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HTGR FUEL RECYCLE DEVELOPMENT PROGRAM

QUARTERLY PROGRESS REPORT
FOR THE PERIOD ENDING MAY 31, 1978

Prepared under
Contract EY-76-C-03-0167
Project Agreement No. 53
for the San Francisco Operations Office
Department of Energy

DATE PUBLISHED: JUNE 1978

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GENERAL ATOMIC COMPANY

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ABSTRACT

This publication continues the quarterly series presenting results of work performed under the National HTGR Fuel Recycle Development Program at General Atomic Company. Results of work on this program prior to June 1974 were included in a quarterly series on the HTGR Base Program.

The work reported includes the development of unit processes and equipment for reprocessing of High-Temperature Gas-Cooled Reactor (HTGR) fuel, the design and development of an integrated pilot line to demonstrate the head end of HTGR reprocessing using unirradiated fuel materials, and design work in support of Hot Engineering Tests (HET). Work is also described on trade-off studies concerning the required design of facilities and equipment for the large-scale recycle of HTGR fuels in order to guide the development activities for HTGR fuel recycle.

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INTRODUCTION

This report covers the work performed by General Atomic Company under Department of Energy Contract EY-76-C-03-0167, Project Agreement No. 53. The work done under this project agreement is part of the program for development of recycle technology for High-Temperature Gas-Cooled Reactor (HTGR) fuels described in the National Program Plan for HTGR Fuel Recycle Development (GCR-76/19).

The objective of the program is to provide the technology development necessary for the recycle of HTGR fuels. The design of an HTGR recycle reference facility including equipment design and operating procedures which are licensable and commercially feasible for the reprocessing and refabrication of spent fuel will be done. Work at General Atomic Company is concentrating on the following National Program tasks: Program Management (Task 000); Studies and Analyses (Task 100); Fuel Handling Task 200); Fuel Reprocessing (Task 300); Fuel Refabrication (Task 500); In-Plant Waste Treatment (Task 600); General Support (Task 800); Major Facilities (Task 900).

Task 000, Program Management. The functions of this task include overall planning, scheduling, budgeting, reporting, management control of the program, and coordination of activities.

Task 100, Studies and Analyses. The purpose of this task is to perform generic studies and analyses in support of the program's developmental tasks and Task 900 projects. The work will include analyses of reactor mass flow and fuel cycle flowsheets; environmental studies and analyses in support of the major facility projects; economic/cost-benefit studies in support of commercialization activities and guidelines to facility design

and developmental tasks; and system integration and design studies to establish equipment availability and maintainability requirements, surge storage, and system-interface design requirements.

Task 200, Fuel Handling. The purpose of this task is to develop the fuel handling and shipping technology that will be needed for the HTGR Recycle Reference Facility (HRRF).

Task 300, Fuel Reprocessing. The purpose of this task is to develop the reprocessing technology required for HRRF. The work will include the development of components and the definition of operating techniques and remote maintenance and/or disassembly techniques. Operations that must be developed include: (1) crushing of the fuel elements, (2) solids transport methods, (3) burning the graphite in a fluidized bed burner, (4) separation of the fertile and fissile particles, (5) crushing the silicon carbide coating on fissile particles, (6) burning the crushed particles, (7) dissolution of thorium, plutonium, and uranium in the burner ash, (8) separation of the undissolved solids (silicon carbide hulls, etc.) from the leachate, (9) separation of the thorium, uranium, and plutonium from the fission products and from each other by solvent extraction, (10) process and facility off-gas treatments to ensure that releases are environmentally acceptable and in compliance with regulations, and (11) the primary treatment of solid, liquid, and gaseous wastes from the process, including recycle of nitric acid and water. Task 300 will also develop the processes and equipment required for thorium storage and management.

Task 500, Fuel Refabrication. The purpose of this task is to develop the refabrication technology that will be needed for HRRF. The work will include the definition of flowsheets, the development of components, the definition of operating techniques, and remote maintenance and/or disassembly techniques. Operations that must be developed include: (1) preparation of uranyl nitrate solution for loading, (2) loading of the uranium onto weak-acid resin particles, (3) carbonization of the loaded resin particles, (4) conversion of these particles to adjust the oxygen

content, (5) application of the buffer, inner low-temperature isotropic, silicon carbide, and outer low-temperature isotropic coatings, (6) blending of the fissile particles with fertile and shim particles, (7) molding the blended particles into fuel rods with the pitch-graphite matrix. (8) loading the rods into fuel elements, (9) carbonizing and annealing the fuel rods in the element, (10) installing end plugs and dowels, and (11) cleaning and inspecting the completed element.

Task 600, In-Plant Waste Treatment. The work to be done by this task will ensure that all radioactive waste from HRRF can be suitably processed and packaged for safe shipment and permanent storage. Where the anticipated HRRF wastes are not suitable for processing by the other waste processes, Task 600 will conduct the necessary research and development to either establish complete treatment or render these wastes suitable for processing by the developed techniques of the other programs.

Task 800, General Support. This task includes the development work required for general plant support functions. This work covers safeguard applications, maintenance systems, and in-plant waste treatment.

Task 900, Major Facilities. The purpose of this task is to design, construct, proof-test, and operate hot engineering and cold prototype test facilities that culminate in the detailed design of an HRRF. These facilities include the Hot Engineering Test Facility (HETF). Hot Engineering Test Waste Facility (HETWF), Cold Prototype Test Facility-Reprocessing (CPTF-Repro), Cold Prototype Test Facility-Refabrication, and Cold Prototype Test Facility-Fuel Handling (CPTF-Fuel Handling). The preconceptual design and early conceptual design of HRRF will guide the development work for reprocessing, refabrication, and waste treatment processes, equipment, and instrumentation for process control of recycle operations.

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1. SUMMARY

Generic studies and analyses are being performed to support the HTGR Fuel Recycle Development Program's developmental tasks and Task 900 projects. A reprocessing criticality study is being performed to determine physical constraints on the primary burner, solids hoppers, and other sensitive head-end process equipment. A reference MEU fuel cycle has been defined for preliminary HRRF feasibility studies, and spent fuel element compositions have been calculated to provide basic data for preparation of HRRF flowsheets and material balances, and source terms for shielding and thermal analyses. Spent fuel management studies will be carried out to evaluate alternative means of handling spent MEU fuel from HTGRs, and trade-off and optimization studies are being performed to assess development program cost-effectiveness.

A computer code is being developed to simulate reprocessing operating modes; it will be used to determine system availability allocations, surge storage requirements, and equipment configurations based on maintainability and reliability characteristics.

Maintainability and reliability data have been developed for the dry head-end and wet head-end systems, and will be developed for solvent extraction process equipment.

A conceptual design cost estimate for the Target Recycle Plant (TRP), which has a 50,000 spent fuel element commercial reprocessing capacity, is being updated to current costs and will include design modifications incorporated in the RAMCO HTGR commercialization study. This computerized cost data base will be used for nonproliferation and economic/cost-benefit studies.

A nonproliferation assessment of thorium fuel cycles is continuing with evaluations of priority covert and covert/overt fuel cycle cases. LMFBR, HWR, HTGR, and PWR priority uranium-thorium cases have been completed.

Primary and secondary crushing forces and UNIFRAME vibrations were measured while crushing scrap graphite and unfueled and fueled HTGR elements. Samples of the crushed material from these tests were analyzed for product size distribution, fuel particle breakage, and uranium and thorium content. Data from these tests will be used to evaluate sampling techniques, to evaluate tertiary product as burner feed material, and to establish design criteria for the HTGR fuel reference reprocessing facility (HRRF).

A 48-hour burning test using the 0.20-m (8-in.) primary burner was completed 3 months ahead of schedule. This test verified the feasibility of the reference HRRF primary burner operating cycle using a gravity fines recycle system and TRISO/BISO fresh feed mixture.

Burning rates averaged over 200 g/min, which is the design rate for that burner. Fines recycle and burning proceeded smoothly with no bridging or plugging of lines noted. Temperatures were readily controlled using all four cooling air jackets. A flange on the upper burner exit had to be tightened twice during the run to prevent loss of containment; this is a gasket problem that is now being evaluated. Burner product contains 0.1 wt % carbon, which is below the 2 wt % allowable level.

Other activities affecting the 0.20-m primary burner included installation and use of a fines sampler, completion of a comprehensive training program by four operators, upgrading of fines rotary valve seals, and reduction of plenum material backflow by altering the distributor hole pattern.

Work is well underway on modifying the 0.40-m (16-in.) primary burner to a gravity fines recycle configuration. A mid-reactor feed and fine entry penetration has been installed.

Analytical results from the previous quarterly's classification tests were completed. Calculations based on these results indicate the effects of secondary classification of FSV TRISO/TRISO fuel particles, the effect of lower gas flows on removal of broken BISO particles during classification of LHTGR TRISO/BISO fuel particles, and the distribution of graphite from classification of LHTGR TRISO/BISO fuel particles containing unburned graphite.

Classified particles containing unburned graphite were crushed in the particle crusher, and the effects of graphite on the crushing operation were determined.

The ability of the particle crusher to crush agglomerated particles from primary burner product was tested.

Apparatus for studying the parameters for combustion of perchloroethylene distillation bottoms has been constructed.

A series of 300 separate tests on the effect of conveying line geometry on material transport properties were conducted. The data are presently being evaluated.

The transport control affected by recent modifications has been checked out, and the total control philosophy is being reviewed and updated.

Calibration of process vessels for the 0.50-m (20-in.) dissolver-centrifuge system has been completed. Initial shakedown of the equipment using water as the simulated feed was completed. The equipment performed satisfactorily throughout the shakedown testing.

Modifications were made to the 0.13-m (5-in.) dissolver system in preparation for iodine and ruthenium volatility studies using radioactive tracers. Preliminary results from initial iodine volatility tests reveal that greater than 98% of the total iodine charged to the dissolver was vaporized into the overheads. Complete data reduction is underway and the final results will be reported in the next quarterly progress report.

Drying tests on insols containing residual salts were completed on February 28, 1978, meeting the 189 milestone. One water rinse of about 30 wt % SiC slurry is sufficient to reduce the thorium content in the insols to a safe level for smooth fluidized bed drying. Since the use of steam jet transfer planned for the engineering-scale repulp operation requires a more dilute slurry (about 10 wt %), the planned repulp volume for the 0.50-m dissolver-centrifuge system will encounter no drying problem. The dryer can tolerate up to about 0.3 wt % of residual thorium content in the dried SiC hulls without excessive agglomeration and caking.

A conical distributor appears to work as well as a flat distributor for drying insols, but with the added advantage of simplicity and the potential for combining repulping and drying in one vessel. It is recommended that a new conical distributor, equipped with a bottom product removal valve, be tested.

An overall procurement and installation schedule has been developed that will constantly be updated to keep track of all activities. The detailed design of the engineering-scale off-gas system, including all the adsorption and catalytic reaction vessels and the CO/HT oxidizer, has been completed as scheduled. The fabrication of the vessels and CO oxidizer is in progress. Purchase requisitions for all the heat exchangers, heaters, controllers, recorders, meters, piping, and corresponding fittings have been sent out.

A preliminary hazard analysis and a fault tree analysis were completed for the burner off-gas and dissolver off-gas pilot plant.

One solvent extraction run made last quarter is reported herein. The modified Purex process demonstrated for fissile particle uranium recovery gave satisfactory operational performance even with exaggerated amounts of DBP added to the first cycle system.

The detailed design effort on the nitric acid fractionator has been postponed indefinitely for budgetary reasons. The corrosion tests underway to aid in determination of materials of construction for the acid fractionator will be completed.

All assigned sections to the Conceptual Design Report (CDR) Addenda II document for MEU fuel reprocessing were completed. The compiled document, prepared by Ralph M. Parsons Co., was reviewed and comments were transmitted to UCC-ND to be incorporated into the DOE/UCC-ND approved document.

The input sections for all assigned parts of the reprocessing system design requirement review documents were completed and forwarded to the HET project leader's office.

Updated MEU fuel recycle reprocessing flowsheets were issued, and preparation of the HRRF-Reprocessing head-end material balance was completed. All deliverable end items under the RMPCo subcontract to update the TRP cost data base are on schedule. Breakdown of piping, electrical, and instrumentation costs to the system level is in progress. Work continued on the HRRF remote maintenance systems activity to develop a remote maintenance philosophy and concept for the HRRF-Reprocessing facility. Requirements for integrated remote maintenance handling and support equipment and facilities were established. An engineering support study subcontract was let to Norman Engineering Company to assist GA in the design development of HRRF-Reprocessing head-end remote maintenance equipment systems and facilities.

Several previously proposed spent fuel storage concepts were reviewed for applicability to the HRRF Feasibility Study. Review of the present

HTGR spent fuel storage facility design integral to a reprocessing plant identified several potential design improvements. A major design issue is the choice between water- and air-cooled storage. Information derived from revised ORNL (K. H. Lin) waste treatment system flowsheets is being integrated into a GA update of reprocessing waste treatment process flowsheets that are sufficiently detailed for application to TRP data base/HRRF system allocation cost studies.

2. STUDIES AND ANALYSES (TASK 100)

2.1. SUMMARY

Generic studies and analyses are being performed to support the HTGR Fuel Recycle Development Program's developmental tasks and Task 900 projects. A reprocessing criticality study is being performed to determine physical constraints on the primary burner, solids hoppers, and other sensitive head-end process equipment. A reference MEU fuel cycle has been defined for preliminary HRRF feasibility studies, and spent fuel element compositions have been calculated to provide basic data for preparation of HRRF flowsheets and material balances, and source terms for shielding and thermal analyses. Spent fuel management studies will be carried out to evaluate alternative means of handling spent MEU fuel from HTGRs, and trade-off and optimization studies are being performed to assess development program cost-effectiveness.

Maintainability and reliability data have been developed for the dry head-end and wet head-end systems, and will be developed for solvent extraction process equipment. A computer code is being developed to simulate reprocessing operating modes; it will be used to determine system availability allocations, surge storage requirements, and equipment configurations based on maintainability and reliability characteristics.

A conceptual design cost estimate for the Target Recycle Plant (TRP), which has a 50,000 spent fuel element commercial reprocessing capacity, is being updated to current costs and will include design modifications incorporated in the RAMCO HTGR commercialization study. Support is being provided by Ralph M. Parsons Co. under contract to ORO. This computerized cost data base will be used for nonproliferation and economic/cost-benefit studies.

A nonproliferation assessment of thorium fuel cycles is continuing with evaluations of priority covert and covert/overt fuel cycle cases. LMFBR, HWR, HTGR, and PWR priority uranium-thorium cases have been completed.

2.2. ENGINEERING ANALYSES (SUBTASK 110)

2.2.1. Introduction

The objective of this subtask is to perform generic engineering analyses to support developmental tasks and the projects. Results of studies on criticality, spent fuel definition, spent fuel management strategy, and availability allocations are reported in the following sections.

2.2.2. Activity

2.2.2.1. Criticality. Activity in this area was curtailed somewhat during the past quarter in order to complete the fuel element definitions. However, the following progress can be reported.

During the course of debugging the GA version of KENO-IV, nine validation cases were examined. They are summarized in Table 2.2-1. In each instance, the 16-group Hansen-Roach cross section library was employed. Particular attention should be focused on cases 1, 3, 4, and 5 since they are the results of actual critical experiments. The remaining cases were included to compare KENO-IV with other codes and computational techniques. Although this comparison does show some discrepancies (especially in case 2), there is currently insufficient empirical evidence to discern whether there is an error in KENO-IV or the published data. (Discussions pertaining to the need for future critical experiments can be found in Refs. 2.2-1 and 2.2-2.)

Substantial progress has also been achieved in the development of nuclear criticality safety criteria for HRRF reprocessing. The central concept in these criteria is that of a nuclear system. A nuclear system is defined as a set of components that possess the following two properties:

TABLE 2.2-1
KENO-IV VALIDATION STUDY

Case No.	Fissile Nuclide	H/X ^(a)	C/X ^(b)	Enrichment (%)	Core Shape	Reflector	Reference	k ± σ
1	U-233	0	0	100	Sphere	1.59 mm SS ^(c)	TID-7028, p. 42	1.000 ± 0.013
2	U-233	10	0	100	Sphere	305 mm H ₂ O	Ibid	0.961 ± 0.011
3	U-233	100	0	100	Sphere	305 mm H ₂ O	Ibid	1.036 ± 0.012
4	U-233	1000	0	100	Sphere	1.59 mm SS ^(c)	Ibid	1.078 ± 0.008
5	U-235	0	0	93.5	Sphere	50.8 mm Ni	TID-7028, p. 56	0.987 ± 0.008
6	U-235	0	157.04	93.5	Sphere	203 mm H ₂ O	LAMS-2955, p. 14	0.973 ± 0.010
7	U-235	466.7	157.04	93.5	Sphere	203 mm H ₂ O	Ibid	1.005 ± 0.010
8	U-235	1300	77.46	93.5	Sphere	203 mm H ₂ O	LAMS-2955, p. 15	0.999 ± 0.008
9	U-235	47.0	1271.2	93.5	Infinite cylinder	203 mm H ₂ O	LAMS-2955, p. 25	0.999 ± 0.011

(a) H/X is the hydrogen to fissile isotope atomic ratio.

