RECEIVED BY DTIC OCT 10 1967

GENERAL ATOMIC DIVISION

REC. 3.00 65

GENERAL DYNAMICS CORPORATION

John Jay Hopkins Laboratory for Pure and Applied Science
P. O. Box 608, San Diego, California 92112

INFORMAL AEC RESEARCH
AND DEVELOPMENT REPORT

GAMD-6360

FEASIBILITY STUDY
FOR REPROCESSING HTGR FUELS
BASED ON USING THE
NUCLEAR FUEL SERVICES, INC., REPROCESSING PLANT

Work done by:

Nuclear Fuel Services, Inc.
Box 124
West Valley, New York
with assistance of
General Atomic personnel

Report written by:

Nuclear Fuel Services:
S. L. Reese
P. Burn
General Atomic:
S. E. Donelson
K. G. Steyer

This document, which was prepared primarily for internal use at General Atomic, may contain preliminary or incomplete data. It is informal and is subject to revision or correction; it does not, therefore, represent a final report.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

General Atomic
Subcontract 1143
under
U. S. Atomic Energy Commission
Contract AT(04-3)-167
Project Agreement No. 17

December 15, 1964

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

129

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

TABLE OF CONTENTS

	<u>Page</u>
Introduction	1
Objectives	2
Summary	3
Fuel Element Description	7
Process Descriptions	9
Laboratory Studies	27
Design Philosophy	28
Design Criteria	29
Criticality	31
Plant Limitations	34
Recommendations for Future Work	35

TABLES

1. Material Balance Data for HTGR Fuel Reprocessing Flow Diagram.
2. Sampler List for HTGR Fuel Reprocessing Head-End.
3. Material Balance Data for HTGR Thorium-Uranium Extraction and Partition Flow Diagram.
4. Equipment List for HTGR Fuel Reprocessing Head-End.
5. Equipment Sizes and Duties for HTGR Fuel Reprocessing Head-End.
6. Instrument List for HTGR Fuel Reprocessing Head-End.
7. Utilities Required for HTGR Fuel Reprocessing Head-End.

FIGURES

1. Preliminary Flow Diagram HTGR Fuel Reprocessing.
2. HTGR Head-End Plant Plan Views.
3. HTGR Head-End Plant Section A-A.
4. Oxidizer.
5. Alundum Hoppers.
6. Ash-Alundum Leacher.
7. HTGR Thorium-Uranium Extraction and Partition Flow Diagram.
8. Off-Gas Cyclone and Filter.
9. Off-Gas Scrubber.
10. HNO_3 Stripper.
11. Thorium Evaporator.
12. Projected Production Requirements.

INTRODUCTION

The General Atomic Division of General Dynamics has developed and is actively promoting High Temperature Gas Cooled Reactors (HTGR) for use in commercial electric power production. The fuel for these reactors is enriched uranium and thorium as oxides or carbides in the form of small particles. The particles are coated with pyrolytic carbon and are placed in graphite fuel elements which are about 20 feet long. Fuel of this design permits high burnup in the reactor with 60,000 MWD/T or more projected.

Reprocessing spent fuel elements to recover the uranium values is an important part of the fuel cycle directly affecting the ultimate potential of these reactors. In order to determine the present state of the art and current reprocessing costs for HTGR fuels as part of its AEC sponsored program, General Atomic requested Nuclear Fuel Services to ascertain if a technically sound reprocessing method is available, and to estimate the capital and operating costs associated with reprocessing HTGR fuels. The study was based on using the present NFS plant facilities. However, this plant was designed primarily for reprocessing metal-clad reactor fuel elements, consequently the capability for reprocessing HTGR graphite elements requires additional facilities at the NFS plant.

The technical and design considerations associated with reprocessing HTGR fuels at NFS are presented in this document.

OBJECTIVES

The objectives of the engineering development study leading to reprocessing capability for HTGR fuels are:

1. To ascertain the technical feasibility of processes suitable for the chemical reprocessing of spent HTGR fuel in the NFS West Valley Plant.
2. To select the preferred process for this fuel and prepare a preliminary design of the plant additions required.

SUMMARY

The initial phase of the study was to review the present state of technology regarding the methods of recovering and storing fuel elements and relative to chemical processing techniques to determine if existing processes are amenable to the recovery of uranium and thorium values from HTGR fuel.

The alternatives considered for receiving and storing the fuel were to unload and store under water as presently practiced with metal-clad fuels, or to unload in a concrete shielded cubicle and store dry. Dry storage was chosen for the following reasons:

1. The fuel must be canned in water-tight containers for storage under water. Under dry storage conditions, the elements may be stored uncanned or in simple protective containers.
2. The currently proposed rail cask can be easily unloaded if the cask is not removed from the car and transferred to an unloading pool. In addition, a 125-ton crane would be required to lift the proposed rail shipping cask.
3. A new storage area would be required at the NFS plant in any event since the length of the elements exceeds the present storage pool design maximum by four feet.
4. The decay heat can be removed from the element in dry storage with a very reasonable amount of circulating air.

To process this fuel chemically, the graphite and carbon must be broken down or separated from the fuel to permit further dissolution reactions. The basic processes reviewed were Burn-Leach, Grind-Leach, Burn-Fluoride Volatility, and Wet Burning.

The Burn-Leach process, as the name implies, consists of burning the carbon to CO_2 which is discharged from the stack. The resulting ash is leached with a nitric acid reagent to put the thorium and

uranium in solution. This process was the most desirable of those currently available or under investigation for processing HTGR fuels for the following reasons:

- a. The process has a minimum number of head-end steps, as described in the Process Description Section of this report.
- b. The basic process steps have been successfully demonstrated on a laboratory scale at Brookhaven and Oak Ridge National Laboratories with apparently acceptable uranium recovery. The greatest unknown in the process is its adaptability to reasonable production scale-up.
- c. The leach solution after adjustment can be fed directly into the chemical purification system.
- d. Solid residue handling is reduced to a minimum.

The Grind-Leach process consists of a grinding step wherein the fuel element is ground to a fine powder which exposes the thorium and uranium to the leaching action of nitric acid reagent. Although laboratory tests at ORNL have demonstrated acceptable uranium and thorium recoveries, the Grind-Leach process was rejected principally because operation, maintenance, and the dust problems associated with fine grinding equipment appear formidable in hot operations. In addition, to date it appears that no satisfactory method of separating the fine graphite powder from the leach solution has been devised.

In the Burn-Fluoride Volatility process the carbon is removed by burning in a fluidized bed burner as in the burn-leach process. The ash is then treated with fluorine, converting the uranium and many of the fission products to volatile fluorides. The UF_6 is separated from the high-boiling fission product fluorides by cooling below their condensation temperature. Decontamination from the low-boiling impurities is accomplished by adsorbing the UF_6 on NaF traps, and permitting the gaseous impurities to pass through. The decontaminated UF_6 is desorbed by raising the temperature of the NaF trap, condensed to a liquid and

bottled as product. This process is not considered suitable for HTGR oxide fuels since the thorium associated with the uranium forms a non-volatile fluoride resulting in poor uranium separation. In addition, thorium recovery is not practical using the fluoride volatility process.

A very recent development at ORNL is the Wet Burning process. This is a batch type process in which the fuel is placed in nitric acid in an autoclave. The autoclave is pressurized with oxygen and heated. The carbon oxidizes to CO and CO₂ and the thorium and uranium are simultaneously converted to nitrate solution. At the present stage of development, this process is not suitable for recovery of HTGR fuels since complete dissolution of the oxides of uranium and thorium has not been achieved in the reagents tried. Future developments may make this process attractive.

The feasibility of recovering the thorium for reuse after ten to fifteen years of cooling was examined. Three process schemes were found to be technically feasible. These are (a) extraction from the waste in a separate two-column extraction system; (b) separation from the uranium by stripping the thorium into an aqueous scrub stream in the present plutonium partition column; and (c) extraction of both uranium and thorium in the partition extraction cycle followed by separation of the two in the first uranium cycle extraction column. The thorium would be discharged as a product in the aqueous waste stream from this column. Process (a) requires considerable capital expenditure in the form of a separate extraction system. Process (b) results in uranium refluxing and critically unsafe concentrations could be reached near the top of the partition column. Process (c) is unique in that it combines features of two processes that have been demonstrated to give satisfactory results. It appears that safe uranium concentration can be maintained in the purification columns without loss of throughput using process (c). In addition, modifications to processes currently used would be much less extensive than those required for installation of a single cycle extraction facility.

As a result of the process evaluation summarized in the previous paragraphs a preliminary study of a reprocessing facility for HTGR fuels was generated. This study is based on developing facilities for preparing the fuels for introduction into a solvent extraction process and provides for the following:

(a) fuel receiving; (b) dry unloading; (c) dry storage; (d) semi-continuous crushing; (e) continuous burning; (f) batch leaching, and (g) storage for column feed.

Connections to the solvent extraction system are also included as is the necessary waste storage. Except for the thorium recovery processes, all operations could be performed in a conventional solvent extraction plant using service facilities without major changes.

FUEL ELEMENT DESCRIPTION

The design study is based on fuel elements as presently conceived for the TARGET program. These elements consist of a graphite sleeve with a "telephone dial" hole configuration with the holes packed with ThO_2 and $(\text{Th-U})\text{O}_2$ particle coated with pyrolytic carbon. Minor changes in physical and chemical characteristics can be accommodated without incurring modifications in plant layout or equipment.

HTGR Fuel Element Characteristics

Element Type	TARGET
Length	20' - 0"
Diameter	Approximately 5"
Weight (total)	Approximately 275 lb.
Cooling Period:	
At reactor	90 days minimum
At reprocessing plant	120 days minimum
Total Cooling Period	210 days minimum
Burnup	
Maximum	80,000 MWD/T
Average	72,000 MWD/T
Heat release - 90 days cooled	~ 1700 Btu/hr/element
Fuel Loading	
Th - U ratio	~ 24:1 max. ~ 5:1 min. ~ 11:1 average
Thorium Loading	~ 9.5 kg ave./element
Uranium Loading	~ 1.0 kg ave./element
Fission Product (80,000 MWD/T)	~ 850 g ave./element

For the purposes of this study, it has been assumed that the entire complement of fuel particles cannot be poured from the graphite sleeve and that the sleeve must be destroyed to recover the uranium and thorium fuels.

