SS
23	Drying air heater	2	150 scfm	1.2x10 ³ Btu/hr	4	6		5	350	150	CS
24	Silica gel adsorber	1			24	4			100	-0.1	304L SS
25	Dryer condenser	2		1.1x10 ⁵ Btu/hr	12		6	32	300	-0.1	304L SS
26	Off-gas heater	2		5x10 ³ Btu/hr	12	3		12	150	0.1	304L SS

Item No	Item	No Req'd	Capacity	Duty	Diam (in)	Height (ft)	Length (ft)	Area (ft ²)	Temp (°C)	Pressure (psig)	Material
27	Dryer off-gas filter	2	150 scfm		40	3			150	-0.1	304L SS
28	Screen	2	2 tons/day		24x24		7	3	100	-0.1	304L SS
29	Alundum hopper	2	6000 lb, 50 ft ³		48	6			100	-0.1	304L SS
30	Fissile particle hopper	2	5 ft ³		18	3			100	-0.1	304L SS
31	Silica gel off-gas filter	1	400 scfm		36x84				100	-0.1	304L SS
32	Thorium storage tank	1	1000 gal	4x10 ⁴ Btu/hr	60	8		27	50	-0.1	309 SS
33	HA acid tank	1	175 gal		30	5					304L SS
34	Thorium evaporator	1			30	18			150	-0.1	304L SS
35	Thorium evaporator reboiler	1		1.8x10 ⁶ Btu/hr	18	6		250	135	30	304L SS
36	Thorium evaporator condenser	1		1.8x10 ⁶ Btu/hr	12	7		85	135	-0.1	304L SS
37	Thorium evaporator condensate receiver	1	1200 gal		52	10					304L SS
38	Thorium evaporator product receiver	1	300 gal		42	4.5			50	-0.1	304L SS
39	Ventilation air supply fans	2	20,000 cfm	20 hp							CS
40	Ventilation air exhaust fans	3	20,000 cfm	40 hp							304 SS
41	Ventilation air stack	1	60,000 cfm		36	200					CS
42	Viewing windows	4									
43	TV cameras and monitors	6									
44	Receiving station hoist	1	10 ton								
45	Fuel storage vault crane	1	3 ton								
46	Fissile particle vault crane	1	2 ton								
47	Remote welding machine	1									
48	Standard manipulators	9									
49	Unbolting manipulators	10									
50	Vessel vent filter	1	200 scfm		40	3			50	-0.1	304L SS
51	Vessel vent filter preheater	1	200 scfm	1x10 ³ Btu/hr	6	6			150	30	304L SS
52	Pneumatic transport filter	1	200 scfm		40	3			50	-0.1	304L SS

SOLUTION TRANSFER SYSTEMS

<u>Item No.</u>	<u>System</u>	<u>Motive Force</u>	<u>No. Req'd</u>
1	Leacher acid to leacher	Gravity	2
2	Rinse water to leacher	Gravity	2
3	Leacher to dissolver solution storage tank	Steam jet	2
4	Dissolver solution storage tank to stripper	Air lift	2
5	Stripper to extraction feed tank	Air lift	1
6	Stripper condenser to condensate receiver	Gravity	1
7	Condensate receiver to acid recovery	Steam jet	1
8	Condenser to utility waste tank	Gravity	1
9	Silica gel absorber to utility waste tank	Gravity	1
10	Utility waste tank to low level waste system	Steam jet	1
11	Off-gas scrubber to utility waste tank	Gravity	1
12	Water to extraction feed tank	Gravity	1
13	Extraction feed tank to tank 4D-1	Steam jet	1
14	Acid butt to column 4C-1	Gravity	1
15	4-D10 to thorium evaporator	Air lift	1
16	Thorium evaporator to thorium product tank	Air lift	1
17	Thorium condenser to condensate receiver	Gravity	1
18	Condensate receiver to low level waste system	Steam jet	1
19	Thorium product tank to thorium storage	Steam jet	1
20	Stripper jet out	Steam jet	1
21	Thorium evaporator jet out	Steam jet	1
22	Sumps to waste tank	Steam jet	6

PIPING SYSTEMS

<u>Item No.</u>	<u>System</u>	<u>No. Req'd</u>
1	Air to blow-back filters	5
2	Crusher exhaust air to process filter	2
3	Crusher to burner	2
4	Oxygen and air to burner via preheater	2
5	Cooling air to burner	2
6	Cooling air from burner to stack via filters and cooler	2
7	Water to coolers and condensers	10
8	Burner ash to ash hopper	2
9	Air to pneumatic transport systems	10
10	Ash hopper to weigh hopper	2
11	Chemical addition to silica gel adsorber	1
12	Burner off-gas from cooler to silica gel adsorber	2
13	Hopper vents to process filter	13
14	Chemical addition to leacher	2
15	Chemical addition to leacher solution make-up tank	1
16	Leacher condenser off-gas to scrubber	2
17	Cooler to leacher condenser	2
18	Leacher to leacher solution receiver	2
19	Supply system to transfer jets	15
20	Air supply for air lifts	4
21	Air supply to vent jets	5
22	Water, steam, and air to jackets and coils	11
23	Leacher to alundum and fissile particle hopper	2
24	Alundum hopper to recycle hopper	2
25	Fresh alundum addition to recycle hopper	2