(b) C/X is the atomic ratio of carbon to the fissile isotope.

(c) SS denotes type 304 stainless steel.

1. Each component in the set interacts neutronically with at least one other component in the set.
2. No component in the set interacts neutronically with any component outside of the set.

Then, in order for the reprocessing segment of the HRRF to be safe, it is necessary for each nuclear reprocessing system to satisfy the double contingency principle. This principle dictates that process designs shall incorporate sufficient safety factors to require at least two unlikely, independent, and concurrent changes in process conditions before a nuclear incident is possible.

Such a seemingly innocuous statement actually entails some rather sophisticated considerations. First, it is necessary to classify changes in process conditions as being incredible, unlikely, or anticipated. Of those changes which are unlikely, it must next be determined which are independent and which could result from a common accident mode. (Preliminary investigations into these areas, from the perspective of head-end reprocessing, were completed in conjunction with the system familiarization.) Then a single, unlikely change in process conditions is assumed to occur. A parametric study is performed to discern the nuclear response of the system to this change, along with any dependent changes and all anticipated changes. This step is repeated until all unlikely changes have been analyzed. Upon completion of these studies, the most reactive credible condition or conditions to which the system can be subjected are identified. If the system then possesses a sufficient safety factor, it can be deemed safe. The following HRRF reprocessing safety factors, synthesized from Refs. 2.2-3 and 2.2-4, are recommended:

1. When a criticality constraint is based upon the calculation of the neutron multiplication factor (k), the multiplication factor shall satisfy the relation:

$$k + 2\sigma - \Delta k \leq 0.97 \quad .$$

Here σ , the standard deviation for Monte Carlo codes, has an assigned value of zero when diffusion or transport theory computations are performed. Also, Δk is the maximum negative bias obtained from code validations for systems with a similar geometry and material content (i.e., $k_{\text{calculated}} - k_{\text{experimental}}$). If a code is found to have only a positive bias (i.e., $\Delta k > 0$), then Δk will be assigned a value of zero.

2. The thickness of a slab shall not exceed 85% of the known critical thickness.
3. The diameter of a cylinder shall not exceed 90% of the known critical diameter.
4. Constraints based upon the volume of a component shall not exceed 75% of the known critical volume.
5. The concentration of fissile material shall not exceed 85% of the known critical concentration.
6. The mass of the fissile material shall not exceed 90% of the known critical mass.
7. At least one of the above safety factors shall be in effect for the system under the most reactive credible condition or conditions.

Four key issues now merit elaboration. First, the most reactive credible condition (or conditions) for a system is that for which the actual safety factor is the lowest (e.g., that for which k is the highest or the fissile material mass comes the closest to the critical value). Hence, in order to demonstrate that a sufficient safety factor is present under that condition, it will generally be necessary to show that one is present under all credible conditions.

Second, the present criticality evaluation is addressing only isolated head-end components. This is currently adequate since the safety of individual components is a necessary condition for system safety (although it is not a sufficient condition). Nevertheless, some means of accounting for neutron interaction should be incorporated into this analysis if the results are to be meaningful. Based upon a recommendation proposed in Ref. 2.2-5, this will be accomplished by hypothesizing that, at least to a first order approximation, the reactivity of a component fully reflected by water will be less than or comparable to its reactivity in the presence of other process units.

Third, it was previously indicated that KENO-IV could not be formally validated because of an insufficiency of data from critical experiments. Consequently, it is presently impossible to fully comply with the safety factor pertaining to code calculations. However, the results of investigations cited in Ref. 2.2-1 strongly indicate that the maximum negative bias inherent in both the ENDF/B-IV and Hansen-Roach libraries is -0.04 for U-233 moderated with water. Although there is no hard evidence to either support or contradict such a contention, it will also be assumed that Δk is approximately -0.04 for fissile systems containing a carbonaceous moderator. Hence, until adequate empirical results become available, the following interim safety factor is also recommended:

- When a criticality constraint is based upon the calculation of the neutron multiplication factor by an accepted code employing either ENDF/B-IV or Hansen-Roach cross sections, and no direct validation is possible, the multiplication factor shall satisfy the relation:

$$k + 2\sigma \leq 0.93,$$

(i.e., $\Delta k = 0.04$).

Fourth, at the present stage of HRRF design development it is premature to assess the reliability and accuracy of proposed assay techniques and process monitoring instruments with any degree of certitude. Hence, whether the above safety factors contain an adequate margin to allow for the uncertainties inherent in such process measurements cannot currently be determined. As the state of the facility design progresses, it is imperative that this matter be periodically evaluated and, if necessary, the appropriate safety factors be revised accordingly.

2.2.2.2. Fuel element Definitions. The draft of the report "LHTGR MEU Spent Fuel Element Definition and Block Flows" has been completed and is currently undergoing internal review. Tables 2.2-2 through 2.2-5 summarize the equilibrium fuel elements as they are charged to the reactor core and at 180 days after discharge. Supplemental characteristics of equilibrium fuel appear in Table 2.2-6.

Emphasis is now being directed towards modifying both the FEVER and FRED codes in order to increase their analytical flexibility. In addition, an independent verification of the accuracy of these codes is being conducted.

2.2.2.3. Spent Fuel Management Strategy

2.2.2.3.1. Introduction. During this quarter, efforts were focused on the development of a methodology for carrying out the National Program Plan trade-off and optimization study described in Ref. 2.2-2. In addition, criteria for assessing the merits of each alternative case to be evaluated were defined. Finally, work started on the definition of the technical issues that must be resolved prior to HRRF licensing by any feasible HTGR fuel recycle program.

2.2.2.3.2. Activity. The methodology to be used for this study is shown schematically in Fig. 2.2-1. It employs techniques of cost analysis, risk analysis, and value engineering. The specific steps taken to

TABLE 2.2-2
EQUILIBRIUM M FUEL ELEMENT SUMMARY
(Core Averaged - As Charged)

Component	Mass (kg/FE)
Fissile particles ($\rho = 2.64 \text{ g/cm}^3$)	11.42
Outer PyC coating	2.35
SiC coating (1.85 kg Si)	2.64
Inner PyC coating	1.24
Buffer coating	1.22
Kernel (UCO; $\rho = 10.6 \text{ g/cm}^3$)	3.97
Total U (kernel)	3.55
<div style="display: inline-block; vertical-align: middle;"> $\left\{ \begin{array}{l} 80.2\% \text{ U-238} \\ 19.8\% \text{ U-235} \end{array} \right\}$ by mass </div>	
Total C (kernel)	0.18
Total O (kernel)	0.24
Fertile particles ($\rho = 3.44 \text{ g/cm}^3$)	9.00
Outer PyC coating	2.25
Buffer coating	0.87
Kernel (ThO_2 ; $\rho = 9.9 \text{ g/cm}^3$)	5.88
Total Th (kernel)	5.16
Total O (kernel)	0.72
Graphite block (includes plugs, dowels, matrix, and shim)	97.52
Boron	0.01
Total mass	117.95

TABLE 2.2-3
EQUILIBRIUM 23R FUEL ELEMENT SUMMARY
(Core Averaged - As Charged)

Component	Mass (kg/FE)
Fissile particles ($\rho = 2.16 \text{ g/cm}^3$)	3.96
Outer PyC coating	1.00
SiC coating (0.86 kg Si)	1.23
Inner PyC coating	0.56
Buffer coating	0.38
Kernel (WAR UCO; $\rho = 3.3 \text{ g/cm}^3$)	0.79
Total U (kernel)	0.70
$\left(\begin{array}{l} 4.2\% \text{ U-236} \\ 7.9\% \text{ U-235} \\ 22.9\% \text{ U-234} \\ 65.0\% \text{ U-233} \\ \text{by mass} \end{array} \right)$	
Total C (kernel)	0.04
Total O (kernel)	0.05
Fertile particles ($\rho = 3.44 \text{ g/cm}^3$)	9.00
Outer PyC coating	2.25
Buffer coating	0.87
Kernel (ThO_2 ; $\rho = 9.9 \text{ g/cm}^3$)	5.88
Total Th (kernel)	5.16
Total O (kernel)	0.72
Graphite block (includes plugs, dowels, matrix, and shim)	100.93
Boron	0.01
Total mass	113.90

TABLE 2.2-4
EQUILIBRIUM MS FUEL ELEMENT SUMMARY
(Core Averaged - 180 Days After Discharge)

Component	Mass (kg/FE)
Fissile particles ($\rho \approx 2.64 \text{ g/cm}^3$)	10.38
Outer PyC coating	2.35
SiC coating (1.85 kg Si)	2.64
Inner PyC coating	1.24
Buffer coating	1.22
Kernel (UCO; $\rho \approx 10.6 \text{ g/cm}^3$)	2.93
Total U (kernel)	1.85
$\left\{ \begin{array}{l} 3.9\% \text{ U-235} \\ 3.5\% \text{ U-236} \\ 92.6\% \text{ U-238} \end{array} \right\}$ by mass	
Total C (kernel)	0.18
Total O (kernel)	0.24
Other fission and activation products (fissile particle)	0.66
Fertile particles ($\rho \approx 3.44 \text{ g/cm}^3$)	7.28
Outer PyC coating	2.25
Buffer coating	0.87
Kernel (ThO_2 ; $\rho \approx 9.9 \text{ g/cm}^3$)	4.16
Total Th (kernel)	3.22
Total U (kernel)	0.11
$\left\{ \begin{array}{l} <0.1\% \text{ U-232} \\ 83.0\% \text{ U-233} \\ 14.2\% \text{ U-234} \\ 2.5\% \text{ U-235} \\ 0.3\% \text{ U-236} \end{array} \right\}$ by mass	
Total O (kernel)	0.72
Other fission and activation products (fertile particle)	0.11
Graphite block (includes plugs, dowels, matrix, and shim)	97.52
Boron	0.002
Total mass	115.18

TABLE 2.2-5
EQUILIBRIUM 23RS FUEL ELEMENT SUMMARY
(Core Averaged - 180 Days After Discharge)

Component	Mass (kg/FE)
Fissile particles ($\rho \approx 2.16 \text{ g/cm}^3$)	3.50
Outer PyC coating	1.00
SiC coating (0.86 kg Si)	1.23
Inner PyC coating	0.56
Buffer coating	0.38
Kernel (WAR UCO; $\rho \approx 3.3 \text{ g/cm}^3$)	0.33
Total U (kernel)	0.09
$\left(\begin{array}{l} 0.1\% \text{ U-232} \\ 20.2\% \text{ U-233} \\ 44.4\% \text{ U-234} \\ 19.5\% \text{ U-235} \\ 15.8\% \text{ U-236} \\ \text{by mass} \end{array} \right)$	
Total C (kernel)	0.04
Total O (kernel)	0.05
Other fission and activation products (fissile particle)	0.15
Fertile particles ($\rho \approx 3.44 \text{ g/cm}^3$)	5.62
Outer PyC coating	2.25
Buffer coating	0.87
Kernel (ThO_2 ; $\rho \approx 9.9 \text{ g/cm}^3$)	2.50
Total Th (kernel)	1.66
Total U (kernel)	0.06
$\left(\begin{array}{l} <0.1\% \text{ U-232} \\ 83.0\% \text{ U-233} \\ 14.2\% \text{ U-234} \\ 2.5\% \text{ U-235} \\ 0.3\% \text{ U-236} \\ \text{by mass} \end{array} \right)$	
Total O (kernel)	0.72
Other fission and activation products (fertile particle)	0.06
Graphite block (includes plugs, dowels, matrix, and shim)	100.93
Boron	0.002
Total mass	110.05

TABLE 2.2-6
SUPPLEMENTAL EQUILIBRIUM FUEL CHARACTERISTICS

				<u>g/cm³</u>
Makeup Fissile				
Kernel (UCO) diameter	350	μm		10.6
Buffer thickness	105	μm		1.05
IPyC thickness	35	μm		1.9
SiC thickness	35	μm		3.2
OPyC thickness	45	μm		1.8
Total particle diameter	790	μm		
t/D	0.63			
Recycle Fissile				
Kernel (WAR UCO) diameter	360	μm		3.3
Buffer thickness	65	μm		1.05
IPyC thickness	35	μm		1.9
SiC thickness	35	μm		3.2
OPyC thickness	40	μm		1.8
Total particle diameter	710	μm		
t/D	0.486			
Makeup and Recycle Fertile				
Kernel (ThO ₂) diameter	500	μm		9.9
Buffer thickness	85	μm		1.05
PyC thickness	75	μm		1.90
Total particle diameter	820	μm		
t/D	0.195			

NOTE: At fuel cycle equilibrium, the fuel particle packing fractions for makeup and recycle fuel rods are assumed to be 50% and 25%, respectively.

Fig. 2.2-1. National Program Plan trade-off and optimization study

arrive at the selection of a recommended scenario for the National Program Plan (NPP) are outlined as follows:

1. The programmatic and technical objectives of the study are first formulated in conjunction with the existing National HTGR Fuel Recycle Program Plan and with GCRA commercialization plans.
2. The alternative development scenarios defined in Ref. 2.2-2 are then described, and advantages and disadvantages of each alternative case vis-à-vis the reference National Program Plan are noted. The impact of other R&D programs, such as the FRG Jupiter program, on these scenarios is also described.
3. Next, criteria are defined to judge the feasibility of each alternative scenario. These criteria involve
 - a. Program and technical objectives
 - b. Safety and environmental issues
 - c. HRRF licensing
 - d. Development program personnel training
 - e. Development facility requirements
 - f. Program management
4. Technical issues relative to the design, construction, installation, and hot operation of the HRRF are then identified for resolution during the course of the development program.
5. Now each scenario is evaluated against the assessment criteria (item 3, above) to determine if it adequately provides for resolution of those key technical issues that influence the licensing of the HRRF.

6. After this initial screening, a value engineering analysis of the remaining scenarios is undertaken. This analysis also takes into account the total cost of each scenario. The cost estimates are developed, in part, simultaneously with the initial screening assessment of the original group of scenarios.

The value engineering analysis develops a numerical ratio (value index) for each scenario that reflects a quantitative analog of its merits (numerator) and its total cost (denominator). Those scenarios with the highest value index are the preferred scenarios and are evaluated further.

7. An analysis of cost risks associated with each of the preferred scenarios is then developed based on probabilistic techniques. These uncertainties include development program cost, HRRF capital cost, and recycle fuel element (product) cost.
8. The results of both the value engineering analysis and the analysis of cost risks are then combined with considerations of possible impact of the scenario on HTGR and fuel cycle economics in order to select the most preferred scenario.
9. Finally, specific recommendations to revise the existing National HTGR Fuel Recycle Program Plan are made based on the conclusions of the preceding scenario evaluation (item 8, above).

2.2.2.4. Availability Allocations. Assistance in developing availability calculation methodology and failure mode and effects analysis procedures has been obtained from the Reactor Safety Branch. Failure mode analysis and time-to-repair data for wet and dry head-end systems has been recalculated in a format suitable for statistical analysis. Data previously published in Ref. 2.2-6 has been regenerated to show 5th and 95th percentile, median, mean, uncertainty factor, variance, and standard deviation values. The data tables will be republished as an appendix to the availability allocation interim report due to be completed July 1, 1978.

An outline for the report has been prepared. It will cover:

1. Failure modes and effects analysis procedures
2. Qualifications on the present reliability and maintainability data
3. Identification of additional reliability and maintainability data requirements
4. Possible sources of additional data
5. Identification of additional down time contributors
6. Development program recommendations

REFERENCES

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- 2.2-4. "Barnwell Nuclear Fuel Plant Separations Facility Final Safety Analysis Report Vol. IV," Docket No. 50-332, Amendment No. 8, Allied-General Nuclear Services, April 1976.
- 2.2-5. "HTGR Recycle Demonstration Facility Preliminary Safety Analysis Report (Partial)," Allied Chemical Company, May 1976.
- 2.2-6. Rode, J., and J. Strand, "A Preliminary Maintainability Analysis of the HTGR Dry Head-End Reprocessing Systems," DOE Report GA-A14678, General Atomic Company, November 1977.

2.3. ECONOMIC/COST-BENEFIT STUDIES (SUBTASK 130)

2.3.1. Introduction

A conceptual design and cost estimate for the Target Recycle Plant was developed jointly by General Atomic and the R. M. Parsons Co. (RMPCo) in 1975. This cost estimate was stored on a Tymshare data base (RCYCLE) having the capability to report costs in a number of ways useful for cost-benefit and nonproliferation cost studies. This task includes reactivating the data base and updating the costs and plant design to current status (for backup HEU fuel).