The cooling period of 210 days was established to permit the Pa^{233} to decay to U^{233} . This delay period may vary for future reactors,

depending on the relation of use charges during the storage period to the additional value of U^{233} obtained from the decay of Pa^{233} .

PROCESS DESCRIPTIONS

This section is devoted to more detailed descriptions of the processes investigated in the course of this study with particular emphasis on the Burn-Leach process.

Burn-Leach

After a review of process information available at Oak Ridge National Laboratory, Brookhaven National Laboratory, Argonne National Laboratory, and Los Alamos Scientific Laboratory, a reference process was selected for the study consisting of:

1. Crushing to prepare fuel elements for burner feed.
2. Burning in fluidized bed reactor using alundum particles for a heat transfer medium.
3. Leaching in a separate vessel using HNO_3 and 0.04 mole IF.
4. Adjusting the leach solution and storing. In one purification process the adjusted leach solution can be processed through the extraction columns to recover the uranium and to discard thorium with the fission products. As an alternative, the solution is rendered acid deficient and the thorium recovered as a raffinate from the first uranium extraction cycle column and stored as a separate product.
5. The recovered uranium will be in the nitrate form.

The process block flow diagram showing the burn-leach process is shown in Fig. 1 in the Appendix.

The flow rates associated with this process are given in the Material Balance Data in Appendix Table 1.

Receiving and Cask Decontamination

The receiving area has been planned to accommodate shipping casks received by both rail and truck carriers. General Atomic Drawings 280-1500-100 and 480-1500-100 showing the general arrangement of the shipping casks on the carriers were used as a basis for facility design. The facilities have been designed to permit moderate variations in shipping casks without major modifications. See Building Layout drawings Appendix Figs. 2 and 3.

A 100-ton crane will be used to lift a shipping cask from a tractor trailer onto a movable dolly which will be transferred to the unloading station. A retractable lead shield will be lowered onto the shipping cask. The cask cover will be removed and temporarily stored using a 5-ton hoist located in the receiving station. The fuel elements will then be lifted from the shipping container and transferred to a holding station in the storage area.

In the case of a rail shipment, the cask and rail car will be spotted directly beneath the unloading station, the cask body elevated to a vertical position and the lead shield lowered into position. The cask plugs will be removed by a mechanical manipulator and stored within the unloading station. The fuel elements will be transferred to the holding station as before.

Using this unloading procedure, the fuel elements may be received either in protective shipping cans or as unprotected fuel elements. In the case of uncanned elements, a protective sleeve will be placed in the holding station before the element is unloaded from the shipping container, and the fuel element will be lowered into this container. The unloading operation is performed remotely with visual control.

The container will be used as protection during storage and also for a dust seal during the crushing operations. It is preferred that the element be placed in a flange-topped reusable container prior to shipment to avoid difficulties in grappling bare fuel elements from the shipping containers especially in the event of breakage during shipment, and to minimize dust contamination in the unloading and storage areas.

After the casks are unloaded and refilled with empty containers (if shipping containers are used), they are removed to the present cask decontamination facility and decontaminated and repaired as required.

Fuel Element Storage

The fuel elements in either the protective container or the shipping cans will be stored vertically in planar arrays separated by concrete walls not more than 14-in. thick. The containers will be supported

on rails located at the top of the walls. Access to the storage arrays will be provided by aisles at either end of the array. Storage capacity for 500 fuel element containers sufficient to store the average annual refueling load from two 260 Mw(e) HTGR reactors is provided.

A working inventory of 500 stored fuel elements will permit a burner campaign of 12.5 days at the maximum processing rate of 40 elements per day. No additional storage capacity is foreseen at the fuel reprocessing plant since a 12.5 day operating campaign would be a reasonable working load and the stored inventory could be worked off before additional elements would be available for reprocessing. The operating campaign can be extended beyond 12.5 days if additional 210 day cooled fuel elements can be scheduled to be received from the reactor sites during the processing campaign.

The fuel elements will be retrieved from the holding area by a one-ton remotely operated traveling bridge crane servicing both the storage area and the element crushing cell. Crane operation will be performed remotely from the operating gallery adjacent to the storage cell and will be performed by visual observation through four viewing windows provided in the storage area walls. The crane will be equipped with a manipulator as well as with a self-locking hook thus permitting the use of a vacuum cleaner nozzle along the access aisles and into the storage areas for cleanup purposes in the event of a spill. The storage and crushing areas are also shown in Figs. 2 and 3 in the Appendix.

The choice of using a planar array with transfer aisles at each end eliminates the need for providing a 20' high clear space above the element fuel storage locations and will still permit removal of the elements in and out of storage. The concrete walls will provide protection from a criticality incident.

Ventilation for the storage area amounting to five air changes per hour will be provided. This will permit the removal of a maximum of 1,700 Btu of decay heat per hour per element without excessive heating of the air in the storage area.

Fuel Element Crushing

A heavy-duty crusher with a jaw opening of approximately six inches and a minimum throat opening of approximately one inch has been selected for use in preparing the fuel elements for feed into the burner. Large pieces are desirable to minimize dust generation. The crusher drive motor and shear link will be located outside the crusher cell. The crusher will be enclosed in a purged dry box equipped with sintered metal filters with blow-back devices or a disposable porous carbon filter to keep graphite dust out of the vent line. The fuel element in its protective container will be positioned by the crane on a table extending part way up the transfer aisle in the storage area. The container will be clamped to a mating flange on the crusher dry box and will be hoisted to a vertical position above the crusher. The fuel element will be discharged by gravity into the crusher jaws. A transfer lock composed of two full opening, air-cylinder operated ball valves is provided, one located beneath the jaw crusher and the other just above the fuel element burner.

The crusher will be operated at 15-minute intervals to prepare approximately one quarter of a fuel element for the burner feed. By intermittent operation of the crusher-burner air lock, the burner will be able to remain at operating conditions on a continuous basis. The actual crushing time per charge is expected to be on the order of one minute.

After a fuel element has been crushed, flat surfaces in the crusher dry box will be purged using air jets to dislodge dust. The fuel element container is then returned to the horizontal position on the work table. The fuel element container will be returned by the crane to the storage area and the cycle repeated for the next fuel element. Twenty elements per 24-hour day will be crushed.

Fuel Element Burning

The graphite is burned with oxygen to CO_2 . This operation is performed in a fluid bed in order to avoid local overheating and to

facilitate complete reaction. The bed consists of a mixture of 30, 60, and 90-mesh alundum which is fluidized with the O_2 reactant and the CO_2 product. A gas flow rate of 0.7 to 1.0 linear feet per second has been found to be the most desirable fluidizing range in small burner experience. The graphite and alundum are both fluidized at this O_2 flow rate. The alundum functions as a heat transfer medium as the individual particles travel from the hot reaction areas to the cooling surfaces. In laboratory equipment operated at the National Laboratories it has been found that the reaction proceeds very well at 700 to 750°C. The temperature differential from the center of the burner to the cooling wall was observed to be 50°C. The efficiency of the burner relative to O_2 consumption was about 90% in a continuous burning type of operation. By the time the fuel has passed down the burner through a series of grates and counter-current to the flow of O_2 the residual carbon in the ash has been found to be on the order of 0.1 to 0.2%. No fuels containing actual oxide fuel particles have been processed. It is presumed that these particles will be physically undamaged. In this event results of a brief series of fluidizing experiments using ThO_2 particles in an alundum bed resulted in a rapid segregation of these high density particles to the bottom of the bed. This phenomenon requires that adequate heat be provided in the bottom of the burner to oxidize the pyrolytic carbon coating. Such a phenomenon would increase the heavy metals content of the lower section above the 20% average to 30% maximum shown experimentally to fluidize in a satisfactory manner. This could result in partial alundum separation from the product ash at the burner bottom.

The burner will be a fluidized bed reactor fabricated from 310 stainless steel with a 35" diameter, a 7' long burning zone, and will have a conical bottom section. Several stainless steel grid plates will be provided in the burner to prevent graphite chunks from settling onto the diffuser plate. A sketch of the burner is shown in Appendix Fig. 4. Oxygen, used as the fluidizing medium as well as the burning reactant, will be fed to the burner from storage containers located outside the building, and through a preheater located in the operating gallery raising the temperature to 700°C. A ball check valve will be provided

at the bottom of the burner to prevent discharge of solids through the oxygen inlet line in the event of an interruption in the fluidizing gas flow. A diffuser plate is provided within the burner to divert the oxygen flow to all sections of the burner to permit uniform fluidization of the entire bed.

The alundum will be stored in a hopper located within the burner cell with an access line through the cell wall to permit addition of fresh alundum when required. The alundum will be delivered to the upper end of the burner through an air lock from a hopper shown in Fig. 5. When the alundum within the burner has approximately 20 weight percent of heavy metals, a portion of the fluidized bed will be withdrawn into an alundum ash hopper. Additional charges of crushed fuel and alundum will be made to the burner bed in such a manner that the burner operation is continuous.

The burner has been designed to operate from -2 inches water to 2 psig gas pressure at the top of the burner. By introducing the alundum and fuel particles through air locks the burner can be charged without interrupting fluidization. The locks will be purged with air to prevent discharge of radioactive gasses into the crusher cell.