<u>Item No.</u>	<u>System</u>	<u>No. Req'd</u>
26	Fissile particle hopper to weigh hopper	2
27	Silica gel adsorber to waste tank	1
28	Chemical addition to waste tank	1
29	Pumps to waste tank	6
30	Cell wash-down systems	5
31	Cooling water to overflow pots	2
32	Stripper to feed tank	1
33	Air or steam to spargers	10
34	Vessel vent system	1
35	Air to dryer via preheater	2
36	Steam to air and off-gas preheaters	6
37	Waste tank to NFS waste processing	1
38	Dryer off-gas condenser to waste tank	2
39	Stripper condensate to NFS waste processing	1
40	Thorium feed to NFS processing	1
41	Thorium product to thorium storage tanks	1
42	Thorium evaporation condensate to NFS waste processing	1
43	Thorium evaporator to NFS vent header	1
44	Cooling water discharge header	1
45	Steam condensate header	1
46	Steam and water to building ventilation system	1
47	Supply and drain for water-filled door	2

PROCESS SAMPLERS

<u>Item No.</u>	<u>Stream</u>	<u>Activity (Ci/ml)</u>	<u>No.</u>
<u>Solids</u>			
1	Burner ash	2	2
2	Recycle alundum	0. 2	2
3	Burner off-gas	2	2
4	Burner filter off-gas	2	2
5	Silica gel off-gas	2	1
6	Filter inlet	2	5
7	Filter off-gas	2	6
8	Fissile particles and alundum	2	2
9	Fissile particles	2	2
<u>Liquids</u>			
1	Leacher acid make-up	None	1
2	Scrubber	2. 5	1
3	Leacher solution receiver tank	2. 5	2
4	Stripper condensate receiver	0. 1	2
5	Utility waste tank	0. 1	1
6	Thorium storage tank	0. 1	1
7	Extraction feed tank	2. 5	1
8	Thorium product receiver	0. 1	1
9	Thorium condensate receiver	0. 1	1
10	Leacher	2. 5	2

INSTRUMENTATION

<u>Symbol</u>	<u>Location</u>	<u>Type</u>	<u>Range</u>	<u>Number</u>
FRC	Oxygen to burner	Orifice	15-150 scfm	2
FRC	Air to burner	Orifice	10-100 scfm	2
PR	Burner gas pressure	Metal bellows	0-50 psig	2
DpRAHL	Burner bed differential pressure	DP cell	0-10 psig	2
DpRAH	Burner differential pressure	DP cell	0-25 psig	2
TRC	Burner bed temperature	Potentiometer	250-1000°C	2
TR-12	Burner and burner bed temperature	Potentiometer	250-1000°C	2
PI	Burner cooling air pressure	Metal bellows	0-10 psig	2
PRAH	Burner pressure	Metal bellows	-1-+4 psig	2
DpIAH	Burner filter pressure differential	DP cell	0-1 psig	2
TRAH	Burner gas preheater	Potentiometer	100-1000°C	2
TR-2	Burner filter off-gas temperature	Potentiometer	0-750°C	2
	Burner cooler off-gas temperature			
TR-3	Cell temperature, recycle alundum hopper, ash hopper	Potentiometer	0-500°C	2
TI	Off-gas cooler water outlet	Potentiometer	0-100°C	2
ARAH	Off-gas analyzer CO	Conductivity	0-20%	2
AR	Off-gas analyzer CO ₂	Conductivity	0-100%	2
FR	Off-gas flow	Orifice	15-150 scfm	2
FR	Air to burner discharge pneumatic transfer	Orifice	3-30 scfm	2