2.3.2. Activity

The assistance of RMPCo was obtained for this activity through a contract with ORO. RMPCo has provided the following:

1. Piping and instrumentation diagrams, equipment lists, layouts, and costs for design additions, including
 - a. Glassification of calcined high-level wastes.
 - b. Solidification of recovered thorium.
 - c. Fixation of carbon dioxide containing C-14.
2. Identification of quality assurance levels for all hardware items in the plant. Previous cost increment information applicable to the identified quality levels for specific types of equipment will be added to the cost data.
3. Recommendations for updating costs from 1975 dollars include:
 - a. Material escalation factors as shown in Table 2.3-1.
Comparison with national indices is also shown. RMPCo data are being used as they reflect their actual experience.

TABLE 2.3-1
 ESCALATION RATES FOR A TYPICAL PARSONS PROJECT -
 ESCALATION, JUNE 1975 TO JUNE 1977

Index ^(a)	Title	Equivalent National Index Change
WPI-11-4	General purpose machinery and equipment Escalation multiplier = $\frac{\text{May 1977}}{\text{June 1975}} = \frac{161.0}{142.7} = 1.128$	1.131
WPI-11-7	Electrical machinery and equipment Escalation multiplier = $\frac{\text{May 1977}}{\text{June 1975}} = \frac{214.8}{193.3} = 1.111$	1.09
WPI-06	Chemicals and allied products Escalation multiplier = $\frac{\text{May 1977}}{\text{June 1975}} = \frac{142.1}{130.4} = 1.09$	1.07
WPI-1072	Metal tanks Escalation multiplier = $\frac{\text{May 1977}}{\text{June 1975}} = \frac{225.7}{194.8} = 1.159$	1.101
WPI-1061	Steam and hot water equipment Escalation multiplier = $\frac{\text{May 1977}}{\text{June 1975}} = \frac{186.3}{167.9} = 1.110$	1.127
WPI-1166-04	Chemical industry machinery Escalation multiplier = $\frac{\text{May 1977}}{\text{June 1975}} = \frac{194.1}{170.6} = 1.138$	1.127
AHE SIC 28 ^(b)	Labor-petroleum and atomic industries Escalation multiplier = $\frac{\text{May 1977}}{\text{June 1975}} = \frac{154.4}{129.4} = 1.193$	1.189
Handy Whitman Southeast Atlantic	Reinforced concrete construction Escalation multiplier = $\frac{\text{May 1977}}{\text{June 1975}} = \frac{180.6}{165.9} = 1.089$	1.04

(a) Wage-price index.

(b) Average hourly earnings in standard industrial classification.

- b. Labor rates and productivity factors as shown in Table 2.3-2. Similar information for 1978 has been provided but will not be applied until material escalation indices for 1978 are available.

RMPCo had previously updated the Target Recycle Plant to a high-gain, high-enriched uranium fuel basis for the RAMCO studies (Ref. 2.3-1). The RAMCO update has been reviewed for application to the current activity. The resulting major unit equipment list and throughput basis is shown in Table 2.3-3. This list correlates with cost estimate reports available from the data base and can be used for extrapolating costs to other designs.

Additional activity during the quarter included:

1. Reviewing reprocessing, refabrication, and waste handling flowsheets to identify required design and cost updates.
2. Reviewing the building design and layout to reflect updated equipment lists.
3. Updating three-point estimates included in the data base, and modifying all report generators to show the calculated mean material and labor cost. A new report generator showing low, most likely, high, and mean material and labor costs for major plant systems was developed. All report generators have also been modified to reflect the system allocation to functional areas developed for HRRF (Ref. 2.3-2).
4. The GA Cost Development Department is reviewing the TRP piping and instrumentation diagrams for reassignment of costs to functional areas.

TABLE 2.3-2
COMPOSITE CRAFT LABOR RATES BY CENTURY ACCOUNT
(Eastern Tennessee Base)

Account No.	Name	Crew Composite Rate (\$/h)
0100	Power generators and drivers	16.87
0200	Electrical equipment	17.73
0300	Monitoring equipment	16.01
0400	Production assembly equipment	17.11
0500	Process feeders	16.82
0600	Control panels and computers	17.74
0700	Nuclear fuel handling equipment	16.26
0800	Packaged plants	0.0
0900	Samplers and analyzers	16.01
1000	Hoists, cranes, and other manipulators	16.26
1100	Columns, extraction, sorption	16.26
1200	Vessels (pressure)	19.87
1300	Heat exchangers, condensers, chillers	17.14
1400	Furnaces, heaters, burners, stacks, coaters	19.43
1500	Pumps and drivers	16.82
1600	Boilers	17.91
1700	Cooling towers	13.10
1800	Compressors and blowers	16.77
1900	Tanks	19.71
2000	Materials handling equipment	16.26
2100	Reduction equipment, mills, compactors, crushers	17.23
2200	Separation equipment, filters, demisters, etc.	17.21
2300	Concentration equipment	17.21
2400	Agitators, mixers, and blenders	17.59
2500	Reactors	19.88
2600	Feed hoppers, bins, chutes and silos	19.92
2700	Classification and screening equipment	17.05
2800	Other major equipment (specialized)	17.11

TABLE 2.3-2 (Continued)

Account No.	Name	Crew Composite Rate (\$/h)
2900	Heating, ventilating, and air-conditioning (HVAC)	19.20
3000	Rod and ball handling equipment	16.35
3100	Flotation equipment	17.63
3200	Launders and sumps	19.70
3300	Cleaning and decontamination equipment	19.40
3400	Dampers, louvers, guide vanes for HVAC	19.78
3500	Loading and unloading equipment	15.08
3600	Transfer equipment and rolling stock (wheeled)	15.97
3700	Mobile equipment	15.37
3800	Weighing, metering, and packaging equipment	16.53
3900	Maintenance shop, garage, and laboratory equipment	14.70
4000	Open	0.0
4100	Concrete work and piling	13.11
4200	Pipe, valves, and fittings - above ground	19.43
4300	Structural steel	16.33
4400	Instruments and controls	16.01
4500	Painting - protective coatings	12.80
4600	Electrical	15.66
4700	Insulation	17.32
4800	Roads, parking, paving, railroads, and fencing	13.63
4900	Building and vaults	14.54
5000	Building furniture and fixtures	14.54
5100	Large specialty structures	14.54
5200	Pipe, valves, and fittings - below ground	13.94
5300	Other civil work	13.65
5400	Analytical equipment	16.00
6100	Spare parts	17.10
6300	Site preparation	13.67

Productivity factors:

0.65 for equipment, instrumentation, electrical, and piping

0.80 for buildings, HVAC, and painting

TABLE 2.3-3
HTGR COMMERCIAL RECYCLE PLANT - UNIT OPERATION AND UNIT THROUGHPUT
(High Gain HEU Fuel)

System No.	System Description	Units	Unit Throughput
1000	Shipping, receiving and storage		
	Spent fuel handling	2 unloading areas	2 casks/day/area (rail) + 3 casks/day/area (truck)
	Spent fuel storage	2600 wells	6 FE/well
	Refab fuel handling	1 loading area	1 cask (rail)/day (2-truck)
	Refab fuel storage	1770 storage wells	5 FE/well
	Thorium storage	7 outdoor storage tanks (includes concentration equipment)	5 years, 4600 l/day, 260 days
	Solid waste storage	Storage for 2500 0.46 m x 4.57 m (18 in. x 15 ft) canisters	5 yr storage, 500 canisters/yr
2000	Maintenance	Cask/container refurbishing	700 casks, 8000 containers/yr
	Reprocessing		
	Primary crushing	2 crushers	107 FE/day/crusher
	Primary burning	6 burners	36 FE/day/burner 0.91 m (2.5 ft)
	Particle classifying	8 2-stage classifiers	733 kg part/day/classifier
	Secondary crushing	2 crushers	471 kg part/day/crusher
	Secondary burning	3 burners	314 kg part/day/burner
	Dissolution/separation	8 dissolvers	1750 l/day/dissolver (ave)
	Insols drying	4 dryers	152 kg fiss. part/day/dryer
	Accountability storage	9 tanks	1590 l/day/tank (ave)
	Solvent ex-thorex	One 3-cycle line	10,544 l/day feed
	Solvent recovery	One 2-cycle line	85,574 l/day feed
	Solvent ex-purex	One 2-cycle line	2118 l/day feed
	Product handling	12 storage tanks	412 l/day/tank (ave)

TABLE 2.3-3 (Continued)

System No.	System Description	Units	Unit Throughput
3000	Refabrication - U-233		
	Uranium feed	22 tanks	85 kg U/day, 2M
	Sphere load, dry	4 lines	22 kg U/day/line
	Kernel carbonization	9 carb lines	10 kg U/day
	Carbonization support equip		
	Kernel conversion	6 conv lines	14 kgs U/day
	Particle coating	16 coaters	6 kgs U/day/coater
	Kernel and particle storage	10 modules	1.3 tonne particles
	Particle metering and blend	12 modules	350 kg/module/day
	Fuel rod formation	3 molding units	67,832 rods/unit/day
	Fuel rod storage	920 containers	1,424,472 rods/unit/day
	Fuel rod loading	3 modules	44 FE/day/module
	Cure-in-place	6 furnaces	22 FE/day/furnace
	Final element assembly	3 lines	45 FE/day/line
	Scrap recovery		20% overall scrap factor
3000	Refabrication - U-235		
	Uranium feed	13 tanks	18 kg U/day, 2M
	Sphere load, dry	1 line	18 kg U/day/line
	Kernel carbonization	3 carb lines	9 kg U/day/line
	Kernel conversion	2 conv lines	9 kg U/day/line
	Particle coating	4 coaters	5 U/day/coater
	Kernel and particle storage	2 modules	0.2 tonne particles
	Particle metering and blend	4 modules	112 kg/module/day
	Fuel rod formation	1 unit	19,872 rods/unit/day
	Fuel rod loading	1 module	12 FE/day/module
	Cure-in-place	1 furnace	12 FE/day/furnace
	Final element assembly	1 line	12 FE/day/line

TABLE 2.3-3 (Continued)

System No.	System Description	Units	Unit Throughput
3000	Sample inspection Fuel rod inspection Fuel element inspection	5 sets 4 sets	
4000	Waste treatment Off-gas treatment Liquid waste treatment Solid waste treatment HLLW solidification ILW ^(c) treatment Waste leach Solids incineration Tritiated water Filter compactor LLW ^(d) yard Equip compacting	 Includes 2 HLLW ^(a) tanks Includes 1 ILLW ^(b) tank 1 calcining line 1 dryer 1 leacher 2 incinerators 1 line 1 compactor 55 m x 110 m (180 ft x 360 ft) paved yard with berm 1 compactor	 Refab 100 FE/day 809,990 l/tank (1 yr) 378,500 l (6 mo) 190 FE/day 190 FE/day 190 FE/day, 143 FE/day 190 FE/day, 143 FE/day 190 FE/day 190 FE/day, 143 FE/day 190 FE/day, 143 FE/day 190 FE/day, 143 FE/day

(a) High level liquid waste.

(b) Intermediate level liquid waste.

(c) Intermediate liquid waste.

(d) Low level waste.

REFERENCES

- 2.3-1. "Conceptual Cost Estimates - RAMCO HTGR Fuel Recycle Commercialization Studies," The Ralph M. Parsons Company, July 15, 1977.
- 2.3-2. "HTGR Fuel Recycle Development Program Quarterly Progress Report for the Period Ending February 28, 1978," DOE Report GA-A14878, General Atomic Company, March 1978, p. 2-13.

2.4. SYSTEMS INTEGRATION AND DESIGN STUDIES (SUBTASK 140)

2.4.1. Introduction

The objectives of these studies are to complete the development of a computer code for simulation of reprocessing operating modes, and to assist UCC-ND in the nonproliferation assessment of thorium fuel cycles. Results obtained during this reporting period are summarized in the following sections.

2.4.2. Activity

2.4.2.1. Simulation Code Development. An interim report on the work completed through March 1978 on head-end simulation (Ref. 2.4-1) has been completed. The report briefly describes the simulation methodology and provides detailed user instructions in appendices. It will serve as an interim user's manual.

Code development activity has been reduced to a very low level due to assignment of personnel to higher priority work items. The modeling completed to date is shown in Figs. 2.4-1 and 2.4-2. Each of the unit operations shown is described in an event subroutine processed by a commercial computer language package, GASP IV (Ref. 2.4-2). The relationship of the user-written event subroutines to the GASP IV simulation package is shown in Fig. 2.4-3. The simulation model incorporates reliability and maintainability data being developed under Subtask 110 (see Section 2.2.2.4). Random failures and random maintenance durations are incorporated in the flow of events, and appropriate interruptions in fuel material processing are included. The crusher end-of-service event shown in Fig. 2.4-4 illustrates the bypassing of processing when equipment is down for maintenance. Additional down-time contributions such as product hopper unavailability are also modeled as shown in Fig. 2.4-4.

ITEM: UNIFRAME CRUSHER

QUANTITY: Maximum 2

VARIABLES: NCRUSH = 1 or 2

COMMENTS: Model can be run with one or two crushers to evaluate number needed to meet availability requirements.

CRUSHER PRODUCT
RECEIVING/WEIGH HOPPER

Maximum 2
(1 per crusher)

NCRUSH = 1 or 2

0.7 m³ volume (~25% freeboard, 60% packing fraction). Each holds five fuel elements. This allows 1 hr for first of five fuel element batch to be checked for product acceptability before releasing five fuel element batch to product surge storage.

CRUSHER PRODUCT
SURGE STORAGE HOPPER

Maximum 12
(6 per crusher)

NHOP(1) = 0 to 6
NHOP(2) = 0 to 6

1.2 m³ volume (25% freeboard, 60%* packing fraction): Requires maximum of 30 deg angle with vertical for gravity flow feed from receiving/weigh hopper. Each holds eight fuel elements. Maximum considered is about one day's surge. Minimum needed will be determined from simulation study.

*60% has generally been used as a spherical particle packing fraction. It is recognized that the crushed fuel element material packing fraction could be <60%; however, to simplify fuel element burning calculations in the model as the material content changes to a high particle percent, the 60% packing factor is used here and 25% freeboard is allowed.

Fig. 2.4-1. Crushing system model

ITEM: Primary Burner Feed/Weigh Hopper

QUANTITY: 1 per Burner

VARIABLES: NBURN (1) = 2 to 6
NBURN (2) = 2 to 6

COMMENTS: 0.7 m³ volume (25% freeboard, 60% packing fraction. Five fuel element batch for initial burner feed (0.6-m burner L/D of 3 = 4.4 FE).
or,
0.3 m³ volume (25% freeboard, 60% packing fraction). Two fuel element batch for initial burner feed (0.4-m burner L/D of 3 = 1.3 FE).

ITEM: Primary Burner System

QUANTITY: Maximum 12

VARIABLES: NBURN (1) = 2 to 6
NBURN (1) = 2 to 6
BDIAM = 0.4 or 0.6
XMXLD = 5.0
XMNLD = 3.0

COMMENTS: Diameter of burners can be varied in the model. Approximately ten 0.4-m burners should handle HRRF throughput. The number can be increased to 12 if needed. Lesser numbers of 0.6-m burners will be used. Burners operate from a minimum bed height of L/D = 3 to a maximum bed height of L/D = 5 (see Appendix D, Primary Burner Operating Description). For modeling purposes primary burner discharge hoppers and the Fines recycle systems will be assumed to be an integral part of the burners.

Fig. 2.4-2. Burner model

Fig. 2.4-3. Functional flow chart of a GASP IV program

2.4.3. Nonproliferation Assessment of Thorium Fuel Cycles. Additional preliminary conceptual designs for several covert/overt and covert spent fuel metal recovery plants have been prepared for high-priority fuel cycles as part of the Nonproliferation Alternative Systems Assessment Program (NASAP). The reactor fuel cycles were:

1. An HTGR with denatured uranium/thorium (DUTh) initially enriched to 20% U-235.
2. An HTGR with high-enriched U-235 or U-233.
3. A PWR fueled with denatured uranium/thorium initially enriched to 20% U-235 or 12% U-233.

The covert/overt scenario assumes that the metal recovery plant would be built covertly but that all operations starting with diversion of spent fuel would be performed overtly. A premium is placed on minimizing the time required to produce the first 10 kg of fissile material, and the annual production capacity is 100 kg. The covert scenario assumes that construction and operations are both covert. Trickle diversion is essentially continuous, and the annual production capacity is 100 kg of fissile material. It is important that all detectable effluents be contained for covert operation, and that other detectable features and characteristics during both construction and operation be constrained.