With a burning rate of 20 fuel elements a day, 2.8 million Btu's per hour are obtained from the combustion of the carbon within the burner. To remove this heat and maintain a 700°C reactor wall temperature, the burner is cooled by an air stream supplied from a 400 hp blower located in the operating gallery. These conditions can be achieved by circulating 8,750 SCFM with a 300°C temperature rise. Heat transfer is achieved by routing the cooling air into a manifold above the burner then through hairpin or bayonet heat exchangers within the burner and finally down through a plenum along the burner walls. A filter system will be installed between the blower and the plant stack to trap particulates in the event that the burner shell should be damaged and particles from the fluidized bed carried into the cooling air stream. This will prevent discharge of solid waste products to the atmosphere if the burner shell should rupture.

To initiate burning action a charge of low igniting material and alundum are loaded into the burner and fluidized by air passed through the preheater and heated to 400°C . When the burner reaches ignition temperature, oxygen will be used as the fluidizing stream. Burner operation will be controlled by varying the oxygen flow, by maintaining proper pressure differentials between the bottom of the burner and the off-gas plenum, and by controlling cooling air flow as dictated by temperature indications from inside the burner and selected locations on the burner shell.

As a measure of burner operation, a portion of alundum drawn off from the burner will be accumulated in a weighed container with known volume. This hopper, shown in Fig. 5, will provide a density measurement of the alundum bed giving an indication of the heavy metal loading achieved on the alundum particles during burning. This information plus the record of elements crushed and charged into the burner will provide a means of determining burner efficiency and for accumulating a charge for the leacher. All transfer of alundum from the storage hoppers to the various pieces of operating equipment will be performed by gravity flow or by airveyors.

At the end of an operating campaign, the burner and associated hoppers can be cleaned using fresh alundum. This alundum will be circulated and then introduced into the leacher tank for recovery of any uranium values. Spray nozzles are provided for decontamination of this equipment in the event maintenance is required.

Fuel Element Leaching

The dissolution of ThO_2 and $\text{ThO}_2\text{-UO}_2$ solid solutions has been performed on a commercial basis by exposure to boiling Thorex reagent consisting of 13 molar HNO_3 and 0.04 molar fluoride. The presence of fluoride is essential to thorium dissolution.

The leacher can be constructed from 309 stainless steel for use with the Thorex solution. Corrosion data indicates a corrosion rate in 309 stainless steel of less than 1 mil per month when the fluoride

is complexed with aluminum. A small quantity of alundum, on the order of 0.7% the first time through, down to 0.1% in subsequent cycles will also be put into solution. Work reported in ORNL-3627 indicates that excess aluminum does not interfere with the dissolution of thorium. The time required for dissolution decreases with decreasing particle size and with increased burnup (ORNL-3219). Fuel particles of the size used in HTGR reactors may be expected to dissolve completely in less than eight hours.

The leacher is designed to operate on a batch basis consisting of the oxides contained from burning 20 fuel elements and the associated alundum particles. The leacher will be 4 feet in diameter with tangent section 7 feet long. It is shown in Appendix Fig. 6. The leacher will contain a sparger for agitating the leaching solution and to introduce preheated air to dry the alundum remaining after leaching. A dip leg for removing the leaching solution after the reaction is completed is provided together with a special alloy metal filter to prevent carry-over of particulates into the feed adjustment tank. The leacher is provided with a steam jacket rated at 150 pounds. This jacket will serve to heat the leacher to 220°F for leaching and to 350°F for drying the alundum. The leacher will contain a grid of 1/8" thick poison plates spaced on 1" centers containing 1.3 percent boron. This leacher design is based on the assumption that the fuel particles disintegrate to a fine dust in the burner which remains uniformly distributed throughout the alundum. If the oxide fuel particles do not disintegrate, classification may occur in the burner. The ash feed and the leacher will then contain more uranium and it is expected that a smaller leacher will be required for nuclear safety. Fortunately the volume of ash will be much smaller also.

Leaching operations will be performed as follows:

1. The leacher will be loaded with a batch of fuel oxides and alundum from the ash hopper.
2. Leaching solution containing 13 M HNO_3 , .04 M HF , 0.04 M Al and .075 M $\text{Cd}(\text{NO}_2)_2$ is made up in a feed preparation tank in the cold

chemical room. This solution is then transferred to the leacher.

3. The leacher is heated to boiling by passing steam through the jacket. The air sparger is activated and the leaching reaction carried to completion. A condenser returns the liquid evaporated to the leacher, and the off-gas is further treated in the scrubber shown in Fig. 9.

4. The leach solution is transferred to the feed adjustment tank and the remaining alundum bed washed with a nitric acid solution and rinsed with water.

5. The alundum is dried by increasing the vessel jacket temperature to approximately 350°F and by blowing preheated air through the sparger. The operating time required to dry the alundum in the production scale leacher is not accurately known. Poor heat transfer conditions are expected because of the tendency of wet alundum particles to cake. It is estimated that drying can be accomplished in from 5 to 10 hours.

Control of the leaching action will be achieved by controlling the jacket temperature. Criticality control is obtained from the poison plates within the leacher and by the addition of cadmium to the leaching solution before introduction to the leacher. Either of these measures singly would prevent a criticality incident.

After leaching, the solution will be transferred to a feed adjustment tank and uranium samples withdrawn to determine the uranium concentration. The molarity of the solution will be adjusted and the concentration of uranium brought to 8.5 grams per liter maximum. The solution will then be transferred to a feed storage tank until sufficient solution is accumulated for a campaign through the extraction columns.

Purification

The uranium is separated from the fission products, thorium and other impurities in the solvent extraction system. This system uses the classical liquid-liquid extraction where aqueous nitrate solutions travel countercurrent to the tributyl phosphate type solvent in pulsed, plate type extraction columns. By varying the acid concentrations in the aqueous stream and the TBP concentration in the solvent

uranium or both uranium and thorium can be salted into the organic. It is re-extracted into the aqueous stream containing little or no acid. Three extraction-re-extraction cycles are used to decontaminate the uranium to an activity level equivalent to unirradiated uranium. It is then passed through silica gel beds to remove trace fission products such as ruthenium. Finally the uranium is concentrated by evaporation and packaged for shipment.

Depending on the flowsheet used in extraction it is possible to separate the uranium from the thorium and fission products together in the first extraction or HA cycle, or the thorium can be carried over with the uranium and separated subsequently and recovered. Both processes are technically feasible and the choice depends on the value of the recovered thorium compared to the over-all cost of separation.

In the case of discarding the thorium, the first extraction column is run using a five percent TBP solvent stream. The flow rates and acid concentration are adjusted so that thorium is not extracted and it is carried to waste with the other fission products. The uranium-solvent stream is carried overhead and through the balance of the purification system.

The waste solution from the first extraction column will be evaporated to reduce volume and the resulting acidic solution put into stainless steel tanks for perpetual storage. Stainless steel tanks are required as thorium must be stored in an acid condition to prevent precipitation of the thorium.

In order to recover the thorium in the feed solution also, the extraction column feed must be made acid deficient by evaporation and a TBP concentration in the solvent stream of 20 percent is used. The solvent stream containing both uranium and thorium is then stripped with water and both thorium and uranium are carried into the first uranium cycle extraction column. The TBP concentration in the extractant to this column is 5 percent. The uranium only is extracted and carried through the balance of the extraction system to complete its

decontamination of fission products. The thorium is removed in the aqueous waste from this column. This flowsheet is shown in Appendix Fig. 7.

The aqueous stream containing the thorium from the second extraction column will be concentrated by evaporation and the acidic thorium solution transferred to a stainless steel storage tank. The thorium at this stage will not be completely decontaminated with the primary contaminants being fission product zirconium, ruthenium, Th-228 and Th-234. These contaminants have a relatively short half life, and after 10 to 12 years storage will decay sufficiently to permit the thorium to be reused without any extraordinary precautions taken in its handling. Additional equipment is required for thorium separation including a nitric acid stripper shown in Appendix Fig. 10 and a thorium boil down evaporator shown in Fig. 11.

Product Storage and Handling

The uranium product will contain between 300 and 1,200 ppm U-232 as well as the U-233. The U-232 decay chain contains several highly energetic gamma emitters which will require shielded storage starting approximately five days after final uranium decontamination in the extraction system. This period is ample for packaging without shielding but the activity will require the use of shielded shipping containers for the U-233 nitrate solutions.

With the exception of the stainless steel storage tanks required for storage of thorium either with the other fission products or as a recovered product the other aqueous waste streams will be handled in a normal manner. The spent alundum from the burner operation will be packaged in barrels and buried as low level waste.

Accountability

It will be particularly difficult to establish a uranium input value for HTGR fuels as it will be extremely difficult to determine the uranium loading until the heavy metals are in solution at the leacher.

Because of the difficulty of taking representative samples from the fuel elements in solid form, accurate determinations of the uranium content will not be possible. Consequently, all solid waste streams including residues from filters, spent alundum packaged for waste disposal, and material recovered from the vacuum system after spills must be carefully analyzed for uranium content before a material balance can be drawn. Normal care in monitoring liquid waste streams for uranium prior to storage or disposal to settling ponds will be practiced.

Plant cleanup after a campaign involving HTGR fuel will need to be particularly rigorous to prevent thorium and U^{233} contamination of other fuels that do not contain these isotopes. Over-all recovery equal to that for other fuels processed by the solvent extraction process may be expected.

Sampling

Process control and uranium accountability samples will be extracted from the crusher cell, burner cell, and leaching cell. These samples both liquid and solid will be drawn to vials within the operating cell, packaged, and placed into lead shielded transfer casks. The shielded casks will be withdrawn from the cells through access locks and transported by hand for transfer to the analytical laboratory. A list of samplers is given in Table 2 of the Appendix.

Process Air and Ventilation

The plant ventilation system is designed to provide five to seven air changes per hour in the storage, burner, crusher, and leacher cells. This number of air changes will be sufficient to keep the temperature of air in the operating areas below 150°F and remove the decay heat of 1,000 Btu average per element in the storage area. A 20,000 CFM fan will be required to provide ventilation air for the operating areas. This air will be discharged through paper absolute filters to remove particulates before discharge to the stacks.