<u>Symbol</u>	<u>Location</u>	<u>Type</u>	<u>Range</u>	<u>Number</u>
PI	Pressure in pneumatic transfer line from burner	Metal bellows	0-2 psig	2
ZI	Burner ash discharge valve		Closed to open	2
ZI	Crushed fuel air lock valve	Switch		4
ZI	Fresh alundum addition air lock valve	Switch	Closed or open	4
ZI	Recycle alundum hopper to burner valve	Switch	Closed or open	2
ZI	Ash hopper to weigh hopper valve	Switch	Closed or open	2
LI	Level in recycle alundum hopper		0-8 ft	2
LI	Level in ash hopper		0-7 ft	2
RR	Burner cell radiation level	Ion chamber	1-10 ⁶ r/hr	2
ZI	Weigh hopper to leacher valve	Switch	Closed or open	2
LI	Level in weigh hopper		0-6 ft	2
WIAH	Weight of weigh hopper	Balance or strain gauge	0-4000 lb	2
LRAH	Liquid level in leacher	Bubbler, DP cell	0-10 ft	2
DR	Specific gravity of liquid in leacher	Bubbler DP cell	0-2.5	2
TR	Solution temperature in leacher	Potentiometer	0-150°C	2
TR-2	Leacher condenser cooling water outlet and off-gas temperatures	Potentiometer	0-150°C	2
LRAH	Liquid level in off-gas scrubber	Bubbler, DP cell	0-5 ft	1

<u>Symbol</u>	<u>Location</u>	<u>Type</u>	<u>Range</u>	<u>Number</u>
DI	Specific gravity of liquid in off-gas scrubber	Bubbler, DP cell	0-2	1
TI	Off-gas scrubber liquid temperature	Potentiometer	0-100°C	1
FI	Air to off-gas scrubber recirculator air lift	Orifice	0.2-2 scfm	1
DpIAHL	Differential pressure across off-gas scrubber tower	Bubbler, DP cell	0-20 in. H ₂ O	1
TI	Off-gas scrubber gas outlet temperature	Potentiometer	0-100°C	1
FI	Air to pneumatic transfer, leacher to alundum and fissile particle hopper	Orifice	3-30 scfm	2
PI	Pressure in pneumatic transfer line, leacher to alundum and fissile particle hopper	Metal bellows	0-2 psig	2
ZI	Valve in transfer line from leacher to alundum and fissile particle hopper	Switch	Closed or open	2
LI	Alundum level in leacher		0-6 ft	2
LRAH	Liquid level in leacher solution receiver	Bubbler, DP cell	0-8 ft	
DR	Specific gravity of liquid in leacher solution receiver tank	Bubbler, DP cell	0-2	2
TI	Temperature of solution in leacher receiver	Potentiometer	0-100°C	2
FI	Air to air lift, leacher receiver to stripper	Orifice	0.2-2 scfm	2
LRCAH	Liquid level in stripper	Bubbler, DP cell	0-15 ft	1
DRC	Specific gravity of liquid in stripper	Bubbler, DP cell	0-3	1
TRAH-6	Stripper solution, overflow pot, off-gas, and cell temperatures	Potentiometer	0-175°C	1

<u>Symbol</u>	<u>Location</u>	<u>Type</u>	<u>Range</u>	<u>Number</u>
FRC	Steam to stripper sparger	Orifice	5-50 lb/hr	
PI	Steam pressure to stripper sparger	Metal bellows	0-50 psig	1
FR	Steam to stripper coil	Orifice	30-300 lb/hr	1
PIAH	Steam pressure to stripper coil	Metal bellows	0-250 psig	1
DpIAH	Stripper tower differential pressure	Bubbler, DP cell	0-20 in. H ₂ O	1
TI-2	Stripper condenser cooling water outlet and off-gas temperatures	Potentiometer	0-100°C	1
DpIAH	Differential pressure of silica gel bed	Bubbler, DP cell	0-20 in. H ₂ O	1
LIAH	Liquid level in silica gel adsorber	Bubbler, DP cell	0-4 ft	1
ZI	Valve on silica gel adsorber drain	Switch	Closed or open	1
DpIAH	Differential pressure of filter	Bubbler, DP cell	0-5 in. H ₂ O	1
FI	Steam flow to off-gas heater	Orifice	5-50 lb/hr	1
TIC-2	Inlet and outlet gas temperature to off- gas heater	Potentiometer	0-100°C	1
FR	Off-gas flow rate	Orifice	30-300 scfm	1
LRAH	Liquid level in stripper condenser receiver	Bubbler, DP cell	0-8 ft	1
DR	Specific gravity in stripper condenser receiver	Bubbler, DP cell	0-1.5	1
TI	Solution temperature of stripper condenser receiver	Potentiometer	0-100°C	1
LRAH	Liquid level in utility waste tank	Bubbler, DP cell	0-8 ft	1
DR	Specific gravity in utility waste tank	Bubbler, DP cell	0-1.5	1