A draft report, "Preliminary Evaluation of HTGR Alternate Fuel Cycles - Fuel Fabrication and Recycle," was prepared in collaboration with ORNL and submitted to DOE-NPD. The purpose of this report was to provide technical and economic data on fuel recycle processes and facilities for alternative HTGR fuel cycles for use in the International Nuclear Fuel Cycle Evaluation (INFCE) to determine a strategy that best meets the needs of low proliferation risk, safety and licensability, minimum environmental impact, good economics, and low uranium resource requirements.

The information in the report covers the following HTGR fuel cycles:

1. MEU/Th (20%ε), throwaway cycle
2. MEU/Th, recycle U-233, denature in process
3. MEU/Th, recycle U-233, denature in situ
4. MEU/Th, recycle all U, denature in situ
5. HEU/Th (old reference)
6. HEU (spiked)/Th
7. Pu/Th converter
8. HEU-233/Th (U-233 makeup from breeder)
9. MEU-233/Th (denatured U-233 makeup from breeder)
10. MEU/Th-HEU-233 recycle
11. 40%ε MEU/Th, recycle all U, denature in situ
12. MEU/Th, recycle all U, denature in process

REFERENCES

- 2.4-1. Holder, N., B. Haldy, and M. Jonzen, "Reprocessing System Availability Definition by Process Simulation - Interim Report on Head End Simulation," DOE Report GA-A14910, General Atomic Company, May 1978.
- 2.4-2. Pritsker, A. Alan B., The GASP IV Simulation Language, John Wiley and Sons, New York, 1974.

3. FUEL REPROCESSING (TASK 300)

3.1. FUEL ELEMENT SIZE REDUCTION (SECONDARY SUBTASK 311)

3.1.1. Summary

Primary and secondary crushing forces and UNIFRAME vibrations were measured while crushing scrap graphite and unfueled and fueled HTGR elements. Samples of the crushed material from these tests were analyzed for product size distribution, fuel particle breakage, and uranium and thorium content. Data from these tests will be used to evaluate sampling techniques, to evaluate tertiary product as burner feed material, and to establish design criteria for the HTGR fuel reference reprocessing facility (HRRF).

Selective upgrading of the UNIFRAME is continuing. An analysis of crusher component wear was initiated.

3.1.2. UNIFRAME Testing - Phase IV Tests

The Phase IV tests of the UNIFRAME were performed to determine the effectiveness of the upgrading modifications and to measure crushing stress and vibration.

3.1.2.1. Introduction. In preparation for the Phase IV tests, the UNIFRAME was upgraded to reduce product holdup, to eliminate bearing heatup, to install strain gages and load cells for measurement of crushing forces in the primary and secondary crushers, and to permit installation of a rotary feed valve at the screener hopper outlet to the transport system.

3.1.2.2. Test Objectives. The major objectives of the Phase IV tests were:

1. To verify the responses of all strain gage and load cell channels.
2. To acquire primary and secondary crushing force and vibration data.
3. To determine the start-under-load capability of the primary and secondary crushers, and to measure the associated forces.
4. To evaluate the reduction in holdup effected by the upgrading modifications.
5. To verify that bearing heatup has been eliminated.
6. To measure the size differences between tertiary product and combined screener and oversize crusher product so that the use of tertiary product as burner fuel may be evaluated.
7. To evaluate the effectivity of the feeder valve in reducing particle breakage.

3.1.2.3. Test Preparations. After completion of UNIFRAME upgrading modifications and installation of the special instrumentation required to measure primary and secondary crushing forces and UNIFRAME vibrations (see Section 3.1.2.8), the material transfer line was connected from the new feeder valve located at the bottom of the screener product hopper to the product storage bunker. The oversize crusher discharge was connected to a vacuum cleaner so that separate analysis of screener and oversize product could be accomplished in all tests except LF-810, which produced only tertiary product.

3.1.2.4. Feed Materials. The following types of materials were used as feed for the Phase IV tests:

1. Two batches of rectangular cross-sectional scrap graphite blocks.
2. Six unloaded half-length and full-length scrap graphite elements.
3. Two Fort St. Vrain (FSV) H-327 graphite control rod elements fueled with TRISO/TRISO particles.

3.1.2.5. Test Operations. The 10 Phase IV tests were performed as follows.

3.1.2.5.1. Test SG-801

This test consisted of a 10-min run at no load for equipment check-out, after which 30.8 kg (68 lb) of scrap graphite blocks were crushed for a total run duration of 35 min. There was no overheating of any of the primary or secondary pitman bearings. The graphite crushed quickly into product of normal size distribution for graphite scrap.

3.1.2.5.2. Test SG-802

This test utilized 125.7 kg (277 lb) of scrap graphite blocks to stimulate the toggle strain gage and load cell instrumentation. During this test, all strain gages did not respond. A start-under-load test of the secondary crusher was also performed. This was not successful until the feed chunks were rearranged manually several times.

3.1.2.5.3. Test SF-803

After reworking the strain gage channels external to the UNIFRAME, test SF-803 was performed by crushing an unloaded, half-length, drilled, 62.6 kg (138 lb) scrap fuel element block to stimulate the load measuring instrumentation. Improved response was observed during this test although

all channels were still not operating properly. Primary crushing took 23 s. Ninety-five percent of the secondary crushing was complete in 90 s; however, 9 min were required to complete secondary crushing. Investigation was initiated to determine the cause of the excessive secondary crushing time.

3.1.2.5.4. Test SF-804

After further checkout of strain gage instrumentation, test SF-804 was performed to measure UNIFRAME stress and vibration. This test utilized an unloaded, half-length, drilled, 64 kg (141 lb) scrap fuel element block that required 75 s for primary crushing and 27.5 min for secondary crushing. This excessive secondary crushing time was apparently the result of a decrease in the coefficient of friction. Suspected causes of this decrease were: (1) high graphite moisture content, (2) graphite coating or conditioning of the jaw surfaces, or (3) excessive resiliency in the secondary stationary jaw resulting from the load cell assembly installation. As the resiliency allows some movement of the secondary feed material at the start of a crushing stroke, sliding friction instead of static friction would hold the material in place for crushing. Since samples of the SF-804 product did not indicate high moisture, items (2) and (3) are the most likely causes of the excessive crushing times in the secondary crusher.

Because several strain gages did not respond correctly during this test, the primary and secondary pitman assemblies were subsequently removed from the UNIFRAME, the defective toggle strain gages were replaced, and duplicate strain gages were installed on all toggle plates. After response testing of all strain gages, each pitman assembly was then reinstalled in the UNIFRAME in preparation for subsequent tests.

3.1.2.5.5. Test SF-805

This test utilized a half-length, scrap, unfueled element weighing 57.6 kg (127 lb). Crushing durations were 20 s in the primary and 24.5

min in the secondary. All strain and vibration instrumentation responded correctly.

3.1.2.5.6. Test SF-806

This test was performed using a full-length, unloaded fuel element weighing 88.7 kg (195.5 lb). Crushing durations were 65 s for the primary crusher, and 13.8 min for the secondary crusher. The side-entry rod was required to clear the secondary crusher. Acceptable data were acquired from all strain and vibration channels.

3.1.2.5.7. Test SF-807

This test utilized an unloaded, full-length, scrap fuel element weighing 88.9 kg (196 lb). Normal crushing loads as well as start-under-load forces and capabilities in the secondary crusher were measured. All three restart tests attempted were successful. Crushing times were 31 s in the primary crusher and 10.2 min in the secondary crusher. The side-entry rod was required to clear the secondary crusher.

3.1.2.5.8. Test SF-808

This test was performed using an unloaded, full length, scrap fuel element weighing 89.4 kg (197 lb). Normal crushing loads as well as start-under-load forces in the primary crusher were measured. The three primary crusher restarts were successful after resetting a circuit breaker that was tripped during the third test. Crushing times were 3 min intermittent operation for the primary crusher and 16.3 min for the secondary crusher while using the side-entry rod to clear the secondary crusher.

3.1.2.5.9. LF-809

This test utilized a full-length, loaded, FSV fuel element weighing 109 kg (241 lb). Crushing times were 25 s in the primary crusher and

6.0 min in the secondary crusher. A cruciform-shaped deflector was used in place of the cone in the center of the screener, but oversize material continued to accumulate in this center area. Normal primary and secondary crushing forces were measured during this test.

3.1.2.5.10. Test LF-810

This test was performed using a full-length, loaded, FSV fuel element weighing 109.5 kg (241.5 lb). The screener was removed and the oversize crusher inlet blocked for this test so that the tertiary product could be evaluated as burner feed material. Crushing times were 24 s in the primary crusher and 8.0 min in the secondary crusher. Primary and secondary crushing forces were measured.

Samples from this test and test LF-809 were split from the crusher product using the Quality Control Equipment Company sampler Model DD. Sample burn-back and chemical analysis results are compared in another section with the manufacturing specifications to evaluate the sampler accuracy.

3.1.2.6. Material Balances. To obtain complete material balance information, each of the fuel elements used in the Phase IV tests was weighed just prior to charging; the resulting crushed products were weighed at the conclusion of each test. The average quantity of material unaccounted for (MUF) in the individual tests was 0.66% of the original charge. The highest MUF in an individual test was 1.77%, and the lowest was less than 0.15%. The total MUF for all of the Phase IV tests was 0.68%. Recovered material in each test includes the residual material removed from the center of the screener after each test. Complete material balance data for all of the Phase IV tests are given in Table 3.1-1.

Holdup during the Phase III test series was 0.13%, indicating that the upgrading modifications that were made to reduce holdup were ineffective. Since the crushers and inside ventilation enclosures were thoroughly

TABLE 3.1-1
MATERIAL BALANCES

Test No.	Charge (kg)	Recovery (kg)	Gain (+) or Loss (-)	MUF (%)
SG-801	33.90	33.30	(-)0.6	1.77
SG-802	125.70	124.51	(-)1.19	0.95
SF-803 & 804	126.53	125.35	(-)1.18	0.93
SF-805 & 806	146.26	146.48	(+)0.22	0.15
SF-807	88.89	88.69	(-)0.20	0.23
SF-808	89.34	88.71	(-)0.63	0.71
LF-809	109.29	108.04	(-)1.25	1.14
LF-810	109.52	108.75	(-)0.77	0.70
TOTALS	829.43	823.83	(-)5.60	0.66

cleaned prior to the Phase IV tests, however, it would be expected that some of this increased holdup could be attributed to replacing removed material and that MUF in subsequent tests should approach the 0.13% value of the Phase III tests. Also, since none of the upgrading modifications increase holdup significantly, the fuel element crushing system still meets the design criterion that holdup shall be minimized.

3.1.2.7. Product Characteristics. After weighing to determine the relative distribution of screener and oversize crusher products, each was reduced in a 12 to 1 sample splitter or in the Quality Control Equipment Company Model DD sampler to obtain a suitable sized sample for subsequent screen analysis to determine the product size distribution. From the screening results, the wt % of material in each of the fractions and the cumulative wt % less than each size were determined. To obtain an estimate of what the combined screener and oversize crusher product size distributions (i.e., system product) would be, the composites were calculated using the screen analysis and the relative quantities of the two products. These analyses provided the following information:

1. Comparisons of the screener and oversize product size distributions obtained by crushing graphite scrap, unfueled elements, and loaded FSV elements.
2. Comparisons of product size distributions of loaded FSV elements with and without the screener and oversize crusher.
3. Determination of the size distribution of tertiary product material larger than 4750 μm for evaluation of this material as burner feed.

3.1.2.7.1. Crusher Product Size Distribution

Size distributions of combined screener and oversize crusher product from each test are given in Tables 3.1-2 through 3.1-9, while the oversize

TABLE 3.1-2
TOTAL COMBINED SCREENER AND OVERSIZE PRODUCT
FOR TEST SG-801

Product Size (µm)	Screener		Oversize		Total Product Wt (g)	Wt %	Cum Wt %
	Sample Wt (g)	Product Wt (g)	Sample Wt (g)	Product Wt (g)			
+4750	7.9	363	127.0	306.0	669	2.06	100.01
-4750 +4000	71.4	3,278	70.8	170.6	3,449	10.65	97.94
-4000 +2800	213.7	9,811	100.8	242.9	10,054	31.03	87.30
-2800 +2000	102.1	4,687	103.7	249.8	4,937	15.24	56.27
-2000 +1000	96.1	4,412	127.3	306.7	4,719	14.56	41.03
-1000 +850	16.7	767	19.6	47.2	814	2.51	26.46
-850 +425	64.9	2,979	64.6	155.6	3,135	9.68	23.95
-425 +355	13.4	615	9.1	21.9	637	1.97	14.27
-355 +250	15.7	721	9.7	23.4	744	2.30	12.31
-250	69.0	3,168	31.5	75.9	3,244	10.01	10.01
SUBTOTALS	670.9	30,800	664.1	1,600.0	32,400		
Screener Accumulation					900		
Holdup					600		
TOTAL					33,900		

TABLE 3.1-3
TOTAL COMBINED SCREENER AND OVERSIZE PRODUCT
FOR TEST SG-802

Product Size (μm)	Screener		Oversize		Total Product Wt (g)	Wt %	Cum Wt %
	Sample Wt (g)	Product Wt (g)	Sample Wt (g)	Product Wt (g)			
+4750	2.80	588	89.5	1,418	2,006	1.62	100.0
-4750 +4000	29.30	6,156	53.3	844	7,000	5.65	98.3
-4000 +2800	160.80	33,784	81.5	1,291	35,075	28.3	92.7
-2800 +2000	88.90	18,678	99.0	1,568	20,246	16.3	64.4
-2000 +1000	88.40	18,573	144.0	2,281	20,854	16.8	48.1
-1000 +850	16.00	3,362	22.1	350	3,712	3.0	31.2
-850 +425	66.80	14,035	72.6	1,150	15,185	12.2	28.2
-425 +355	12.20	2,563	10.0	158	2,721	2.2	16.0
-355 +250	15.60	3,278	11.8	187	3,465	2.8	13.8
-250	62.30	13,089	38.1	603	13,692	11.0	11.0
SUBTOTALS	543.10	114,104	621.9	9,850	123,956		
Screener Accumulation					554		
Holdup					1,188		
TOTAL					125,698		

TABLE 3.1-4
TOTAL COMBINED SCREENER AND OVERSIZE PRODUCT
FROM TESTS SF-803 AND SF-804

Product Size (μm)	Screener		Oversize		Total Product Wt (g)	Wt %	Cum Wt %
	Sample Wt (g)	Product Wt (g)	Sample Wt (g)	Product Wt (g)			
+4750	2.5	487	20.0	349	828	0.67	100.00
-4750 +4000	45.1	8,790	26.0	443	9,233	7.45	99.33
-4000 +2800	208.0	40,531	75.5	1,287	41,817	33.76	91.88
-2800 +2000	92.1	17,949	134.3	2,288	20,267	16.36	58.12
-2000 +1000	89.9	17,521	210.3	3,583	21,104	17.04	41.76
-1000 +850	13.0	2,534	31.8	542	3,076	2.48	24.73
-850 +425	52.2	10,173	94.5	1,610	11,783	9.51	22.24
-425 +355	10.3	2,007	14.9	254	2,261	1.83	12.73
-355 +250	13.9	2,709	19.1	326	3,035	2.45	10.91
-250	49.9	9,725	44.1	751	10,476	8.46	8.46
SUBTOTALS	576.9	112,432	670.5	11,425	123,881		
Screener Accumulation					1,467		
Holdup					1,182		
TOTAL					126,530		

TABLE 3.1-5
TOTAL COMBINED SCREENER AND OVERSIZE PRODUCT
FROM TESTS SF-805 AND SF-806

Product Size (µm)	Screener		Oversize		Total Product Wt (g)	Wt %	Cum Wt %
	Sample Wt (g)	Product Wt (g)	Sample Wt (g)	Product Wt (g)			
+4750	3.5	991	26.1	777	1,768	1.2	100.0
-4750 +4000	37.8	10,703	36.9	1,099	11,802	8.0	98.8
-4000 +2800	157.3	44,541	108.3	3,224	47,765	32.6	90.8
-2800 +2000	72.0	20,387	158.8	4,728	25,115	17.1	58.2
-2000 +1000	73.5	20,812	157.0	4,764	25,486	17.4	41.1
-1000 +850	10.7	3,030	15.1	450	3,479	2.4	23.7
-850 +425	41.8	11,836	48.2	1,435	13,271	9.0	21.3
-425 +355	8.0	2,265	7.4	220	2,486	1.7	12.3
-355 +250	10.9	3,086	9.7	289	3,375	2.3	10.6
-250	39.0	11,043	37.0	1,102	12,145	8.3	8.3
SUBTOTALS	454.5	12,870	597.2	17,998	146,693		
Holdup					435		
TOTAL					146,258		