The off-gas from the burner will be passed through a cyclone to remove large particulates, a sintered metal filter equipped with a blow back device (see Appendix Fig. 8), an air-cooled heat exchanger to reduce the temperature to 120^oF, a silica gel trap to remove ruthenium and cesium, an absolute filter, and a blower which then discharges to a stack.

The off-gas from the leacher will be passed through a reflux condenser, an acid scrubber, and then to the burner off-gas line ahead of the absolute filters. (See Appendix Fig. 9)

Plant Auxiliaries and Utilities

Normal plant utilities and supplies of steam and water can be taken from the available outlets of the purification plant. An electric substation will be provided. Liquid oxygen facilities will be installed alongside the new facilities. Leaching solutions will be made up in tanks in the cold chemical makeup and storage area.

Process Description - Alternate Processes

A variation on the reference process that was considered was burning in a static bed burner or in a rotary kiln. The static bed burner was ruled out because of the danger of a mass of fuel coming to rest next to the burner walls producing a local spot with a high heat flux, overheating, and burning through the furnace liner. A further disadvantage of static bed burning is the difficulty of obtaining complete combustion. Carryover of unburned insoluble carbon particles into the extraction columns could clog up instrumentation lines or produce sludge at the aqueous-solvent interface causing problems in column operation. The mechanical difficulties of sealing and maintaining a rotary kiln burner remotely were considered to outweigh the problems of operating a fluidized bed burner. Much of the operating equipment for a kiln must be located inside the cell, thereby increasing downtime for maintenance.

The assumption was made for the purposes of this study that the fuel particles would adhere to the graphite sleeve to some extent, preventing cutting the fuel element, pouring out the particles and discarding the graphite sleeve. This assumption may prove to be in error, and

mechanical disassembly could be incorporated into the process replacing the crusher.

There are several methods of preparing the fuel element for feed for the burner. Crushing was selected over sawing or chopping because of the ruggedness of the basic piece of equipment and the ability to feed the element from the container into the crusher by gravity. Chopping was eliminated because of the tendency of the fuel element to shatter along the holes. The resulting small pieces would tend to wedge in the transfer mechanism. Sawing has the advantage that the unfueled element ends can be removed and transferred to solid waste and are not included in the feed for the burner. Disposal of the solid wastes by burial and the attendant extra handling, largely offsets the extra burner capacity required to burn the unfueled ends. In addition, maintenance of the saw and its attendant mechanical positioning devices remotely within a dust-proof enclosure would be a difficult task.

Process Description - Grind-Leach

Some experimental work has been reported on recovery of thorium and uranium from Peach Bottom reactor fuel compacts by a grind-leach process and the results are encouraging from percent recovery standpoint. The engineering problems, however, are more difficult than for burn-leach and have not been completely solved.

The fuel must be ground fine enough to assure that all of the pyrolytic carbon coated spheres have been cracked open since the leach reagent will not disintegrate pyrolytic carbon coatings. The cores of the smallest spheres in HTGR fuel are quite small at approximately 200 microns in diameter and grinding to 100 percent through 200 mesh would be required for the HTGR fuel. This fine powder is then digested or leached with 13 $\underline{\text{M}}$ HNO_3 0.04 $\underline{\text{M}}$ HF and 0.04 $\underline{\text{M}}$ $\text{Al}(\text{NO}_3)_3$. A neutron poison such as 0.075 $\underline{\text{M}}$ Cd might be required. The thorium and uranium along with most of the fission products will go into solution in about 8 hours and the slurry must then be filtered to remove the fine graphite particulate. The graphite filter cake must then be washed

to reduce thorium and uranium holdup to no more than a few tenths of a percent of the total metals charged. The graphite filter cake may then be packaged and buried as a solid waste or it could be reslurried in dilute caustic and stored as a thick slurry in a mild steel waste tank. The filtrate is adjusted for extraction feed in the same way that the burn-leach solution is handled.

The experimental work performed at ORNL resulted in recoveries of 99.35 percent for uranium and 99.96 percent for thorium when Peach Bottom fuel was ground and leached as described above. A pre-treatment of 0.02 M KMnO_4 at 100°C for one hour is required before extraction in order to destroy surface active compounds generated by ThC_2 and UC_2 reactions with nitric acid.

The engineering problems of remotely grinding HTGR fuel to 200 mesh particle size, filtering the carbon and removing it to storage appear considerably more difficult to solve than those involved in the burn-leach process. The resulting solid waste is estimated at 60 cubic feet per day at a 20 rod per day processing rate. This far exceeds the alundum solid waste from the burn-leach process estimated at one cubic foot per day.

The savings would be in the form of reduced equipment costs and reduced process chemical costs. The burner and all associated equipment such as alundum hoppers, blowers, oxygen supply, preheater, off-gas cooler, and fuel crusher would be eliminated. The fine grinding equipment and its associated cyclones, filters, and screens would have to be supplied along with the slurry filter and graphite packaging equipment.

Process Description - Burn-Fluoride Volatility

In the burn-fluoride volatility process the fuel is burned as described in the burn-leach process. It is then transferred to a separate fluid bed reactor made of nickel or inconel and treated with fluorine at 450°C to 500°C . The uranium is converted to UF_6 and carried

through an NaF bed at 400°C. This bed removes the volatile fission products. The UF_6 is then condensed in a cold trap as product. The alundum and NaF are solid wastes which must be packaged in small cylinders and stored behind thick shielding with air or water cooling for a number of years before they are sufficiently cool to bury.

Experiments at BNL with Peach Bottom fuel have given uranium recoveries of 99%. The carbide fuels disintegrate to fine dust during burning which is not likely to occur with oxide fuels. The uranium in the thorium particles will not be reached effectively by the fluoride since thorium does not produce a volatile fluoride and uranium recovery may be expected to be low. The thorium goes with the waste in this process.

Process Description - Wet Burning

Recent experiments at ORNL have shown that graphite containing thorium and uranium carbides when heated to 300°C in 2 M nitric acid under an oxygen pressure of 500 to 1500 psi converted the graphite to CO_2 and dissolved the uranium and thorium. The carbon oxidation rate was 0.05 to 0.3 gm per gram of carbon present each hour. It has been postulated that periodic gas removal and recharging of the autoclave with oxygen would permit satisfactory operation at 300 psi. It was necessary to pressurize to 1500 psi in order to put all of the required oxygen in at one time. This process will not dissolve the oxide of thorium using the reagents experimented with to date. A large number of batch units would be required to achieve the production rate desired in the plant.

The wet burning process has not been developed sufficiently on either a laboratory or engineering scale to be adopted for commercial use. The process shows considerable promise for further development.

Thorium Recovery Processes

Thorium constitutes over 92% of each process unit of 500 kg of heavy metals. Three possible methods of separating the thorium from the uranium and fission products were examined.

The most desirable flowsheet from the standpoint of process experience is to purify the thorium in a separate two column extraction system. In this process the uranium is separated from the thorium and about 99.5% of the fission products in the partition cycle extraction column. The organic phase contains 5% tributyl phosphate (TBP) and will become saturated with uranium well below the minimum critical concentration in the extraction system. The thorium and fission products are discharged together from the bottom of the column in the aqueous waste (HAW) stream.

This stream is fed to a separate extraction column to recover the thorium. The feed stream no longer poses a criticality problem with the uranium removed and it may be safely extracted with a 30% TBP concentration in the solvent. The aqueous waste from this column will contain practically all of the fission products. This waste will be boiled down to reduce volume, neutralized, and stored in carbon steel waste storage tanks. The aqueous stream containing the thorium and some traces of radioactive Zr, Nb, and Ru, is re-extracted in a strip column. It is then reduced in volume to about 2 molar thorium and stored for about 2 years to permit decay of the active thorium isotopes and the trace fission products. Shielded stainless steel storage is required for this solution during the decay period.

A process flowsheet has been developed at ORNL extracting the thorium with the uranium in the partition cycle extraction column. This process is the basis of this engineering study and is discussed in detail in the Process Description - Burn-Leach section of this report. The process appears feasible but lacks the experience factor enjoyed by the separate cycle system. It has the advantage of much less extensive capital additions to the present plant. It appears that 20% TBP can be used safely in the partition cycle extraction column; however, whether the safety factor is satisfactory has not been resolved.

A third process flowsheet that would require very little in capital equipment additions was investigated. In this flowsheet the uranium and thorium are extracted together in the partition cycle extraction column.

The thorium is scrubbed out in the partition cycle Pu partition column. It appears that uranium refluxing would be excessive in the upper section of the partition column since the aqueous scrub stream would be very low in acid as it enters the top of the column. The uranium concentration could exceed the minimum critical concentration in this column, therefore the process has been eliminated from further consideration.

LABORATORY STUDIES

In the brief period of this study laboratory checkout of the thorium recovery process could not be accomplished and must be left for future experimental development. The work involved in scaling up the burning and leaching processes is considerable and is also an important facet of future work.

Some laboratory work was done to investigate means of quickly and economically heating the burner to the 700°C operating temperature. Initial results show that porous carbon impregnated with metallic nitrates will ignite spontaneously after heating to 400°C, and this reaction will heat the reactor to the 700°C operating temperature in a matter of minutes. Nine minutes were required in these initial laboratory experiments to reach operating temperature. Quick burner heatup minimizes the operating cost of intermittent burner operation.

In connection with the use of oxide fuel in the HTGR fuel elements, it is possible that they may not disintegrate in the fluid bed burner. ORNL made a series of laboratory fluidization tests with dense ThO_2 particles in alundum. These particles were found to work rapidly to the bottom of the bed when fluidized at one linear foot per second gas flow. These particles were fairly fluid at about 2.4 linear feet per second gas flow. However, at this flow it is difficult to maintain the fine alundum in the bed. This phenomenon suggests the possibility of classifying the product in the burner. Burning experience with unirradiated prototype fuel is needed to gain insight as to what may be expected in practice.