<u>Symbol</u>	<u>Location</u>	<u>Type</u>	<u>Range</u>	<u>Number</u>
TI	Solution temperature in utility waste tank	Potentiometer	0-100°C	1
TRAH	Temperature in extraction feed tank	Potentiometer	0-50°C	1
LRAH	Liquid level in extraction feed tank	Bubbler, DP cell	0-10 ft	1
DR	Specific gravity in extraction feed tank	Bubbler, DP cell	0-2	1
FI	Cooling water to extraction feed tank coil	Orifice	5-50 gpm	1
LI	Level in alundum and fissile particle hopper		0-6 ft	2
ZI	Valve from alundum and fissile particle hopper to screen		Closed to open	2
FIC	Drying air to alundum and fissile particle hopper	Orifice	20-200 scfm	2
TIC	Temperature of drying air to alundum and fissile particle hopper	Potentiometer	0-200°C	2
DpI	Differential pressure across alundum and fissile particle hopper	Bubbler, DP cell	0-30 in. H ₂ O	2
TI-2	Alundum and fissile particle hopper off-gas and condenser cooling water outlet temperature	Potentiometer	0-200°C	2
TIC	Off-gas heater outlet temperature	Potentiometer	0-200°C	2
DpIAH	Filter pressure differential	Bubbler, DP cell	0-5 in. H ₂ O	2
II	Current to screen motor	Ammeter	---	2
LIAH	Level in alundum hopper		0-5 ft	2
LIAH	Level in fissile particle hopper		0-3 ft	2
ZI	Alundum hopper outlet valve	Switch	Closed or open	2

<u>Symbol</u>	<u>Location</u>	<u>Type</u>	<u>Range</u>	<u>Number</u>
ZI	Fissile particle hopper outlet valve	Switch	Closed or open	2
FI	Air to pneumatic transfer from alundum hopper	Orifice	3-30 scfm	2
FI	Air to pneumatic transfer from fissile particle hopper	Orifice	2-20 scfm	2
PI	Pressure in pneumatic transfer line from alundum hopper	Metal bellows	0-2 psig	2
PI	Pressure in pneumatic transfer line from fissile particle hopper	Metal bellows	0-2 psig	2
RR	Leacher cell radiation level	Ion chamber	$1-10^6$ r/hr	2
FRC	Acid flow to column 4-C1	Rotometer	0.08-0.8 gpm	1
69 LIAHL	Level in acid head tank	Bubbler, manometer	0-7 ft	1
FI	Air to air lift, 4-D10 to thorium evaporator	Orifice	0.2-2 scfm	1
LRCAHL	Level in thorium evaporator	Bubbler, DP cell	0-10 ft	1
DRCAH	Specific gravity in thorium evaporator	Bubbler, DP cell	0-2	1
DpIAH	Differential pressure across thorium evaporator tower	Bubbler, DP cell	0-30 in. H ₂ O	1
TR-2	Solution temperature in thorium evaporator and overflow pot	Potentiometer	0-150°C	1
TI-2	Thorium evaporator condenser cooling water outlet and condenser off-gas temperatures	Potentiometer	0-100°C	1
PIAHL	Thorium evaporator reboiler steam pressure	Metal bellows	0-40 psig	1

<u>Symbol</u>	<u>Location</u>	<u>Type</u>	<u>Range</u>	<u>Number</u>
FI	Steam flow to thorium evaporator reboiler	Orifice	30-300 lb/hr	1
RMAH-2	Filter off-gas stream	Ion chamber		1
LRAH	Thorium product receiver liquid level	Bubbler, DP cell	0-6 ft	1
DR	Specific gravity in thorium product receiver	Bubbler, DP cell	0-1.5	1
TI-2	Temperature in thorium product and condensate receivers	Potentiometer	0-100°C	1
RMAH-2	Cooling water effluent and steam condensate	Scintillation crystal		1
TRAH-2	Burner cooling air inlet and outlet temperature	Potentiometer	0-500°C	2
RMAH	Burner cooling air radiation monitor	Scintillation crystal		2
DPRAH	Burner cooling air filter differential pressure	DP cell	0-5 in. H ₂ O	2
PC	Vent line pressure	DP cell	0-10 in. H ₂ O	4
TIC-2	Vessel vent heater inlet and outlet temperature	Potentiometer	0-100°C	1
DPI	Ventilation air filter differential pressure	Manometer	0-5 in. H ₂ O	2
LRAL	Stripper overflow pot level	Bubbler, DP cell	0-100 in. H ₂ O	1
DR	Stripper overflow pot density	Bubbler, DP cell	0-2	1
LRAL	Thorium evaporator overflow pot level	Bubbler, DP cell	0-100 in. H ₂ O	1
RR-2	Radiation level in utility and feed tank cells	Ion chamber	1-10 ⁶ r/hr	1
LRAH	Thorium evaporator condenser receiver liquid level	Bubbler, DP cell	0-6 ft	1
DR	Thorium evaporator condenser receiver specific gravity	Bubbler, DP cell	0-1.5	1
TR-12	Fuel and fissile particle vault temperature	Potentiometer	0-300°F	1

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