TABLE 3.1-6
TOTAL COMBINED SCREENER AND OVERSIZE PRODUCT
FOR TEST SF-807

Product Size (µm)	Sample Wt (g)	Product Wt (g)	Sample Wt (g)	Product Wt (g)	Total Product Wt (g)	Wt %	Cum Wt %
+4750	1.3	186	22.1	443	629	0.71	100.0
-4750 +4000	39.0	5,569	41.4	831	6,400	7.2	99.3
-4000 +2800	199.1	28,432	106.0	2,127	30,559	34.4	92.1
-2800 +2000	87.2	12,452	127.7	2,562	15,014	16.9	57.6
-2000 +1000	85.8	12,252	127.9	2,566	14,818	16.7	40.7
-1000 +850	13.0	1,856	13.0	261	2,117	2.4	24.0
-850 +425	48.9	6,983	39.5	793	7,776	8.8	21.6
-425 +355	10.0	1,428	6.5	130	1,558	1.8	12.8
-355 +250	14.0	1,999	8.4	168	2,168	2.4	11.0
-250	50.2	7,169	24.0	482	7,651	8.6	8.6
SUBTOTALS	548.5	78,327	516.5	10,363	88,689		
Holdup					199		
TOTAL					88,888		

TABLE 3.1-7
TOTAL COMBINED SCREENER AND OVERSIZE PRODUCT
FOR TEST SF-808

Product Size (μm)	Screener		Oversize		Total Product Wt (g)	Wt %	Cum Wt %
	Sample Wt (g)	Product Wt (g)	Sample Wt (g)	Product Wt (g)			
+4750	2.7	395	40.1	845	1,240	1.4	100.0
-4750 +4000	44.0	6,440	47.0	990	7,430	8.4	98.6
-4000 +2800	203.8	29,829	85.3	1,798	31,627	35.7	90.2
-2800 +2000	90.2	13,202	99.0	2,086	15,288	17.2	54.6
-2000 +1000	82.1	12,017	102.8	2,166	14,183	16.0	37.3
-1000 +850	12.2	1,786	11.3	238	2,024	2.3	21.3
-850 +425	44.2	6,469	34.7	731	7,200	8.1	19.1
-425 +355	8.9	1,303	5.0	105	1,408	1.6	11.0
-355 +250	12.1	1,771	6.7	141	1,912	2.2	9.4
-250	40.8	5,972	20.0	421	6,393	7.2	7.2
SUBTOTALS	541.0	79,184	451.9	9,523	88,705		
Holdup					637		
TOTAL					89,342		

TABLE 3.1-8
TOTAL COMBINED SCREENER AND OVERSIZE PRODUCT FOR TEST LF-809

Product Size (μm)	Screener		Oversize		Total Product Wt (Kg)	Wt %	Cum Wt %
	Sample Wt (g)	Product Wt (Kg)	Sample Wt (g)	Product Wt (g)			
+4750	4.10	0.574	18.23	311	0.884	0.8	99.9
-4750 +4000	71.28	9.972	29.48	503	10.474	9.9	99.2
-4000 +2800	205.70	28.776	109.20	1861	30.637	28.8	89.3
-2800 +2000	88.35	12.360	142.62	2431	14.791	13.9	60.5
-2000 +1000	99.82	13.964	153.23	2612	16.576	15.6	46.6
-1000 +850	40.88	5.719	22.38	381	6.100	5.7	30.9
-850 +425	102.77	14.377	46.35	790	15.167	14.3	25.2
-425 +355	16.10	2.252	8.00	136	2.389	2.2	10.9
-355 +250	14.00	1.959	10.88	185	2.144	2.0	8.7
-250	45.88	6.418	38.43	655	7.073	6.7	6.7
SUBTOTALS	688.88	96.371	578.8	9865	106.236		
Screener Accumulation					1.801		
Holdup					1.253		
TOTAL	688.88	96.371	578.8	9865	109.290		

TABLE 3.1-9
TOTAL COMBINED SCREENER AND OVERSIZE PRODUCT
FOR TEST LF-810

Product Size (μm)	Tertiary		Total Product Wt (g)	Wt %	Cum Wt %
	Sample Wt (g)	Product Wt (g)			
+4750	25.18	5,482	5,482	5.04	100.00
-4750 +4000	43.44	9,458	9,458	8.69	94.96
-4000 +2800	136.60	29,741	29,741	27.35	86.27
-2800 +2000	62.15	13,532	13,532	12.44	58.92
-2000 +1000	74.32	16,181	16,181	14.87	46.48
-1000 +850	28.48	6,201	6,201	5.71	31.61
-850 +425	77.40	16,852	16,852	15.49	25.90
-425 +355	8.20	1,785	1,785	1.65	10.41
-355 +250	10.30	2,243	2,243	2.07	8.76
-250	33.42	7,276	7,276	6.69	6.69
SUBTOTALS	499.49	108,752	108,752		
Holdup			771		
TOTAL			109,523		

product size distribution from test LF-810 is given in Table 3.1-10. Graphical comparisons are shown in Figs. 3.1-1 through 3.1-5. From these tables and figures it can be seen that:

1. The reduced quantity (33.9 kg) of scrap graphite material combined with short crushing times in test SG-801 resulted in coarser product than in test SG-802, where the 125.7 kg batch encountered excessive crushing times in the secondary crusher. The fraction of oversize material, which is determined primarily by screener-oversize crusher processing, is comparable (2.06% and 1.62%) in both tests.
2. The product size distributions from crushing scrap unloaded fuel elements in tests SF-803 through SF-808 were quite similar. Fractions of oversize product remained between 0.67% and 1.4% for these tests.
3. Comparison of product from tests LF-809 and LF-810, which were performed with and without the screener and oversize crusher, respectively, revealed an additional 4.2% of oversize particles in the tertiary product (the final product in test LF-810). To better determine the size distribution of the oversize material in LF-810 product, an additional 706 g of oversize material was separated from the bulk product and graded with five screens from 4750 μm to 12,500 μm as shown in Table 3.1-10 and Fig. 3.1-5. From these wt % distributions, it can be seen that 81% of the oversize material is no larger than 6300 μm , and 18% was between 6300 μm and 8000 μm (5% of the total product).

The LF-809 product in sizes less than 4750 μm mesh size is less coarse than in test LF-810, indicating that quantities of screener product are being diverted into the oversize crusher.

TABLE 3.1-10
SIZE DISTRIBUTION OF OVERSIZE PRODUCT
FROM TEST LF-810

Oversize Product Size (μm)	Sample Wt (g)	Sample Wt %	Total Product Wt %	Total Product Cum Wt %
+12,500	-0-	-0-	-0-	100.00
-12,500 +9,500	0.4	0.056	<0.001	100.00
-9,500 +8,000	4.1	0.580	0.030	100.00
-8,000 +6,300	128.1	18.147	0.910	99.97
-6,300 +4,750	<u>573.3</u>	81.215	4.090	99.05
TOTAL	705.9

Fig. 3.1-1. Size distribution comparisons for tests SG-801 and SG-802

Fig. 3.1-2. Size distribution comparisons for tests SF-803, SF-804, SF-805, and SF-806

Fig. 3.1-3. Size distribution comparisons for tests SF-805 and SF-808

Fig. 3.1-4. Size distribution comparisons for tests LF-809 and LF-810

Fig. 3.1-5. Additional oversize material from test LF-810 separately graded

3.1.2.7.2. Sampler Accuracy Evaluation and Particle Breakage Calculations

The cross-cutting sampler used for tests LF-809 screener product and LF-810 bulk product was Quality Control Equipment Company's Model DD. This mechanism utilizes a hollow blade, which moves in a flat arc across the falling stream of feed material. A portion of the material stream falls down the hollow blade to the discharge tube. The speed at which the hollow blade sweeps across the material stream, as well as the frequency of such moves, can be varied, allowing some flexibility in individual and bulk sample sizes. This device is gentle with the material, making it suitable from a particle breakage standpoint. Considerable height (approximately 1 m) is required, however, to fit the sampler in a gravity flow line.

To sample material from these test products, the sampler feeder valve was set at 18.9 rpm (control setting 3.0) with a blade traverse time of 3 s and 5.8 s interval between traverses. These settings extracted 0.5% to 0.7% aliquots of the total product.

The LF-809 and LF-810 samples collected with the Model DD sampler were weighed, screened, weighed, burned-back, weighed, and sent to the chemistry laboratory for the following analyses:

1. Leach and determine the wt % of uranium and thorium from broken particles.
2. Crush, burn, and leach. Determine the wt % of uranium and thorium in unbroken particles.
3. Calculate total uranium and thorium wt %.

The fuel composition as indicated by this procedure was calculated and compared with the manufacturing assay to determine the sampler accuracy and fuel particles breakage as follows:

Model DD Sampler Accuracy in Phase IV Tests

• Test LF-809

1. Screener Product

Weight of sample before burn-back	682.7 g
Weight of product	96,371 g
Sample fraction = 7.084×10^{-3} =	1:141.2
Weight after burn-back	92.88 g
U/Th from broken particles	
U = 0.07% =	0.065 g
Th = 2.87% =	2.666 g
Th/U ratio	41.00
U/Th after crush-burn-leach	
U = 2.59% =	2.41 g
Th = 47.95% =	44.54 g
Th/U ratio	18.5
Total crusher product U/Th	
U = 2.66% =	2.47 g
Th = 50.82% =	47.20 g
Th/U ratio	19.11

2. Oversize Crusher Product

Weight of product	9865 g
Weight of sample before burn-back	577.9 g
Sample fraction = 5.858×10^{-2} =	1:17.07
Weight after burn-back	7.34 g
U/Th from broken particles	
U = 0.01% =	7.34×10^{-4} g
Th = 23.39% =	1.72 g
Th/U ratio	2339
U/Th after crush-burn-leach	
U = 0.04%	0.002936
Th = 27.00%	1.982
Th/U ratio	675

Total oversize crusher product U/Th

U = 0.05% =	0.003670 g
Th = 50.39% =	3.699 g
Th/U ratio	1008

3. Indicated U/Th in Total Product

U = $2.47 \times 141.2 + 0.003670 \times 17.07 =$	348.8 g
Th = $47.20 \times 141.2 + 3.699 \times 17.07 =$	6728 g
Th/U ratio	19.3

4. Actual Feed Material Composition

U	384 g
Th	6749 g
Th/U ratio	17.6

5. Sampler Error in Test LF-808

Error in U composition = $\frac{\text{U error}}{\text{Actual U}} = \frac{384-349}{384} = 9.1\%$

Error in Th composition = $\frac{\text{Th error}}{\text{Actual Th}} = \frac{6749-6728}{6749} = 0.31\%$

Average test LF-809 sampler error = 4.7%

- Test LF-810 (Tertiary Product. Screener and Oversize Crusher Removed for This Test)

Weight of product	108,252 g
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Weight of sample before burn-back	676.4 g
-----------------------------------	---------

Sample fraction = $0.006248 =$	1:160.0
--------------------------------	---------

Weight after burn-back	89.2 g
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U/Th from broken particles

U = 0.06% =	0.0535 g
-------------	----------

Th = 2.47% =	2.203 g
--------------	---------

Th/U ratio	41.2
------------	------

U/Th after crush-burn-leach

U = 2.30% =	2.052 g
-------------	---------

Th = 42.57% =	37.97 g
---------------	---------

Th/U ratio	18.5
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Total U/Th	
U = 2.36% =	2.105 g
Th = 45.04% =	40.18 g
Th/U ratio	19.1
Indicated U/Th in total product	
U = 2.105 x 160.0 =	336.8 g
Th = 40.18 x 160.0 =	6429 g
Actual feed material composition	
U	384 g
Th	6749 g
Th/U ratio	17.6
Sampler error in test LF-810	
Error from U analysis = $\frac{384-336.8}{384} =$	12.3%
Error from Th analysis = $\frac{6749-6429}{6749} =$	4.74%
Average test LF-810 error =	8.5%

Model DD Sampler Accuracy in Previous Tests

- Test UL-65

Weight of product	121,300 g
Weight of sample	1358.9 g
Sample was divided as follows	
+425 sample aliquot	
Aliquot weight before burn	377.22 g
Aliquot weight after burn	66.28 g
U/Th analysis	
U = 4.17% =	2.76 g
Th = 63.0% =	41.76 g
-425 Sample aliquot	
Aliquot weight before burn	16.7 g
Aliquot weight after burn	0.27 g
U/Th analysis	
U = 3.77% =	0.01 g
Th = 69.5% =	0.19 g

Total U/Th in samples

$$U = 2.76 + 0.01 = 2.77 \text{ g}$$

$$Th = 41.76 + 0.19 = 41.95 \text{ g}$$

Indicated U/Th in total product

$$U = 2.77 \text{ g} \frac{121,300}{377.22} = 853.0 \text{ g/FE}$$

$$Th = 41.95 \frac{121,300}{377.22 + 16.7} = 12,918 \text{ g/FE}$$

Actual U/Th in fuel element

$$U = 919.5 \text{ g}$$

$$Th = 13,616 \text{ g}$$

Sampler Error

$$\text{Uranium error} = \frac{919.5 - 853.0}{919.5} = 7.2\%$$

$$\text{Thorium error} = \frac{13,616 - 12,918}{13,616} = 5.1\%$$

Model DD Sampler Recommendations

Fuel element composition as indicated by samples extracted with the Model DD sampler vary from 0.3% to 12.3% error in tests performed to date. The following recommendations, therefore, should be considered for further evaluation and refinement of techniques using this type sampler:

1. Set the Model DD sampler to collect larger samples (about 1%) of the total product.
2. For each product batch, collect three separate samples for burn-back and chemical analysis.
3. Perform comparisons with samples extracted by the 12:1 sample splitter and by other types of samplers to determine which produces the most accurate and consistent indications of product composition.

Fuel Particle Breakage

Calculations. The fuel particle analytical results performed for the sampler evaluations are also used to determine fuel particle breakage.

These calculations are as follows:

- Test LF-809

1. Screener Product

Weight of sample after burn-back	92.88 g
U/Th from broken particles in burned-back sample	
U = 0.07% =	0.065 g
Th = 2.87% =	2.666 g
Th/U ratio	41.00
Total U/Th in burned-back sample	
U = 2.66% =	2.47 g
Th = 50.82% =	47.20 g
Th/U ratio	19.11

Since fissile particles in TRISO/TRISO fuel are 8.00% U and 37.76% Th at a 4.72:1 Th/U ratio, 0.307 g thorium in the broken particles are associated with the 0.065 g uranium from fertile particles, and the remaining 2.36 g Th are from fertile particles. Therefore:

$$\text{Fissile particle breakage} = \frac{0.065 \text{ g}}{2.47 \text{ g}} = 2.6\%$$

$$\text{Fertile particle breakage} = \frac{2.36 \text{ g}}{47.20} = 5.0\%$$

2. Oversize Crusher Product

Weight of sample after burn-back	7.34 g
U/Th from broken particles in burned-back sample	
U = 0.01% =	$7.34 \times 10^{-4} \text{ g}$
Th = 23.39% =	1.72 g
Th/U ratio	2339

Total U/Th in burned-back crusher product sample.

U = 0.05% =	0.003670 g
Th = 50.39% =	3.699 g
Th/U ratio	1008

3. Then:

$$\text{Fissile particle breakage in oversize crusher} = \frac{7.34 \times 10^{-4}}{0.003670} = 20\%$$

$$\text{Thorium from broken fertile particles} = 1.72 - (7.34 \times 10^{-4} \times 4.72) = 1.717 \text{ g}$$

$$\text{Fertile particle breakage in oversize crusher} = \frac{1.717}{3.699} = 46\%$$

Total particle breakage in test LF-809:

$$\text{Total fissile particle breakage} = \frac{0.065 + 7.34 \times 10^{-4}}{2.47 + 0.003670} = 2.7\%$$

$$\text{Total fertile particle breakage} = \frac{2.36 + 1.717}{47.20 + 3.699} = 8.0\%$$

● Test LF-810 (All tertiary product)

Weight of sample after burn-back	89.2 g
----------------------------------	--------

U/Th from broken particles in burned-back sample

U = 0.06% =	0.0535 g
Th = 2.47% =	2.203 g
Th/U ratio	41.2

Total U/Th in burned-back sample

U = 2.36% =	2.105 g
Th = 45.04% =	40.18 g
Th/U ratio	19.1

$$\text{Fissile particle breakage} = \frac{0.0535}{2.105} = 2.5\%$$

Thorium in broken fertile particles = $2.203 - (0.0535 \times 4.72) = 1.950$

Fertile particle breakage = $\frac{1.950}{40.18} = 4.9\%$

Particle Breakage Test Results. Fissile particle breakage in the tertiary product of tests LF-809 and LF-810 was within the $\leq 2.6\%$ criterion. When the tertiary product is combined with the excessive breakage in the oversize crusher product, however, this criterion is exceeded.

Fertile particle breakage exceeded the $\leq 0.8\%$ criterion in all cases, and was increased an additional 60% when combined with oversize crusher product. Particle breakage can therefore be minimized if tertiary product is qualified as burner feed and the screener and oversize crusher removed from the size reduction process.