DESIGN PHILOSOPHY

The philosophy used in the design and construction of current reprocessing plants will be used for construction of the new facilities. All routine operations are performed by devices such as air cylinders, air-operated valves, and mechanical drives located and controlled as much as possible from outside the cells. Master-slave manipulators are used only for maintenance or emergency functions. Concrete shielding of appropriate thickness, generally five feet, is used as the primary protection, however lead is used in locations such as transfer locks or to shield various cell penetrations. Shielded viewing windows are incorporated in those spaces containing mechanically operated equipment but are not included in the chemical cells. Contact maintenance procedures will be used within the cells throughout the plant with the exception of the traveling bridge crane serving the storage and crushing areas. Provision has been made to draw this crane into a shielded repair area in the event of a breakdown. A limited amount of maintenance can also be performed by the mechanical manipulator in the crusher cell.

No cooling water or other aqueous solutions have been incorporated in the plant equipment designs with the exception of the leacher. It has been located within its own cell and is located below the level of all other pieces of equipment precluding accidental flooding of other work stations containing uranium. This design feature permits the use of large diameter process equipment without considering water moderation and reflection in criticality.

Contact maintenance will be used for all equipment with in-cell provisions for adequate decontamination. Maximum use of equipment isolation is projected to minimize the extent of decontamination required in order to perform maintenance.

DESIGN CRITERIA

The head-end facilities have been sized to accommodate an initial production rate of 20 fuel elements per day through the crushing, burning and leaching operations. This processing rate will suffice for the period 1972-1976 in accordance with the projected production requirements shown in Appendix Figure 12.

The burning equipment for the HTGR fuel elements cannot be operated on the same days that the existing plant is dissolving other fuels because of the site restriction for releasing radioactive gases to the atmosphere. Consequently, burning will be limited to approximately 130 operating days a year. Space has been provided in the design for an additional crusher, burner and leacher when the production load warrants between 1976 and 1978.

The extraction equipment can also be operated for HTGR fuels approximately 130 days per year. Based on processing 500 kg heavy metal daily, the NFS plant processing capacity would be reached in 1979-1980. At that time, additional reprocessing facilities would be required. The plant design study is based on a forecast for the continued success of HTGR reactors. Before commitments must be made for plant construction starting in 1969-1970, the requirements for plant size can be predicted on the number of HTGR reactors actually contracted.

The facilities have been designed to accommodate graphite fuel elements 5" in diameter and approximately 20'-0" long containing $(U-Th)O_2$ or ThO_2 fuel particles coated with pyrolytic carbon, with an average uranium content of 8.5%, and containing no burnable poisons. The fuel is expected to have a maximum burnup of 80,000 MWD/T and will be cooled 210 days before reprocessing. Changes in these conditions would have the following effects:

1. Increase in the average uranium content may reduce the extraction rate in the purification system in order to maintain safe uranium concentrations in the extraction columns.

2. Increase in fuel element diameter may reduce the number of elements that can be accommodated in the spent fuel storage cell.
3. Increase in fuel element length would require major alterations to the fuel unloading station and storage area.
4. Addition of a few grams of burnable poisons in each fuel element would not affect reprocessing.
5. An increase in burnup or a decrease in cooling time before reprocessing may require dilution of the extraction feed solution and reduce the heavy metal processing rate in order to avoid radiation damage to the solvent. The daily burning rate may also be affected if additional gaseous fission products were present.

In addition to the processing equipment described, each of the major functions will be supported by auxiliary equipment and services. Details of the size and purpose of supporting equipment are listed in Appendix Tables 4 and 5. Primary instrumentation and control equipment required is listed in Table 6. Appendix Table 7 lists the additional utilities required to operate the head-end facility.

CRITICALITY

Reprocessing HTGR fuel by a burn-leach head-end results in several nuclear criticality control problems that are somewhat different than those encountered during processing of metal fuel elements in existing plants.

In the fuel shipping cask, criticality control is by mass limitation in the truck cask which contains only seven fuel rods and by fixed neutron poison grids in the rail cask which contains sixty fuel rods. The minimum number of rods that can form a critical array in a water moderated system is twenty-one.

The fuel is unloaded one rod at a time and placed in dry storage in the form of planar arrays of twenty rods, on 8-inch centers, separated with 14 inches of concrete between arrays. This storage area would be safe even if water-flooded. Fuel is removed for crushing and burning one rod at a time.

The burner contains approximately 1000 kilograms of alundum, 200 kilograms of thorium and 14 kilograms of fissile uranium when it is operating. In addition, there are from 10 to 100 kilograms of graphite present in the burner bed. No water or other hydrogenous material is allowed to enter the burner during fuel processing. The burner is 35 inches ID by 7 feet high and criticality is controlled by mass limitation of an unmoderated system.

The ash hopper which collects the burner bed material contains approximately the same masses as the burner of alundum, thorium, and uranium but only contains a few kilograms of carbon. It is also considered to be safe by batch control of an unmoderated system.

Segregation of fuel ash from alundum in the burner or ash hopper is guarded against by means of a weigh hopper which checks ash density. Such a segregation could lead to an unsafe condition in the leacher. Future development work will be required to determine to what degree this segregation can be controlled and the final design will incorporate such controls. This may result in a leacher that is small and has safe geometry control. At present the design concept incorporates a leacher that assumes no ash segregation and therefore must be large

for process reasons. Criticality is prevented by a fixed grid of neutron poison in the leacher of boron-stainless steel. A backup control is supplied by soluble neutron poison (cadmium nitrate) in the leaching reagent.

The feed adjustment tanks also contain boron-stainless steel poison grids. At this point in the process a sample is taken to check on uranium inventory. The steam stripper is of safe geometry in its upper section and contains boron-stainless steel in its 18 inch reboiler section. The solution also contains the soluble cadmium nitrate poison as a backup.

The feed solution holdup tank is safe by virtue of concentration control. However, since the total mass of uranium in this tank is approximately 250 kilograms and the solution may be stored for several months before being extracted, the tank also contains a boron-stainless steel poison grid which will make it safe in the unlikely event that the uranium precipitates. Periodic samples are taken from this tank to guard against such an occurrence.

In the extraction column feed uranium concentration is at a safe 8.5 grams per liter. No-flow and low-flow alarms are provided on extraction column input streams to prevent uranium concentrations exceeding the safe limit of approximately 50 grams per liter in the 10 inch columns. The solvent strength is reduced to 20 percent TBP as an additional guard against uranium concentration buildup in the columns.

Once thorium and uranium are removed from the feed it may be boiled down safely as high level waste but it is first sampled to determine that it contains no dangerous amounts of fissile material. The stream flows throughout the remainder of the first cycle extraction are controlled to limit uranium concentration to no more than 4.5 grams per liter.

In the subsequent extraction cycles only 5 percent TBP solvent is used and stream flows are again limited to control uranium concentrations to 4.5 grams per liter. The final uranium product boildown system is of safe geometry design.

The burner ash segregation problem, uranium precipitation during storage and extraction with 20 percent TBP require further development study, however, there is reasonable certainty that any unforeseen difficulty in these areas can be overcome by proper mechanical design and choice of operating conditions.

PLANT LIMITATIONS

The existing plant and site have the following limitations:

1. A maximum of 12,000 curies of Kr^{85} can be released to the atmosphere daily. This figure is based on the exposure limits permitted by 10 CFR-20.
2. The uranium concentration to the 10' extraction column is limited to 8.5 g per liter. This limitation is imposed to prevent the uranium concentration in the extraction column from exceeding critically safe conditions in the solvent solution in the event that the aqueous scrub flow should be reduced while the feed flow is maintained.
3. The extraction columns have a throughput limit of approximately 800 gallons per hour per square foot for total organic and aqueous flow. The extraction of thorium requires an abnormally high solvent to aqueous flow ratio and the presence of enriched uranium requires the use of low concentrations for criticality control. Since intercycle sampling is not routinely done these low concentrations must be overly conservative. These factors limit the heavy metal throughput for the solvent extraction columns to approximately 500 kilograms per day.

RECOMMENDATIONS FOR FUTURE WORK

While the burn-leach process outlined in this report is based on a large accumulation of data developed by ORNL and BNL, there is a need for additional process development work to be done before an actual mechanical design of the head-end can be undertaken. The unique construction features of the HTGR and the high process through-put required introduce several unknowns. All of the previous burning and leaching work done by ORNL and BNL has been done using beaded thorium and uranium carbide fuels rather than oxide fuels. In addition, the work was done in small fluidized and static beds ranging from 2 inches to 5 inches diameter.

Leaching and alundum drying work done to date has also been done with oxidized carbide fuel on a small scale. Only one burning experiment has been performed on fuel of moderate burnup (9000 mwd/t) which was again carbide fuel.

The scaleup problems of going from four to thirty-five inches on the burner are too great for good engineering design and a large pilot plant burner must be set up to determine design requirements and operating characteristics for the plant-scale burner. The same scale-up problems exist in connection with the leaching operation. All of this work should be done with representative oxide bead fuel.

Some small scale hot cell tests are required to check fission product volatility and leaching behavior on highly irradiated fuel specimens.

Some fluidizing studies must be made to check fuel bead segregation in alundum beds and determine fluidizing velocities, optimum alundum bead sizes, and heat transfer coefficients.

The extraction flowsheet will have to be checked out in small experimental columns and possibly with cold solutions in the solvent extraction plant columns. Cold startup runs on all of the HTGR head-end equipment will be required before irradiated fuel can be processed in it.

Corrosion rates on stainless steel and long term stability data are required for thorium solutions that are to be stored for future use. Corrosion rates are also required for process solutions on boron-stainless steel poison grids. Erosion of burner walls and internal grids must also be studied.