Since the fraction of particles broken in tests LF-809 and LF-810 is comparable to the fraction breakage in the Phase III tests, it does not appear that use of the feeder valve has reduced breakage in TRISO/TRISO fuel. Comparisons with TRISO/BISO fuel particle breakage can be made using data from subsequent sequential runs.

3.1.2.8. UNIFRAME Stress and Vibration. To measure primary and secondary crushing forces and vibrations, the UNIFRAME was instrumented for the Phase IV tests as follows:

1. Strain gages were installed in duplicate on each primary and secondary pitman toggle plate. The gages were located in the approximate center of each plate equidistant from each toggle bushing centerline. Plate strain is constant throughout the center region in each plate so exact location is not critical. After response testing of all gages with portable instrumentation, one gage of each pair was connected to the control room instrumentation channels and the other retained as a spare. The strain gages and toggles were identified with the alpha-numerical designations shown in Fig. 3.1-6.

Fig. 3.1-6. Toggle strain gage installation diagram

2. The existing load cells on the primary crusher stationary jaw were connected to control room instrumentation channels to measure and record crushing forces on this jaw.

A load cell assembly was designed, fabricated, and installed between the back of the stationary jaw and the UNIFRAME columns. This assembly consists of a load support frame and two load cells. After a small retraction of the upper shafts from the stationary jaw, this arrangement together with associated toggle strain gages and instrumentation measures and records the secondary crushing forces.

3. The existing accelerometer installed at the top of the UNIFRAME in the region of maximum deflection was instrumented to measure vibrations in the horizontal plane. Since previous tests had shown the vertical plane vibrations to be essentially nil, the Z-axis of the accelerometer was not connected.
4. Results of the Phase IV stress and vibration measurements will be presented in General Atomic Report GA-A14978, "Stress and Vibration Measurement in the UNIFRAME Cold Engineering-Scale HTGR Fuel Element Size Reduction System" by R. D. Crabtree, G. T. Cramer, and E. J. Steeger.

3.1.2.9. Conclusions. The Phase IV tests were successful in that all of the test objectives were met. Conclusions derived from the test objectives are discussed below:

1. Responses of all strain gage and load-cell channels were verified. This was accomplished after installation of duplicate gages on the toggle beams to provide an alternate sensor for those sensors damaged during installation.

2. Primary and secondary crushing forces and UNIFRAME vibrations were measured under normal operating and start-under-load conditions.
3. The primary crusher will consistently start under load, but the start-under-load capability of the secondary crusher is intermittent.
4. Total product holdup in the UNIFRAME has not been significantly reduced by the upgrading modifications. Inspections to be performed during the subsequent wear analysis may indicate reduction of holdup on individual components.
5. The bearing heatup problems encountered during previous tests have been corrected.
6. Tertiary product has only 4% more oversize product than the combined screener and oversize crusher product. Use of tertiary product as burner feed material will be evaluated in subsequent burner runs.
7. Use of the feeder valve to control product flow from the UNIFRAME discharge to the transfer system did not reduce particle breakage in TRISO/TRISO FSV fuel. Continued testing with TRISO/BISO fuel is recommended.

3.1.3. UNIFRAME Upgrading and Wear Analysis

The primary and secondary crushers, screener, and oversize crusher are being removed from the UNIFRAME to permit machining and installation of the graphite test bearing and to facilitate inspection and analysis of wear on crushing surfaces, bearings, material chutes, and the sceener.

3.1.4. Documentation and Calculations

Preparation of General Atomic Report GA-A14978, "Stress and Vibration Measurement in the UNIFRAME Cold Engineering-Scale HTGR Fuel Element Size Reduction System," is in progress.

3.2. CRUSHED FUEL ELEMENT BURNING (SECONDARY SUBTASK 312)

3.2.1. Summary

On March 30, 1978, a 48-hour burning test using the 0.20-m (8-in.) primary burner was completed 3 months ahead of schedule. This test verified the feasibility of the reference HRRF primary burner operating cycle using a gravity fines recycle system and TRISO/BISO fresh feed mixture.

Burning rates averaged over 200 g/min, which is the design rate for that burner. Fines recycle and burning proceeded smoothly with no bridging or plugging of lines noted. Temperatures were readily controlled using all four cooling air jackets. A flange on the upper burner exit had to be tightened twice during the run to prevent loss of containment; this is a gasket problem that is now being evaluated. Burner product contains 0.1 wt % carbon, which is below the 2 wt % allowable level.

Other activities affecting the 0.20-m primary burner included installation and use of a fines sampler, completion of a comprehensive training program by four operators, upgrading of fines rotary valve seals, and reduction of plenum material backflow by altering the distributor hole pattern.

Work is well underway on modifying the 0.40-m (16-in.) primary burner to a gravity fines recycle configuration. A mid-reactor feed and fine entry penetration has been installed, a new support platform has been completed, and process equipment components are starting to be received from our fabricator.

3.2.2. 0.20-m Primary Burner

3.2.2.1. 48-h Run Using TRISO/BISO Fresh Feed. Activity Plan 524401, Issue E, calls for a 48-h run to be made on the reconstructed 0.20-m primary burner by June 30, 1978. Feed was to be a mixture of TRISO/BISO

fuel particles and graphite in proportions representative of a typical fuel element.

Two 8-h shakedown runs had already been made on the burner as specified in the activity plan. They had proven the operability of the reconstructed burner, including such features as a gravity fines recycle system, a lowered susceptor to increase heating capabilities near the burner distributor, a series of level sensors and flow sensors, a vacuum fines sampler to take discrete samples from the fines bunker, a bellows sealed burner tube cooling air jacket, a gas inlet distributor modified to reduce plenum particle drainage, and improved instrumentations in many areas.

3.2.2.1.1. Feed

A mixture of BISO and TRISO coated fuel particles and -0.48 cm full spectrum graphite was prepared as feed for the burner. The BISO and TRISO fuel particle mix was product from FY-77 sequential operations on the 0.40-m primary burner. They were burned back to ThO_2 microspheres and SiC coated WAR type fuel particles as a result of the earlier processing. Composition by wt % was as follows:

TRISO coated WAR-type fuel particles	4.4
ThO_2 microspheres	13.4
Carbon	<u>82.2</u>
	100.0

3.2.2.1.2. Run Narrative

Prior to beginning operation, a system operability check was made on the burner. This, as well as the entire burner run, followed the guidelines set forth in "Operating Procedure: 0.20-m Primary Burner," document number OP 524301, Issue A.

Figures 3.2-1 through 3.2-4 give pertinent burner variables as a function of run time.

Fresh feed, which was started at 3.3 rpm, was maintained for approximately 50 min. During this time, a CO₂ flow of 645 slpm was maintained, with no O₂ flow. The bed differential pressure gave an accurate picture of the bed weight, which during feeding was found to increase steadily. After addition of 26 kg of fresh feed, burner heatup via induction heating was initiated. Wall temperatures increased to their maximum allowable 900°C, but the bed temperature had not responded.

Gradual increases in plenum CO₂ flow were made to promote fluidization. Initial bed mixing occurred suddenly, causing a large rearrangement of the fluidized bed accompanied by a piston effect that ejected about 1 kg of material from the bed. This material plugged the cyclone gas entry and stopped process gas flow. The burner was shut down and the plug removed. It was decided to fully fluidize the bed during feed-in on future runs to eliminate this deep bed rearrangement situation.

The bed was then reheated to 700°C, and the plenum O₂ ramp was begun. The burn rate was averaging 210 g/min.

Filter differential pressure was at 4 kPa. Bed DP was at 15 kPa, with ±5 to 7.5 kPa fluctuations at 1 to 2 s intervals indicating good slugging behavior.

The burner temperature was controlled very easily using only limited amounts of lower cooling air. Bed temperature kept steady at approximately 900°C. Upper cooling air was used to keep the fines recycle line cool. The fines rotary valve was maintained below 500°C at all times.

The upper cooling air can be directed three ways: (1) fines pipe, (2) cyclone, and (3) above bed. During this run, no above-bed cooling air was necessary. The fines entered the fines upflow pipe at about 725°C.

Fig. 3.2-1. CO concentration for 0.20-m primary burner, 48-h run

Fig. 3.2-2. Off-gas concentration for 0.20-m primary burner, 48-h run

Fig. 3.2-3. Above-bed temperatures for 0.20-m primary burner, 48-h run

Fig. 3.2-4. Mid-bed temperatures for 0.20-m primary burner, 48-h run

The fines pipe is cooled at the rate of $9 \text{ m}^3/\text{min}$ air flow. Just prior to entering the cyclone, the internal temperature is 630°C . The cyclone, cooled at the rate of $5.6 \text{ m}^3/\text{min}$, further lowers the temperature to 450°C . As the fines reenter the burner, they have cooled to 400°C . These cold fines entering the burner have the effect of cooling the bed temperature. This implies that the fines are entering the bed and mixing in.

At this point, the gas flows were being held constant: plenum CO_2 at 175 slpm, vertex CO_2 at 75 slpm, MR CO_2 at 60 slpm; plenum O_2 at 180 slpm, vertex O_2 at 50 slpm, and MR O_2 at 70 slpm.

The fines rotary valve seals held up well with no leaks throughout the run. Approximately 8 h into the run, a slight leakage near the burner gas exit was noted during visual inspection. A gasket allowed leakage through a flange. No contamination occurred during this time period. At this point it was decided to shut down to fix the flange. The fines bunker was then inspected and found to contain 15 kg of fines. These were sampled and found to be 99% carbon. At the end of the run, the fines bunker was again examined and found to contain only 1.5 kg.

Restart of the 48-h run proceeded smoothly. Bed fluidization was ensured prior to heat-up. Startup proceeded in the same way. The temperature of the bed increased to 700°C , at which time the plenum O_2 ramp began. Fines recycle was initiated at 820°C . Fresh feed was established at somewhat less than the burn rate so that a particle bed could be built up while the carbon level decreased. This was done with the fresh feed rotary valve operating at 1.5 rpm.

In-bed temperature response showed a well-defined temperature distribution. Thermowell temperatures stayed within the 900° to 940°C range throughout operation, with the exception of the lowest thermocouple, which indicated a temperature of about 870°C . This thermocouple was located directly above the point where vertex gas enters, which produced a cooling effect. The thermocouple located near the opening through which

the recycled fines entered the burner was also a few degrees cooler demonstrating the moderating effect that fines recycle has on the bed. Fines bunker temperature varied between 400° and 500°C. Temperature profile and level sensors indicated a maximum fines inventory of approximately 15 kg. The temperature of the fines rotary valve stayed under 450°C for the entire run.

Temperatures were controlled easily throughout this portion of the operation. Lower cooling air was at a minimum, and above-bed cooling was found unnecessary. Cyclone and fines pipe cooling were used when necessary. Cyclone cooling air varied from 0 to 4.8 m³/min, and fines pipe cooling from 2.8 m³/min to 6.3 m³/min. Heat transfer throughout the fines recycle loop was large as evidenced by the fact that the fines left the burner at about 850°C and entered the fines bunker at less than 500°C. Heat transfer to the fines line and cyclone can be controlled by adjusting the fines recycle rate.

O₂ concentration was maintained below 5% during most of the run. The O₂ off-gas concentration graph shows a sharp increase at 25 h. At this point, the bed had apparently burned to a low carbon state. Fresh feed rate was increased and the situation was immediately under control.

Almost simultaneously, the upper burner tube outlet gasket began to leak again. Apparently the thermal cycling, which this flange was exposed to during the bed temperature drop, caused the bolts to loosen. The bolts were tightened and the run continued as before. Plans to change the gasket design have been made.

Thirty-nine hours into the run an interim product dump was effected. Prior to the product dump, fresh feed was stopped, and the carbon was depleted out of the bed. As the carbon content decreased, O₂ breakthrough occurred. When the bed was very low in carbon, combustion-generated heat was no longer sufficient to maintain 900°C bed temperatures. The induction heater kept the bed at 850°C, and when the burn rate dropped to less than

10 g/min, an interim dump of 25 kg was made. Analytical results later revealed a carbon content of less than 0.1%. Fresh feed was once again continued, and the burner was restarted. Figure 3.2-3 shows off-gas O_2 rose again at 48 h, which was the start of the tailburn. Here again the bed carbon was burned out. The level of O_2 in the burner off-gas during the run was noted to increase slightly when the bed cooled slightly. Thus, strict control of bed temperature is important for the vessel as well as for control of off-gas composition.

Gas flows were held constant: plenum O_2 at 230 slpm, vertex O_2 at 62 slpm, and mid-reactor O_2 at 80 slpm; plenum CO_2 flow was 240 slpm, vertex CO_2 75 slpm, and mid-reactor CO_2 42 slpm. About 35 h into the run it was decided to try to increase fines burning. Mid-reactor O_2 flow was increased to 115 slpm. This proved to be very effective, and no difficulties were encountered. Vertex O_2 flow was then stopped to determine if burner operation would be affected. Since no change in burner operation occurred, vertex O_2 will be eliminated as plenum and mid-reactor oxygen can perform as well. Also, operator control will be simplified.

Bed differential pressure reached a maximum of 36 kPa. Throughout operation it gave an accurate reading which easily translated into bed weight. Filter differential pressure stayed around 3.8 kPa.

Level sensors were installed in the burner, feed hopper, and fines bunker. The level sensors in the bed give an accurate picture of the slugging material. They are located at four depths, and as the bed height increases and slugging occurs lights on an indicator panel in the control room show what is happening. Similarly, the level sensor in the feed bunker gives an indication of the volume of material it contains. Fines bunker level sensors were found to give erroneous indications of fines level due to material resting on top of the horizontal sensors.

Both bunkers have aeration pads to help keep the level constant. The fresh feed bunker material tends to cone in the middle despite aeration because the graphite is in larger chunks. The fines bunker maintains an even level.

Flow sensors are located in the pipes from the fines bunker and from the feed bunker. These pipes join together in a Y and enter into the burner. Flow sensors in this area indicate whether or not feed or fines are flowing. Fines flow sensors worked well throughout the run, but the feed sensor showed flow intermittently. This was probably due to the nature of the granular feed material as it bounced down the feed pipe.

3.2.2.1.3. Product

Material was removed during the final bed removal (84.5 kg) and during an interim product dump (23.3 kg). Final bed carbon content was 0.1 wt %, while interim product carbon content was 0.03 wt %. These are both far below the design criteria level of 2 wt % carbon content. Product bulk density was measured at 3.7 g/cm³. Size distributions are shown in Fig. 3.2-5.

The fluid bed was "slumped" twice during the run for flange tightening, and 1.8 kg of particles were found in the plenum drain can.

Three fines samples were taken 10 h, 20 h, and 40 h into the run. Each weighed about 200 g. Carbon content was 99%, 97.7%, and 99.2%, respectively. This may have been due to the relative cleanliness of the feed fuel particles (they went in unbroken), which kept the noncombustible fines generation due to broken particles low.

Fines bunker inventory after the run was 1.5 kg. This was observed 4 days after the burner run was over. This means that many filter fines were dislodged in time due to normal platform vibrations.

Fig. 3.2-5. Product size distribution for 0.20-m primary burner, 48-h run

Fuel particle breakage in the final product is being determined using analytical chemistry. The results are not yet available. A small proportion of agglomerates were found, and they are also being examined. Slumping the fluidized bed three different times could have contributed to agglomeration of fuel particles.

3.2.2.1'.4. Acceptance Criteria

Activity Plan 524401, Issue E, details eight acceptance criteria. These were all met as shown below:

1. No feed line blockage.
2. Product heel to be less than 0.5 wt %; no heel was observed.
3. Burner heatup time to be less than 2 h; 45 min required.
4. Off-gas filter pressure drop to be less than 35 kPa; a maximum of 4.2 kPa was observed.
5. Main burn rate to be at least 200 g/min; peak burn rate was 240 g/min.
6. Fines heel to be less than 0.5 wt % of throughput; the fines heel including filter coating was only 0.3 wt % of throughput.
7. Product particle breakage to be less than 5 wt %; visual examination indicates less than 2 wt % breakage.
8. Product carbon content to be less than 1 wt %; actual carbon content was 0.1 wt %.

3.2.2.1.5. Conclusions

The success of this run indicated that gravity fines recycle can be used to burn elutriated fines from a primary burner system. One of the important results was that the fines rotary valve held up well at the nominal 450°C fines recycle temperature; no seal leakage was noted, and the high temperature bearings worked well throughout the run.

3.2.2.2. Fines Sampler. A fines sampler capable of adaptation to a fully remote sampling mode has been installed and successfully tested on the 0.20-m primary burner gravity fines recycle system.

Sampling of the fines recycle stream is necessary to determine non-combustible broken particle content of the fines. This will increase during the course of a burner cycle or campaign, and may require operator action, especially during extended (more than 100 h) operations.

In order to provide that capability, a simple vacuum technique for discrete withdrawal of fines samples has been installed. A schematic of the equipment is shown in Fig. 3.2-6, and its operating procedure is given.