PLANT DESCRIPTION

The head-end facilities will be constructed using design criteria and equipment and piping specifications consistent with those used for the existing plant. The facilities will be located on the north side of the NFS plant with the new unloading station centered on an extension of the present railroad siding. The operating cell walls above grade will be constructed of 5'0 of concrete. Thickness of cell walls below grade will be commensurate with the load bearing requirements of the upper floors. Use of high density concrete will be restricted to areas in which the shielding is reduced such as around cell plugs, access doors, viewing windows, and cell penetrations. Cell floors will be covered with stainless steel and sloped to critically safe sumps to facilitate decontamination procedures. Outer walls of the operating galleries will be constructed of concrete block.

Ventilation air will be circulated from the areas least likely to be contaminated into the more highly radioactive areas. All ventilation will be drawn through absolute filters before discharge to the stack.

TABLE I

MATERIAL BALANCE DATA FOR HTGR FUEL REPROCESSING FLOW (Figure 1)

Basis: 20 Fuel Elements Per Day Through Stream 33; 50 Fuel Elements Per Day Streams 34 through 53

Stream Number	1	2	3	4	5	6	7	8
Stream Name	Fuel	Cask	Storage	Fuel	Fuel	Crusher	Crusher	Crusher
Elements Per Day	Shipment	Unloading	Loading	KG/Day	Can	Off-Gas	Vent Gas	Fines
	(60	12	12		20	KG/Day		KG/Day
Carbon	Elements			2140	per	2.14		2.14
Thorium	per cask			187	day	0.19		0.19
Uranium	and 4 ship-			13.44		0.013		0.013
Oxygen as Metal Oxide(MO ₂)	ments per			34.6		0.035		0.035
F. P.	year by			17.08		0.017		0.017
Alundum (Al ₂ O ₃)	rail or 7							
Water	elements							
	per cask							
	and 35 ship-							
	ments per							
	year by							
	truck)							
SCFM								
Oxygen								
Nitrogen								
Air						10	10	
Carbon Dioxide								
Carbon Monoxide								
MOLS Per Day								
NO + NO ₂								
Liters Per Day								
Molarity M								
HNO ₃								
F ⁻ 3								
Al ⁺⁺⁺								
Cd (NO ₃) ₂								
Th								
U								
Grams Per Liter								
U								
F. P.								
Th								

MATERIAL BALANCE DATA FOR HTGR FUEL REPROCESSING FLOW DIAGRAM

Basis: 20 Fuel Elements Per Day

Stream Number	9	10	11	12	13	14	15	16	17	18	19
Stream Name	Crushed Fuel	Burner Feed Gas	Oxygen	Air	Burner Ash	Burner Off-Gas	Burner Off-Gas Fines	Filtered Off-Gas	Off-Gas	Off-Gas	Off-Gas

Elements Per Day

Kilograms Per Day

Carbon	2140				2.14						
Thorium	187				187.	0.37	0.37	.004			
Uranium	13.44				13.44	.025	0.025	.00025			
Oxygen as Metal Oxide (MO ₂)	31.6				34.6	.069	0.069	.00069			
F. P.	17.08				17.08	.034	0.034	.00034			
Alundum					1000.	2.	2.				
Water											

SCFM

Oxygen		114	110.3			11.4		11.4	11.4	11.4	11.4	∞
Nitrogen		14				14		14	14	14	14	
Air				17.7								
Carbon Dioxide						97.2		97.2	97.2	97.2	97.2	
Carbon Monoxide						5.4	.	5.4	5.4	5.4	5.4	

MOLS Per Day

NO + NO₂

Liters Per Day

Molarity M

HNO₃
F³⁻
Al⁺⁺⁺
Cd
Th
U

Grams Per Day

U
F. P.

MATERIAL BALANCE DATA FOR HTGR FUEL REPROCESSING FLOW DIAGRAM

Basis: 20 Fuel Elements Per Day

Stream Number	20	21	22	23	24	25	26	27	28
Stream Name	Leach	Leacher	Leacher	Dried	Alundum	Alundum	Alundum	Stripper	Stripper
Elements Per Day	Reagent	Product	Off-Gas	Off-Gas	Recycle	Waste	Make-up	Vapor	Condensate
Carbon									
Thorium					0.20	0.21			
Uranium					0.02	0.001			
Oxygen as Metal Oxide (MO_2)					950	50	50		
F. P.									
Water									
Alundum									
SCFM									
Oxygen									
Nitrogen									
Air									
Carbon Dioxide									
Carbon Monoxide									
Water Vapor								40	
HNO_3									
MOLS Per Day									
$\text{NO} + \text{NO}_2$			57	57					
Liters Per Dry	807	807							307
Molarity $\underline{\text{M}}$									
HNO_3	13.0	8.4							8.45
I^{--3}	.04	.04							
Al^{+++}	.04	.04							
$\text{Cd}(\text{NO}_3)_2$	.075	.075							
Th		1.0							
U		.071							
Grams Per Liter									
U		16.6							
F. P.		21.2							
Th									
HNO_3									

MATERIAL BALANCE DATA FOR HTGR FUEL REPROCESSING FLOW DIAGRAM

Stream Number	29	30	31	32
Stream Name	Stripper	Stripper	Adjustment	Extraction
Elements Per Day	Steam	Bottom	Stream	Feed
Kilograms Per Day				
Carbon				
Thorium				
Uranium				
Oxygen as Metal				
Oxide (MO_2)				
F.P.				
Water			1342	
Alundum				
SCFM				
Oxygen				
Nitrogen				
Air				
Carbon Dioxide				
Carbon Monoxide				
Water Vapor				
HNO_3				
MOLS Per Day				
$\text{NO} + \text{NO}_2$				
Liters Per Day	242	242	1342	1614
Molarity <u>M</u>				
HNO_3		-0.15		-0.02
F^{3-}		0.133		0.02
Al^{+++}		0.133		0.02
$\text{Cd}(\text{NO}_3)_2$		0.267		0.04
Th		3.33		0.50
U		0.237		
Grams Per Liter				
U		55.5		8.3
F. P.		70.5		10.6
Th				
HNO_3				

TABLE NO. 2
 SAMPLER LIST FOR HTGR FUEL REPROCESSING
 HEAD END

Solids

<u>Stream</u>	<u>Activity</u>
Waste Al_2O_3 Packaging Station	0.2 curies/gram
Burner Ash ³ Hopper	2 curies/gram
Burner off-gas (unfiltered)	2 curies/gram
Burner off-gas (primary filter discharge)	2 curies/gram
Burner off-gas (silica gel bed discharge)	2 curies/gram
Burner off-gas (absolute filter discharge)	2 curies/gram

Liquids

Leacher Acid Make-up and Feed Tank	None
Input Measurement and Feed Adjustment Tanks (2)	2.5 curies/ml.
Thorium Storage Tank	0.1 curies/ml.
Feed Storage Tank	2.5 curies/ml.

TABLE NO. 3

MATERIAL BALANCE DATA FOR HTGR THORIUM-URANIUM EXTRACTION AND PARTITION
FLOW DIAGRAM (FIGURE 7)

Stream Number Phase	33 Aqueous	34 Aqueous	35 Aqueous	36 Organic	37 Aqueous	38 Organic	39 Aqueous	40 Organic	41 Organic
Stream Name	Extraction Feed HAF	Scrub HAS	Acid HAA	Solvent HAX	Waste HAW	Product HAP	Scrub HBS	Product HBP	Solvent HBX
Kilograms Per Day									
Thorium									
Uranium									
SCFM									
Gallons Per Day	1060	180	275	4080	1515	4080	200	4280	200
Liters Per Day	4020	670	1040	15420	5730	15420	760	16180	760
Molarity, M									
HNO ₃	-0.02	2.0	13.0		2.0	0.2	2.0	0.2	
Th	0.5								
U									
F	0.02								
Al+++	0.02								
Grams Per Liter									
Th	116				0.2	30.2		28.8	
U	8.33				0.003	2.2		2.1	
FP	10.56								
TBP, %				20					20
Moles/Day									
Th									
U									
HNO ₃	80.4	13400	13520	0	1460	3084.	1520	3236	
F-+Al+++									
K Grams/Day									
Th	466.5								
U	33.5								
FP	42.5				42.5				

TABLE NO. 3 (Cont'd)

Stream Number Phase	42 Aqueous	43 Aqueous	44 Organic	45 Aqueous	46 Aqueous	47 Aqueous	48 Aqueous
Stream Name	Waste HBW	Strip HCX	Solvent Waste HCW	Product HCP	Acid	Feed IAF	Strip IAS
Kilograms Per Day							
Thorium							
Uranium							
SCFM							
Gallons Per Day	200	4280	4280	4280	720	5000	500
Liters Per Day	760	16180	16180	16180	2720	18930	1890
Molarity, M							
HNO ₃	1.8	0.01		.21	12.7	2.0	3.0
Th							
U							
F							
Al+++							
Grams Per Liter							
Th	0.02			28.8		24.6	
U	0.001			2.1		1.8	
FP							
EBP, %							
Moles/Day							
Th							
U							
HNO ₃	1370	162		3400	34460	37860	5670
F--Al+++							
K Grams/Day							
Th							
U							
FP							

C.