Testing was accomplished by manually loading some carbon fines into the gravity fines recycle bunker and running through the operating cycle. A 2-s sample was found to yield 300 g of fines. The sample is very conveniently removed in the filter lower removable housing.

3.2.2.3. Training Program for Operators. A program has been set up to ensure that 0.20-m primary burner operators have a thorough knowledge of the equipment, operating techniques, and process rationale. Essential features of the program are:

1. An up-to-date operating procedure.
2. A class on burner operating theory and hardware, including hands-on equipment operating sessions.

OPERATING PROCEDURE

1. CLOSE VALVE 1, OPEN VALVE 2.
2. ACTUATE VACUUM PUMP.
3. OPEN VALVE 1 FOR 2 S, THEN CLOSE.
4. SHUT OFF VACUUM PUMP.
5. REMOVE LOWER FILTER HOUSING TO WITHDRAW FINES SAMPLE.

Fig. 3.2-6. Fines sample system

3. A formal testing procedure consisting of a wide range of essay-type questions.

It is recognized that operating fluidized-bed burners is an exacting job that does not leave margin for error. This is especially true during developmental work, when personnel with only a limited amount of burner operating experience are being asked to run burners during shift operations.

The first step has been to thoroughly update the burner operating procedure. That document has been expanded, edited, and clarified to reflect the current operating philosophy.

After completing the operating procedure, a very thorough essay-type test was composed. The purpose of this test is to ensure that each operator is completely checked out on what the equipment is, where it is, how it operates, why it operates that way, and what to do in a wide spectrum of operating upsets.

In order to convey the knowledge required to satisfactorily complete this test, a training class was set up. The operating procedure formed the core of the training material, with calibration notebooks, Diogenes operating manuals, and piping and instrumentation drawings used as reference materials. Hands-on equipment operation was an integral part of the training. Every portion of the operator qualification tests was discussed in depth during the training classes.

Three operators were qualified on the 0.20-m primary burner. Requalification will normally be a yearly process or whenever major revisions are made to the operator procedure. A similar program will be set up for the 0.40-m primary burner.

3.2.2.4. Fines Rotary Valve Seals. During the initial shakedown run on the 0.20-m primary burner, the fines rotary valve was heated to about 500°C. The rotary seals were noted to be smoking for about an hour, after which no more smoke was seen. It was assumed at the time that an organic binder had baked out of the asbestos seal material.

In the next run, some small amount of fines was seen escaping past the seals. Tightening the seal follower did not help matters. After that run, the seals were disassembled; the asbestos had gotten very hard and non-resilient, which explained the lack of sealing capabilities.

A seal was made using 2.5 cm wide by 0.38 mm thick graphite tape. It was wrapped directly onto the rotor shaft until the proper thickness was reached. The valve was then reassembled, and the graphoil packing was compressed using the existing seal follower. Internal pressure of 7.5 kPa was applied, and no leakage was noted. Maximum pressure at the valve during burner operations has been only 4 kPa. In order to further test the seal effectiveness, a "rosebud" heater was used to heat each seal area to 450°C for a 10-min period. After cooling, no leakage was detected using our standard "snoop" leak testing fluid.

These new graphoil seals were used in the TRISO-BISO 48-h run, and no leakage was noted during the run.

3.2.2.5. Plenum Backflow Reduction. Backflow of fuel particles through the plenum gas distributor has been reduced over four orders of magnitude by increasing distributor pressure drop to greater than the maximum slug pressure fluctuation. In this way, no instantaneous reverse gas flow occurs that would allow material to go back through the distributor holes. Further testing will be done during future burner runs to gather additional backflow data and determine gas distribution effectiveness.

The plenum gas distributor that had been previously used was a 90° cone with a 12 mm lower diameter and a 16.5 cm upper diameter. It had 360 holes, each being 0.9 mm in diameter. During normal operation, with a flow of 450 slpm of CO₂, the pressure drop was 2.5 kPa.

Maximum slugging pressure variations, caused by up-and-down movement of a 50 kg fuel particle fluidized bed, have been observed to be ± 7 to 10 kPa. There was thus a possibility for a significant reverse pressure drop across the distributor, which would yield a reverse gas flow that would allow fuel particles to go backwards through the distributor holes.

During previous burner runs, there has been as much as 850 g/h of plenum backflow. This material is typically at least 90 wt % burned back BISO fuel particles (ThO₂ microspheres).

In order to increase the pressure drop on the existing distributor, the most convenient method is to reduce the total number of holes by welding them closed. It was then calculated that half the holes would need to be closed to yield a pressure drop of 11 kPa, or enough to at least equal the greatest slugging pressure fluctuations. Half of the holes were welded closed and the distributor was reassembled. The pressure drop at 450 slpm of CO₂ was found to be 13 kPa, somewhat higher than predicted.

An 8-h test was then run to determine material backflow rates. A 50-kg bed of burned back TRISO/BISO fuel particles was heated to 800°C for the 8-h period. Slugging characteristics were the same as during actual burning operations. Material backflow amounted to 0.6 g of fuel particles after the 8 h. This is a reduction in backflow rate of 16,000:1 over the final shakedown burner run.

This dramatic reduction in material backflow was due to having sufficient distributor pressure drop to preclude reverse gas flow due to fluidized bed slugging. In upcoming burner runs, any effect due to a

reduced number of distributor holes will be looked for. This will complete test G of Activity Plan 524401, Issue E, which is scheduled for completion September 30, 1978. If there is no problem, then the 0.40-m primary burner distributor will be given a similar modification prior to operating that burner.

During FY-77 sequential operations, almost 2 kg/h of BISO fuel particles were observed to flow backward through the 0.40-m primary burner distributor. This was enough to almost fill the plenum cavity after 48 h; the planned 96-h run during this year's sequential operation would overflow the plenum cavity before the run could be completed. It is therefore necessary to alleviate this situation prior to FY-78 sequential operations.

3.2.3. 0.40-m Primary Burner

3.2.3.1. Gravity Fines Recycle Addition. Work has been progressing on addition of a gravity fines recycle system on the 0.40-m primary burner. As shown in Fig. 3.2-7, a mid-reactor penetration has been installed and is ready for use. Figure 3.2-8 shows the new support platform that will hold the feed bunker and fines recycle equipment. Cooling air supply piping additions are now being installed for fines upflow and cyclone cooling capabilities.

3.2.3.2. Lower Seal Assembly Damage. Disassembly of the Graylock clamp and the lower burner hub revealed that the modified lower seal assembly was damaged. This modification replaced the original graphoil seal with solid graphite elements, split to accommodate assembly, obviating burner removal. Examination revealed that the damage may have resulted from improper installation or excessive stressing and dislocation during burner operation. A second design is being fabricated.

Fig. 3.2-7. Gravity fines recycle system

Fig. 3.2-8. New support platform

3.3. PARTICLE CLASSIFICATION, CRUSHING, AND CRUSHED PARTICLE BURNING (SECONDARY SUBTASK 313)

3.3.1. Summary

Analytical results from the previous quarterly's classification tests were completed. Calculations based on these results indicate the effects of secondary classification of FSV TRISO/TRISO fuel particles, the effect of lower gas flows on removal of broken BISO particles during classification of LHTGR TRISO/BISO fuel particles, and the distribution of graphite from classification of LHTGR TRISO/BISO fuel particles containing unburned graphite.

Product samplers for classifier product were tested and the results compared.

Classified particles containing unburned graphite were crushed in the particle crusher, and the effects of graphite on the crushing operation were determined.

The ability of the particle crusher to crush agglomerated particles from primary burner product was tested.

Checkout of instrumentation and controls on the 0.10-m secondary burner is in progress.

Apparatus for studying the parameters for combustion of perchloroethylene distillation bottoms has been constructed.

3.3.2. Fuel Particle Air Classifier

3.3.2.1. Multistage Classification of TRISO/TRISO Fuel Particles. Earlier test results on single-stage classification of FSV type TRISO/TRISO fuel particles had indicated that secondary classification at a minimum may be

required to achieve satisfactory separation of these fuel particles (Ref. 3.3-1). A test completed last quarter (No. TTMS-1) was undertaken to determine if, in fact, secondary classifications of the fissile and fertile streams improved the separation of the particles. The feed composition, operating procedures, feed rates, and material balances from the test were reported in the previously quarterly (Ref. 3.3-2). The analytical results that were not complete at that time are presented here.

3.3.2.1.1. Analytical Results

The thorium and uranium content of the TRISO fissile and fertile particles used as feed is given in Table 3.3-1. The thorium/uranium ratio (4.595) obtained from analysis of the fissile feed particles was used to calculate the quantity of thorium from fissile particles to distinguish it from the thorium from fertile particles in each of the classified products (i.e., fertile Th % = total Th % - U % x 4.595; U % x 4.595 = fissile Th).

Analytical results and calculations for the classified products are shown in Fig. 3.3-1.

In the initial classification, 7.6% of the fissile particles were contained in the fertile stream (underflow) (i.e., $34 \times 100 \div 3.4 = 41.2$, grams of uranium basis). The thorium/uranium ratio in the fissile stream (overheads) of 4.520 was below the 4.595 ratio in the fissile feed particles, indicating no fertile thorium in the fissile stream. On a heavy metal basis (i.e., HM = uranium + thorium in grams) the heavy metal in the fertile stream was 99.01% fertile material and the heavy metal in the fissile stream was 100% fissile material.

In the secondary classification of the underflow materials, 20.6% of the fissile particles remained in the fertile stream (i.e., $0.7 \times 100 \div 0.7 = 2.7$, grams of uranium basis). Conversely, this represented a removal of 79.4% of the fissile particles initially contained in the fertile stream. The excessive thorium/uranium ratio in the fissile

TABLE 3.3-1
FEED COMPOSITION OF TRISO/TRISO PARTICLES FOR TEST TTMS-1

Material	Particle Wt (g)	U (g)	Th (g)	U (%)	Th (%)	Th/U Ratio
Fissile	600	48	220.6	8.0	37.76	4.595
Fertile	3400	0	1963.5	0	57.75	N/A
Total	4000	48	2184.1	1.2	54.60	45.50

Fig. 3.3-1. Analytical results

stream of 12.832 indicated that 1.3% of the fertile particles were contained in the fissile stream (i.e., $24.4 \times 100 \div 1913.7 + 24.4$, grams of fertile thorium basis). This represents a 1.3% loss of fertile particles from the initial recovery as a penalty for removal of 79.4% of the fissile particles. On a heavy metal basis, the heavy metal in the fertile stream was now 99.80% fertile material, an increase in its purity from the 99.01% of the initial classification. The heavy metal content of the fissile stream was 38.39% fissile material.

In the secondary classification of the overhead materials (fissile stream), the thorium/uranium ratio in the fissile stream of 3.993 was below the 4.595 ratio in the fissile feed particles, indicating no fertile thorium in the fissile stream. Of the fissile particles, 3.1% were contained in the fertile stream (i.e., $0.9 \times 100 \div 27.7 + 0.9$, grams of uranium basis). However, even though no fertile thorium was detected in the initial classification of overhead material, the thorium/uranium ratio of 13.040 in the fertile stream from reclassification of this material indicated fertile particles were present. This could be from any one or a combination of: (1) sample cross contamination, (2) residual material from the initial classification, and (3) analytical error. Because of the relatively small quantities involved, the expense and time delay involved in repeating the analysis were spared. Assuming the 7.4 g of fertile thorium detected were also present in the overheads from the initial classification, but not detected, only 0.4% of the fertile particles were represented (i.e., $7.4 \times 100 \div 1896.8 + 7.4$, grams of fertile thorium basis). On a heavy metal basis, 60.16% of the fertile stream from reclassifying the overheads was fertile material.

In actual processing using two-stage classification, there would be many options open for further treatment of the four resultant products. The one shown at the bottom of Fig. 3.3-1 demonstrates combining the fissile stream from reclassification of the initial fissile stream with the fissile stream from reclassification of the initial fertile stream and, similarly, combining the fertile streams. Both would then continue through the

remaining head-end process as planned for single-stage classification products. The result of this is a fertile stream with 5.0% of the fissile particles (i.e., $1.6 \times 100 \div 30.4 + 1.6$, grams of uranium basis) and a fissile stream with 1.3% of the fertile particles (i.e., $24.4 \div 1921.1 + 24.4$, grams of fertile thorium basis). On a heavy metal basis, the fertile stream contains 99.56% fertile material. This is an improvement over the 99.01% from the initial classification, but a dilution of the 99.80% in the fertile stream from secondary classification of the initial fertile stream. The improvement in the purity of the fertile stream by this type of product combining results in a fissile stream with 86.29% fissile material instead of the 100% fissile material obtained from the initial classification (96.85% assuming the 7.4 g of fertile thorium undetected in the analysis was actually present).

Other methods include recycle of selected streams with fresh unclassified feed. The economics involved and the many combinations possible with proposed future fertile particles of different thorium/uranium ratios are beyond the scope of this report.

3.3.2.1.2. Conclusions and Recommendations

The results of test TTMS-1 demonstrated a large improvement in the separation of FSV TRISO/TRISO fuel particles when compared to the earlier test results. Since the current tests were conducted with whole particles, and the earlier tests were conducted with crushed and burned scrap rod material, the diverse results indicate that interference from unburned carbon and crossover of broken particles led to the indication that secondary classification may be required to separate FSV TRISO/TRISO fuel particles. Unfortunately, the results of secondary classification demonstrated in test TTMS-1 would not be applicable for feeds containing appreciable amounts of broken particles or carbon. These feeds, because of the coating of fertile particles by powder from broken fissile particles and the lower terminal velocities of broken fertile particles and powder, may not be separable to the degree desired by any number of classifications. Therefore, no further tests on secondary classification of FSV TRISO/TRISO fuel particles are planned at this time.

The results of test TTMS-1, however, did provide insight into the classification alternatives available that affect the unbroken particles in the feed. The purity of the fertile stream is improved by secondary classification, while the purity of the fissile stream is not. Further studies are recommended on the economics of gains and losses from secondary classification, alternative plans such as recycle of some streams back into fresh feed, and the effects of MEU and other potential future fuel particles.

3.3.2.2. Classification of Broken TRISO/BISO Fuel Particles. Earlier test results on classification of LHTGR type TRISO/BISO fuel particles indicated that crossover of BISO material into the TRISO particle stream was mainly from broken particles. However, broken TRISO particles apparently did not result in additional crossover of TRISO materials into the BISO particle stream (Ref. 3.3-1). A test completed last quarter (No. TBBC-7) was undertaken to verify these earlier indications and to determine if a lower gas velocity would reduce crossover by allowing the larger broken BISO fragments to drop into the BISO stream without additional TRISO crossover. The feed composition, operating procedures, feed rates, material balance, and product size distributions from the test were reported in the previous quarterly (Ref. 3.3-2). The analytical results, which were not complete at that time, are presented here.

3.3.2.2.1. Analytical Results

Comparisons of the overheads and underflow product distributions with those of the feed are given in Table 3.3-2. The comparisons for the overheads are illustrated in Fig. 3.3-2 and for the underflow in Fig. 3.3-3. The table and the figures show the effect reducing the gas flow has on the size distributions. Although the data are somewhat confounded by losses from processing and screening and removal of product samples, the trend for reducing the quantities of materials in the larger mesh fractions of the overhead materials and the attendant increases in the underflow materials is obvious.