TABLE NO. 3 (Cont'd)

Stream Number	49	50	51	52	53
Phase	Organic	Organic	Aqueous	Aqueous	Aqueous
Stream Name	Solvent IAX	Uranium Product IAU	Thorium Product IATh	Thorium Product Concen- trate	Thorium Evaporator Condensate
Kilograms Per Day					
Thorium					
Uranium					
SCFM					
Gallons Per Day	4000	4000	5500	263	5237
Liters Per Day	15160	15160	20800	1000	19800
Molarity, M					
HNO ₃		0.1	2.07	4.0	1.96
Th				2.0	
U					
F					
Al+++					
Grams Per Liter					
Th			22.2	46.4	
U		2.25	.001	.02	
FP					
TBP, %	5	5			
Moles/Day					
Th					
U					
HNO ₃		516	43014	4000	3900
F--Al+++					
K Grams/Day					
Th					
U					
FP					

7

TABLE NO. 4
EQUIPMENT LIST FOR HTGR FUEL REPROCESSING HEAD END
I FUEL RECEIVING AND TRANSFER

<u>ITEM NO.</u>	<u>ITEM</u>	<u>NUMBER OF ITEMS</u>
1	Cask Unloading Station Dolly	1
2	Unloading Track Extended	1
3	Unloading Station Door (Non-Shielded)	1
4	Cask Plug Crane	1
5	Shielded Window	1
6	Vacuum Cleaning System	1
7	Ventilating System	1
8	Car Puller	1
9	Movable Shield	1

TABLE NO.4 (cont'd)
II FUEL STORAGE

<u>ITEM NO.</u>	<u>ITEM</u>	<u>NUMBER OF ITEMS</u>
1	Fuel Element Storage Rack	1
2	Fuel Element Transfer Crane	1
3	Shielded Window	4
4	Can Trough	1
5	Can Tilter	1
6	Grappler	1

TABLE NO. 4 (cont'd)
III FUEL CRUSHING

<u>ITEM NO:</u>	<u>ITEM</u>	<u>NUMBER OF ITEMS</u>
1	Fuel Element Jaw Crusher	1
2	Off-Gas Filter Unit	2
3	Manipulator	2
4	Off-Gas Fan	1
5	Off-Gas Solids Receiver and Transfer Unit	1
6	Shield Window	1
7	Mirrors	3
8	Sawed Fuel Receiver and Oxidizer Feeder	1
9	Can End Remover	1
10	Off-Gas Cyclone	1
11	Vacuum Cleaning System	1

TABLE NO.4 (cont'd)
IV FUEL BURNING

<u>ITEM NO.</u>	<u>ITEM</u>	<u>NUMBER OF ITEMS</u>
1	Liquid Oxygen Storage and Vaporizer Package	1
2	Liquid Nitrogen Storage and Vaporizer Package	1
3	Air Supply Station	1
4	Feed Gas Mix Station	1
5	Feed Gas Pre-Heater	1
6	Fresh Alundum Transfer Lock	1
7	Recycle Alundum Hopper	1
8	Oxidizer	1
9	Off-Gas Filter Unit	1
10	Off-Gas Cooler	1
11	Silica Gel Adsorber	1
12	Absolute Filter Unit	2
13	Off-Gas Blower	2
14	Particulate Blow Back Unit	1
15	Ash-Alundum Hopper	1
16	Ash-Alundum Airveyor	1
17	Leacher Feed Airveyor	1
18	Recycle Alundum Air Filter	1
19	Ash-Alundum Air Filter	1
20	Recycle Alundum Airveyor	1
21	Density Hopper	1
22	Solid Sampler Unit	1
23	Off-Gas Cyclone	1
24	Cooling Gas Blower	1
25	Cooling Gas Cooler	1

TABLE NO. 4 (cont'd)
V ASH LEACHING

<u>ITEM NO.</u>	<u>ITEM</u>	<u>NUMBER OF ITEMS</u>
1	Ash-Alundum Leacher	1
2	Air Heater	1
3	Reflux Condenser	1
4	Leacher Solution Filter	1
5	Leacher Acid Make-up and Feed Tank	1
6	HNO ₃ Drum Feed Station	1
7	Waste Alundum Airveyor	1
8	Drying Air Station	1
9	Waste Alundum Weigh Hopper	1
10	Waste Alundum Packaging Station	1
11	Leacher Product Storage Tank	1
12	Evaporator Feed Tank	1
13	Leacher Transfer Jet	1
14	Storage Transfer Jet	1
15	Extraction Feed Transfer Jet	1
16	Manipulator	1
17	Shield Window	1
18	Liquid Sampler Unit	1
19	HNO ₃ Stripper	1
20	Stripper Reboiler	1
21	Stripper Condenser	1
22	Acid Scrubber	1
23	Gas Heater	1

TABLE NO. 4 (cont'd)
VI EXTRACTION AND THORIUM STORAGE

<u>ITEM</u> <u>NO:</u>	<u>ITEM</u>	<u>NUMBER OF</u> <u>ITEMS</u>
1	Thorium Storage Tank	2
2	Thorium Evaporator	1
3	Thorium Evaporator Reboiler	1
4	Thorium Evaporator Condenser	1
5	Thorium Evaporator Condensate Tank	1
6	HA Acid Feed Tank	1

TABLE NO. 5

EQUIPMENT SIZES AND DUTIES FOR HTGR FUEL REPROCESSING HEAD END

Item No.	Item	No. of Items	Capacity	Duty Btu/Hr	ID, In.	H Ft	L Ft	Area Ft ²	Temp °C	Press Psig	Mat'l of Const.
1	Liquid Oxygen Storage and Vaporizer Package	1	6,000 gal	(11.5 Ft Sphere)							
2	Liquid Nitrogen Storage and Vaporizer Package	1	2,500 gal	(8.5 Ft Sphere)							
3	Air Supply Station	1		(Valves and Pipe)*							CS
4	Feed Gas Mix Station	1		(Valves and Pipe)							CS
5	Feed Gas Pre-Heater	1		2.14 x 10 ⁵				47			Tubes 316 SS
6	Fresh Alundum Transfer Lock	1	50 lbs								304 SS
7	Recycle Alundum Hopper	1	7,000 62 cu.ft		48 ID	Cyl 4			50	-0.1	304 SS
8	Oxidizer	1	20 ele. per day	2.95 x 10 ⁶	35-44 ID 37-46 OD	Cone 3.5 14		W 81 T 67	400-750	0-6	310 SS
9	Off-Gas Filter Unit	1	128 SCFM 19 Units		27 ID	Cyl 5 Cone 5			400	-0.1	304 SS
10	Off-Gas Cooler	1		1.81 x 10 ⁵	10 ID		6	41	50-400	-0.1	Tube 304 SS Shell 304 SS
11	Silica Gel Adsorber	1			20 ID	3			50	-0.1	304 SS
12	Absolute Filter Unit	2	200 SCFM		12	1	1 1/2		50	-0.1	304 SS
13	Off-Gas Blower	2	200 SCFM						50	-0.1	304 SS
14	Particulate Blow Back Unit	1		(Valves and Pipe)							304 SS
15	Ash-Alundum Hopper	1	2,500 lb 22 C.F.		36 ID	Cyl 3 Cone 2 1/2			750	-0.1	304 SS
16	Ash-Alundum Airveyor	1		(Valves and Pipe)					750	-0.1	304 SS
17	Leacher Airveyor	1		(Valves and Pipe)					200	-0.1	304 SS
18	Recycle Alundum Air Filter	1									
19	Ash-Alundum Air Filter	1									
20	Recycle Alundum Airveyor	1		(Valves and Pipe)							
21	Density Hopper	1			12 ID	Cyl 1 Cone 1					304 SS
22	Solid Sampler Unit										
23	Off-Gas Cyclone	1	128 SCFM		12" ID	Cyl 2 Cone 2			400	-0.1	304 SS
24	Cooling Gas Blower	1	8,580 SCFM	400 HP Motor					50	9	CI
25	Cooling Gas Cooler	1	8,580 SCFM	8 x 10 ⁵	25 OD	20		1090	50	9	CS

*Included in Piping and Valves

TABLE NO. 5 (Cont'd)

Item No.	Item	No. of Items	Capacity	Duty Btu/Hr	ID, In.	H Ft	L Ft	Area Ft ²	Temp °C	Press Psig	Mat'l of Const.
26	Ash-Alundum Leacher	1	56 C.F.		48 ID	7		8.0	370	2	Body 309 SS Coil 309 SS
27	Air Heater	1		5.87 x 10 ⁵				147	50-370	5	
28	Reflux Condenser	1		3.4 x 10 ⁴				5			Tube 309 SS Shell 304 SS
29	Leacher Solution Filter	1									309 SS
30	Leacher Acid Make-Up and Feed Tank	1	34 C.F.		36 ID	4 e/4			50	-0.1	309 SS
31	HNO ₃ Feed Drum Station	1		(Valves and Pipe)							304 SS
32	Waste Alundum Airveyor	1		(Valves and Pipe)							304 SS
33	Drying Air Station	1		(Valves and Pipe)							304 SS
34	Waste Alundum Weigh Hopper	1			12 ID	Cyl 1 Cone 1					304 SS
35	Waste Alun. Packaging Sta.	1									304 SS
36	Leacher Prod. Storage Tank	1	1,500 C.F.	3.3 x 10 ⁵	120 ID	19		275			309 SS
37	Evaporator Feed Tank	2	69 C.F.		48	5 1/2					309 SS
38	Leacher Transfer Jet	1									309 SS
39	Storage Transfer Jet	1									309 SS
40	Extraction Feed Transfer Jet	1									309 SS
41	Manipulator	1									
42	Shield Window	1									
43	Liquid Sampler Unit	1									
44	HNO ₃ Stripper	1		1.0 x 10 ⁵	5 ID	11					309 SS
45	Stripper Reboiler	1		5 x 10 ⁴	18 ID	1 1/2					309 SS
46	Stripper Condenser	1		2.5 x 10 ⁵	10 ID	7		10			Tubes 304 SS Shell 304 SS
47	Acid Scrubber	1			5 ID	14					304 SS
48	Gas Heater	1		7 x 10 ³				2			304 SS
49	Thorium Storage Tank	1	11,000 gal								304 SS
50	Thorium Evaporator	1			30 ID	12					309 SS
51	Thorium Evaporator Reboiler	1		1.68 x 10 ⁵	10 ID	6		5.8			309 SS
52	Thorium Evaporator Condenser	1		1.68 x 10 ⁵	12 ID	7		13.7			309 SS
53	HA Acid Feed Tank	1	300 gal		36 ID	5					304 SS
54	Thorium Evaporator Condensate Tank	1	1,200 gal		52 ID	10					304 SS

TABLE NO. 6
INSTRUMENT LIST FOR HTGR FUEL REPROCESSING
HEAD END

<u>Symbol</u>	<u>Location</u>	<u>Type</u>	<u>Range</u>
<u>HTGR Burn Leach Process Equipment</u>			
FI-1	Air to cask purge	Rotameter	5 to 50 SCFM
RM	Activity monitor transfer cell	CAM	0.5 to 100 mr/hr.
RM	Activity monitor cell off-gas	CAM	0.5 to 100 m4/hr.
TR 6	Air Temp. fuel storage area	6 point pot.	0 to 150°C
DpIAH	Diff. press fuel saw filter	DP cell	0 to 100" H ₂ O
PI	Blow back air to fuel saw filter	Dial press gage	0 to 100 PSI
PI	Pressure in fuel saw enclosure	Dial press gage	-100 to +100" H ₂ O
FI	Purge air to fuel saw	Rotameter	2 to 20 SCFM
LI	Level in alundum makeup storage	Sight glass	0 to 50"
FI	Air to alundum airveyor	Rotameter	0.2 to 2 SCFM
FRC	Oxygen flow to burner	Orifice meter	10 to 100 SCFM
FRC	Air flow to burner	Orifice meter	10 to 100 SCFM
PR	Burner gas pressure	Metal bellows	0 to 50 Psig
PI	Burner Cooling Air Pressure	Metal bellows	0 to 5 Psig
TRC	Gas preheater temp.	Potentiometer	250 to 1000°C
DpRAH	Pressure drop across burner	DP cell	0 to 50 PSI
TRC	Burner bed temperature	Potentiometer	250 to 1000°C
TR-12	Burner and burner bed temp.	Potentiometer	250 to 1000°C
TR	Ash hopper temp.	Potentiometer	100 to 700°C
TR	Weigh hopper temp.	Potentiometer	100 to 700°C
WAH	Weight in weigh hopper	Strain gage	0 to 400
WI	Weight in ash hopper	Strain gage	0 to 2500
WI	Weight in leached alundum hopper	Strain gage	0 to 7500
LA	Level in leached alundum hopper	Indicator	?
LI	Level in ash hopper	Sonic Probe	0 to 8'
FI	Air to leacher	Rotameter	0.3 to 30 SCFM
TRC	Leacher temp.	Potentiometer	0 to 200°C
LRAH	Level in leacher	Bubbler-DP cell	0 to 100" H ₂ O
DR	Density in leacher	Bubbler-DP cell	1.00 to 1.600
PI	Steam to leacher	Metal bellows	0 to 150 Psig
FI	Air to leacher airveyor 1	Rotameter	0.2 to 2 SCFM
FI	Air to leacher airveyor 2	Rotameter	0.2 to 2 SCFM
PI	Air to leacher filter	Metal bellows	0 to 50 Psig
LRAH	Level in input meas. tank No. 1	Bubbler-DP cell	0 to 100" H ₂ O
DR	Density input meas. tank No. 1	Bubbler-DP cell	1.00 to 1.600
TI	Temp. in input meas. tank No. 1	Potentiometer	0 to 150°C
LRA	Level in leacher acid makeup tank	Bubbler-DP cell	
DR	Density in leacher acid makeup tk.	Bubbler-DP cell	1.00 to 1.200
GA	Off-gas analyzer CO-CO ₂	Conductivity	0 to 20% CO 50 to 100% CO ₂
GA	Off-gas analyzer O ₂	Conductivity	0 to 50% O ₂
FR	Off-gas flow	Orificemeter	0 to 150 SCFM
TRA	Cooled off-gas temp	Potentiometer	0 to 300°C
PI	Off-gas pressure	Metal bellows	-20 to +20" H ₂ O
DpIAH	Differential pressure across silica gel beds	DP cell	0 to 20" H ₂ O

TABLE NO. 6 (cont'd)

<u>Symbol</u>	<u>Location</u>	<u>Type</u>	<u>Range</u>
TI	Silica gel beds	Potentiometer	0 to 300°C
LI	Liquid level silica gel beds (for regeneration only)	Bubbler	0-50" H ₂ O
DpIAH	Differential pressure across absolute filters	DP cell	0 to 10" H ₂ O
RMAH	Radioactivity filtered off-gas	ION chamber	10 ⁶ to 10 ⁸ d/minxml. Should detect 10 ⁶ x mpc for Ru, Cs, Kr, I
LRAH	Level input measuring tank No.2	Bubbler-DP cell	0-100" H ₂ O
DR	Density input meas. tank No. 2	Bubbler-DP cell	1.00 to 1.600
TI	Temp. input measuring tank No.2	Potentiometer	0 to 150°C
LRAH	Level ext. feed storage tank	Bubbler-DP cell	0-150" H ₂ O
DR	Density ext. feed storage tank	Bubbler-DP cell	1.00 to 1.600
TI	Temp. ext. feed storage tank	Potentiometer	0 to 150°C
LIAH	Level ext. feed stor. tank vault sump	Bubbler-DP cell	0 to 50" H ₂ O
DRCAH	Density steam stripper reboiler	Bubbler-DP cell	1.00 to 1.600
TP	Temp. steam stripper reboiler	Potentiometer	0 to 200°C
LRAH	Level steam stripper reboiler	Bubbler-DP cell	0 to 30" H ₂ O
TI	Temp. steam stripper overheads	Potentiometer	0 to 200°C
TI	Temperature steam stripper condensate	Potentiometer	0 to 150°C
DpRAH	Diff. press. steam stripper column	DP cell	0 to 20" H ₂ O
LRAL	Level extraction acid feed tank	Bubbler-DP cell	0 to 80" H ₂ O
DI	Density ext. acid feed tank	Bubbler-DP cell	1.00 to 1.400
TR	Temp. thorium product evaporator	Potentiometer	0 to 200°C
LR	Level thorium prod. evaporator	Bubbler-DP cell	0 to 15" H ₂ O
DRCA	Density thorium prod. evaporator	Bubbler-DP cell	1.00 to 1.600
TI	Temp. Th evap. condensate	Potentiometer	0 to 200°C
LRAH	Level Th evap. condensate collection tank	Bubbler-DP cell	0 to 100" H ₂ O
DI	Density Th evap. condensate collection tank	Bubbler-DP cell	1.00 to 1.20
LRAHL	Thorium product storage tank level	Bubbler-DP cell	0-120" H ₂ O
TI(6 p+)	Temp. in thorium product storage tank	Potentiometer	0-150°C

TABLE NO. 7

UTILITIES REQUIRED FOR HTGR FUEL REPROCESSING HEAD END

Item	Natural Gas SCFM	Cooling Water GPM	Electric Power KWH	Comp. Air 50 PSIG	Steam 25 PSIG LB/HR	Run Time HRS/D
Cask Plug Crane			4			(1)
Vacuum Cleaning System			0.5			(1)
Movable Shield			7.5			(1)
Fuel Element Transfer Crane			15			(1)
Fuel Element Jaw Crusher			1			(1)
Manipulator			0.5			(1)
(1) Intermittent, As required for Material Transfer						
Off-Gas Fan			1			(1)
Vacuum Cleaning System			0.5			(1)
Ventilation Fan			20			24
Feed Gas Preheater	3.6					24
Off-Gas Cooler		18				24
Off-Gas Blower			3			24
Off-Gas Blower, Spare			3			
Cooling Gas Blower			300			24
Cooling Gas Cooler		82				24
Ash-Alundum Airveyor				X		(1)
Leacher Airveyor				X		(1)
Recycle Alundum Airveyor				X		(1)
Ash-Alundum Leacher					40	20
Air-Heater	60					12
Reflux Condenser		4			150 PSIG 8	20
Gas Heater						
Waste Alundum Airveyor				X		(1)
Leacher Transfer Jet					X	(1)
Storage Transfer Jet					X	(1)
Extraction Feed Transfer Jet					X	(1)
Stripper Reboiler					150 PSIG 58	24
Stripper Condenser		25				24
Thorium Evaporator Reboiler					150 PSIG 530	24
Thorium Evaporator Condenser		45				24

FIGURE 1
PRELIMINARY FLOW DIAGRAM
HTGR FUEL REPROCESSING

FIGURE 2
HTGR HEAD END PLANT---PLAN VIEWS

SECTION A-A

FIGURE 3
HTGR HEAD END PLANT---SECTION A-A

NO. OF ITEMS	HOPPER	A	B	C
1	RECYCLE ALUNDUM	4'-0"	4'-0"	3'-6"
1	ASH ALUNDUM	3'-0"	3'-0"	2'-6"
1	WASTE ALUNDUM WEIGH	1'-0"	1'-0"	1'-0"
1	DENSITY	1'-0"	1'-0"	1'-0"

MATERIAL 304 S/S

FIGURE 5
ALUNDUM HOPPERS

NOTE & LEGEND
 1 - - - - - INDICATES EXISTING EQUIPMENT
 2 - - - - - INDICATES NEW EQUIPMENT

FIGURE 7
PRELIMINARY FLOW DIAGRAM
HTGR THORIUM-URANIUM EXTRACTION
AND PARTITION

CYCLONE

SCALE 1" = 1'-0"

MATERIAL 304 S/S

FILTER
SCALE $\frac{1}{2}$ " = 1'-0"

FIGURE 8
OFF-GAS CYCLONE AND FILTER

MATERIAL 304 S/S

FIGURE 9
OFF-GAS SCRUBBER

SCALE 1/2" = 1'-0"

FIGURE 10
 HNO_3 STRIPPER

SCALE $\frac{1}{2}" = 1'-0"$

REBOILER
70° Pt-30° Ir
HEAT EXCHANGE TUBES

EVAPORATOR

CONDENSER

MATERIAL 304 S/S

FIGURE 11
THORIUM EVAPORATOR

SCALE $1/2'' = 1'-0''$

FIGURE 12
PROJECTED PRODUCTION REQUIREMENTS