The thorium and uranium analytical results and calculations for the classified products are given in Table 3.3-3. These results show that the

TABLE 3.3-2
MATERIAL SIZE DISTRIBUTIONS FOR TEST TBBC-7, CLASSIFICATION OF
WHOLE AND BROKEN LHTGR TRISO/BISO FUEL PARTICLES

Mesh Fraction (μm)	Overheads		Underflow		Total	
	Feed (g)	Product (g)	Feed (g)	Product (g)	Feed (g)	Product (g)
+425	1707.1	1012.4	2782.0	3389.9	4489.1	4402.3
-425 +355	30.4	10.8	121.3	133.2	151.7	144.0
-355 +250	293.3	78.3	57.0	271.5	350.3	349.8
-250 +180	389.7	283.0	3.7	76.1	393.4	359.1
-180 +125	137.9	140.2	0.7	0.5	138.6	140.7
-125 +75	53.8	45.4	0.6	0.1	54.4	45.5
-75 +45	6.0	7.5	0.4	0.0	6.4	7.5
-45 +38	1.2	3.6	0.1	0.0	1.3	3.6
-38	32.1	13.1	1.1	0.0	33.2	13.1
Totals	2651.5	1594.3	2966.9	3871.3	5618.4	5465.6

Fig. 3.3-2. Comparison of overhead feed and product (TRISO/BISO), test TBBC-7

Fig. 3.3-3. Comparison of underflow feed and product (TRISO/BISO), test TBBC-7

TABLE 3.3-3
PRODUCT COMPOSITION FOR TRISO/BISO PARTICLE CLASSIFICATION,
TEST TBBC-7

Mesh Size (μm)	Weight (g)				Weight (%)				Heavy Metal (%)		
	U	Th	Other	Total	U	Th	Other	Total	U	Th	Total
UNDERFLOW											
All	121.2	3016.9	733.2	3871.3	3.13	77.93	18.94	100	3.86	96.14	100
+425	126.4	2067.2	1196.3	3389.9	3.73	60.98	35.29	100	5.76	94.24	100
-425	0	949.7	0	481.4	0	100	0	100	0	100	100
OVERHEADS											
All	181.3	301.3	1111.7	1594.3	11.37	18.90	69.73	100	37.56	62.44	100
+425	166.8	4.7	840.9	1012.4	16.48	0.46	83.06	100	97.28	2.72	100
-425 +355	0.9	0.7	9.2	10.8	8.28	6.64	85.08	100	55.28	44.72	100
-355 +250	1.3	38.9	38.1	78.3	1.68	49.64	48.68	100	3.28	96.72	100
-250	12.2	257.1	223.5	492.8	2.48	52.17	45.35	100	4.54	95.46	100

material removed from the overheads by lowering the classification velocity was predominantly broken BISO fertile particles, but included whole TRISO fissile particles. Since the +425 μm material in the underflow contained all of the uranium present in that stream, this indicated that it was whole TRISO particles that entered the BISO stream. Earlier, it had been postulated that the crossover of uranium may have come from a fine coating of oxidized uranium on the BISO particles, but the apparent lack of uranium on the -425 μm material renders this unlikely. The quantity of uranium in the fertile stream was 40% of the total ($121.2 \text{ g} \times 100 \text{ underflow} \div 121.2 \text{ g} + 181.3 \text{ g overheads}$), and represents the penalty for recovering the additional broken BISO particles. On a heavy metal basis, the thorium was 96.14% of the total in the fertile stream. This purity could be improved, of course, by using a higher classification velocity with the attendant loss of broken BISO particles as a penalty.

On a heavy metal basis, the uranium was 37.56% of the total in the fissile stream. Further improvement of the purity of this stream would probably be difficult, as study of the thorium content in the various mesh fractions shows. The thorium content of the +425 μm material was 2.72% of the total heavy metal. This rose to 44.72% in the -425+355 μm material, 96.72% in the -355+250 μm material and 95.46% in the -250 μm material, a clear indication that the thorium is present as small fragments of broken particles.

The quantity of thorium in the -250 μm material was 85% of the total thorium in the overheads ($257.1 \text{ g} \times 100 \div 301.9 \text{ g}$). Sufficient reduction of the gas velocity to allow these small BISO fragments to fall into the fertile stream without being accompanied by a large percentage of the fissile stream (i.e., 9% of the total thorium, $301.3 \text{ g} \times 100 \text{ overheads} \div 301.3 \text{ g} + 3016.9 \text{ g underflow}$) probably represents the minimum loss that is practical unless particle breakage is reduced.

3.3.2.2.2. Conclusions and Recommendations

The results of test TBBC-7 demonstrated that the larger mesh fractions of broken BISO fertile particles could be removed from the TRISO fissile

stream by a reduction in the classifier gas velocity, but included a corresponding loss of whole TRISO particles to the fertile stream. The effectiveness of this reduction was limited by the quantity of broken BISO particle material in the smaller mesh sizes. However, since higher or lower velocities will obviously result in more crossover of BISO or TRISO particles, respectively, no further testing on classification of broken fuel particles will be conducted at this time, but efforts to reduce particle breakage will be pursued. Further studies are recommended to determine the economics of the gains and losses from selectively increasing the purity of the fissile or fertile stream by making adjustments to the classification gas velocity.

3.3.2.3. Classification of TRISO/BISO Fuel Particles and Unburned Graphite.

The potential exists for an upset condition where it would become desirable as a process alternative to process fuel particles containing unburned graphite through the secondary burning stage rather than to recycle them for continued burning in the primary burner. This would require classification to separate the fissile and fertile particles prior to crushing and secondary burning. A test completed last quarter (No. TBCC-11) was undertaken to determine the feasibility of the operation, the distribution of carbon in the fissile and fertile streams, and the effects on operating parameters and separation efficiency. The feed composition, operating procedure, feed rates, material balance, and product size distributions from the test were reported in the previously quarterly (Ref. 3.3-2). The analytical results not complete at that time are presented here.

3.3.2.3.1. Analytical Results

The thorium, uranium, and burnable carbon analytical results and calculations for the classified products are given in Table 3.3-4.

The burnable carbon constituted over 52 wt % of the material in the underflow and over 43 wt % of the material in the overheads. This was composed of the graphite and the burnable coatings on the particles. Of the burnable carbon contained in the underflow, over 44 wt % was graphite.

TABLE 3.3-4
PRODUCT COMPOSITION FOR CLASSIFICATION OF TRISO/BISO PARTICLES
WITH UNBURNED GRAPHITE, TEST TBCC-11

	Underflow	Overheads	
Analytical Results			
Burnable carbon, %	52.43	43.03	
Thorium, %	41.55	4.49	
Uranium, %	0.02	6.22	
Burnable Carbon Distribution			
Graphite, %	44.42	50.15	
BISO Coatings, %	55.47	7.30	
TRISO Coatings, %	0.11	42.55	
Total	100.0	100.0	
Heavy Metal Distribution			
Thorium, %	99.95	41.93	
Uranium, %	0.05	58.07	
Total	100.0	100.0	
Heavy Metal Recovery			
			<u>Total</u>
Thorium, %	95.07	4.93	100.0
Uranium, %	0.92	99.03	100.0

In the overflows, over 50 wt % of the burnable carbon was graphite. This even distribution of the graphite content precludes the depletion of burnable materials in one stream or the other as needed to reduce the risk to the secondary burner.

The heavy metal content of the underflows was 99.95% thorium, which is as good as experienced in earlier tests. However, the thorium constituted almost 42% of the heavy metal in the overheads, which is unsatisfactory for unbroken particles. Although over 99% of the uranium was recovered in the overheads, the recovery of only 95% of the thorium in the underflow resulted in excessive crossover and loss of fertile material.

3.3.2.3.2. Conclusions and Recommendations

The results of test TBCC-11 demonstrated the particle sizes of unburned graphite that would be found in the fissile and fertile streams after air classification. With the graphite feed size distribution used, the percentage of burnable graphite in both recovery streams constituted an undue risk to the secondary burner system. This result, coupled with the crossover of fertile material to the fissile stream, makes this process alternative undesirable.

3.3.2.4. Classifier Interim Design Report. The results of the current tests, all previous tests, and the pilot plant sequential operations that were conducted with the engineering-scale particle classifier were compiled into a single report, "Interim Design Report: Engineering Scale HTGR Fuel Particle Classifier," which is being prepared for publication.

3.3.2.5. Product Samplers - Fuel Particle Air Classification System. Product samplers previously used in the fuel particle air classification system were 15-cm (6-in) laboratory Vezin samplers manufactured by the Denver Equipment Company. The Vezin samplers require removal and emptying of a tray to obtain the sample. This was considered unwieldy for hot cell use. Therefore, a gravity feed particle sampler was designed, constructed, and installed in the underflow (i.e., fertile stream) product collection system of the air classifier for testing (see Fig. 3.3-4).

Fig. 3.3-4. Sampler classifier

3.3.2.5.1. Gravity Feed Particle Sampler Test

The feed material for the gravity sampler test was underflow product from the classification test (No. TBBC-7) TRISO/BISO fuel particles (see Section 3.3.2.2). This material, originally from the pilot plant sequential operations, contained both whole and broken fuel particles and, therefore, was typical of the materials that were required to be sampled. The material was fed to the classifier at the feed rate normally used. However, in order to minimize losses to the overflow, the air velocity used was slightly lower than in the original classification. A summary of the test is given in Table 3.3-5.

At the conclusion of the test, the material in the sample was 8.5% of the total material discharged to the underflow. This quantity is considered excessive. Therefore, in the future methods will be investigated for reducing the percentage of material in the sample while maintaining the accuracy.

A comparison of the screen analysis of the gravity sample with that of the underflow material indicated no differences greater than those normally found between two screen analysis on identical material (see Table 3.3-6).

The sample and the underflow material were split sampled. Two samples of each were analyzed for uranium and thorium content to provide a further comparison. These results are given in Table 3.3-7. The analytical laboratory's estimates of the analytical errors are $\pm 0.1\%$ for uranium and $\pm 0.5\%$ for thorium. Therefore, from Table 3.3-7, no significant difference exists between the results from the sample and the underflow material or between the split samples of the same materials.

3.3.2.5.2. Vezin Particle Sampler Test

The remaining material from the gravity sampler test was used as feed for testing the Vezin sampler under identical conditions. A summary of the test is also given in Table 3.3-5.

TABLE 3.3-5
RUN SUMMARY OF CLASSIFIER PRODUCT SAMPLER TESTS

	Gravity Sampler	Vezin Sampler
Vibratory feeder, %	100	100
Air velocity, m/s	5.5	5.5
Recovery		
Underflow, %	91.5	96.8
Sample, %	8.5	3.2

TABLE 3.3-6
SCREEN ANALYSIS OF CLASSIFIER PRODUCT SAMPLER TESTS

Mesh Size (μm)	Weight %			
	Gravity Sample	Underflow	Vezin Sample	Underflow
+425	89.07	88.29	89.93	88.50
-425 +355	3.23	3.16	2.76	2.65
-355 +250	6.23	6.33	5.98	6.19
-250 +180	1.47	2.22	1.34	2.65
-180	0	0	0	0

TABLE 3.3-7
ANALYTICAL RESULTS OF CLASSIFIER PRODUCT SAMPLER TESTS

Duplicate Samples	Uranium (%)		Thorium (%)	
	Sample	Underflow	Sample	Underflow
A. Gravity Sampler				
No. 1	3.55	3.51	76.92	76.79
No. 2	3.58	3.53	76.57	76.17
Avg.	3.57	3.52	76.75	76.48
Range	0.03	0.02	0.35	0.62
B. Vezin Sampler				
No. 1	3.22	2.82	78.09	77.55
No. 2	3.24	2.88	78.04	77.54
Avg.	3.23	2.85	78.065	77.545
Range	0.02	0.06	0.05	0.01

At the conclusion of this test, the material collected in the sample tray was 3.2% of the total material discharged to the underflow. This was an improvement in sample size over the gravity sampler. However, the accuracy of the Vezin sampler was poorer.

A comparison of the screen analysis of the Vezin sample with that of the underflow material again indicated no difference greater than those normally found on identical material (see Table 3.3-6).

Identically, as with the gravity samples, the Vezin sample and the underflow material were split sampled and two samples of each were analyzed for uranium and thorium. These results are given in Table 3.3-7. From the table it can be seen that the uranium content of the Vezin sample was significantly higher than that of the underflow, but that no significant difference was displayed between the thorium contents of the two. However, the difference between the averages was approximately twice as great as the difference with the gravity sampler (i.e., $76.75 - 76.48 = 0.27\%$ for the gravity sampler and $78.065 - 77.545 = 0.52\%$ for the Vezin sampler).

3.3.2.5.3.1 Conclusions

The gravity sampler appears to provide a more representative sample of classifier product than does the Vezin sampler and is, therefore, preferable for that reason. However, the quantity of the sample needs to be reduced and methods of accomplishing this without loss of accuracy will be pursued in the future.

3.3.3. Fuel Particle Crusher

Classified materials from the classification of fuel particles containing unburned graphite (test No. TBBC-11; see Section 3.3.2.3) were crushed in the improved (see Ref. 3.3-2) fuel particle crusher to determine the effect of the graphite on the crushing operation.

The classified overflow (TRISO fertile stream) and underflow (BISO fissile stream) materials were charged separately to the fuel particle crusher (test No. ACC-13). All of the overflow material passed through the crusher, indicating the nip angle was sufficient for crushing the size of graphite fragments that would normally be contained in that stream. However, only a small quantity (about 60 g) of the underflow material passed through the crusher. Apparently the larger graphite fragments (i.e., $> 4000 \mu\text{m}$) failed to crush and quickly blinded the gap for crushing of even the smaller particles. The feed size distribution for these two tests is given in Tables 3.3-8 and 3.3-9.

After one of the earlier primary burner runs, a small quantity of agglomerated particles was found in the product. Each of these agglomerates generally consisted of no more than three or four particles, but the potential existed that they might not crush and would blind the gap of the crusher. Therefore, a small quantity of the agglomerates was fed to the particle crusher to test its ability to process this material (test No. ACC-15). All of the material passed through the crusher without problems. Since the majority of these agglomerates were $+1000\text{--}2000 \mu\text{m}$ in size, they were expected to crush as the material from the classified overheads with graphite had done previously.

3.3.4. Secondary Burners

3.3.4.1. 0.10-m Secondary Burner. Checkout of instrumentation and control on the 0.10-m secondary burner is in progress. Rerouting of wiring due to expansion of the control room necessitated the thorough checkout. Minor problems encountered are being corrected as found in preparation for the upcoming test with advanced fuel particle types.

3.3.4.2. 0.20-m Secondary Burner. A draft of an interim design report on the 0.20-m secondary burner is being prepared for publication. This report details the design task, includes historical test information, and

TABLE 3.3-8
CLASSIFIED LHTGR TRISO/BISO FUEL PARTICLES AND GRAPHITE
OVERHEADS (FERTILE STREAM) FOR PRODUCT CRUSHING TEST

	Mesh Fraction (μm)	Overheads (Fertile)	
		Feed	
		Weight (g)	%
Coarse	+4750	0	0
Graphite	-4750 +4000	0	0
Range	-4000 +2800	0.5	<0.1
	-2800 +2000	12.0	1.3
	-2000 +1000	77.5	8.1
Particle	-1000 +850	24.8	2.6
Range	-850 +425	765.5	80.3
Fine	-425 +355	9.4	1.0
Graphite	-355 +250	13.2	1.4
Range	-250	50.5	5.3
Total		953.4	100.0

TABLE 3.3-9
CLASSIFIED LHTGR TRISO/BISO FUEL PARTICLES AND GRAPHITE UNDERFLOW
(FISSILE STREAM) PRODUCT CRUSHING TEST

	Mesh Fraction (μm)	Underflow (Fissile)	
		Feed	
		Weight (g)	%
Coarse	+4750	41.1	1.4
Graphite	-4750 +4000	132.9	4.8
Range	-4000 +2800	381.1	13.8
	-2800 +2000	117.4	4.2
	-2000 +1000	26.0	1.0
Particle	-1000 +850	1911.5	69.1
Range	-850 +425	153.8	5.6
Fine	-425 +355	0	0
Graphite	-355 +250	0.5	<0.1
Range	-250		0.1
Total		2766.5	100.0

shows how the design addresses the equipment goals and operational objectives. Design calculations and considerations that support the selection of major components are included.

3.3.5. Combustion of Perchloroethylene Distillation Bottoms

Perchloroethylene is used for scrubbing the off-gasses in the HTGR fuel refabrication process. The perchloroethylene is recycled after distillation, which leaves only the distillation bottoms for disposal. Currently, a molten salt technique has been considered as the method of disposal. Combustion in a fluidized bed has been proposed for study as an alternative method. However, several uncertainties arise regarding the feasibility of using a fluidized bed system. Therefore, initial tests in laboratory-scale apparatus will be conducted to reduce the uncertainties.

Those areas of concern identified at present are:

1. The lowest practical temperature for complete combustion below the melting point of the Na_2CO_3 bed.
2. The need for a chromic trioxide coated alumina catalytic afterburner.
3. Corrosion of burner components.
4. Agglomeration or local melting in the Na_2CO_3 bed.
5. Liquid feed nozzle plugging.
6. The effects of addition of kerosene on combustion temperature.
7. The quantities of fines from NaCl production.

A schematic of the laboratory apparatus proposed for the tests is shown in Fig. 3.3-5. Basically it operates as follows. Using a hypodermic syringe, the sample mixture is injected through a septum into a heated, moving air stream. The air stream transports the sample and initial combustion products, if any, into a packed bed of Na_2CO_3 granules. The bed is maintained at the specified test temperature. The Na_2CO_3 reacts with the HCl formed by combustion-producing NaCl . Unburned materials and products of combustion (CO_2 and H_2O) exit the bed. At the exit, an evacuated tube isolated by double valving serves as a sampler for subsequent chromatographic analysis. The existing gas stream then passes through a cooling coil into a perchloroethylene bubbler. Particulates and off-gas products, which are soluble in perchloroethylene solution, and water will be analyzed to determine the conditions of combustion.

Initial checkout will be conducted on all equipment to determine operating requirements. This will be followed by scoping tests using pure perchloroethylene and mixtures with kerosene added, if required. If combustion of perchloroethylene proves feasible, testing with the actual perchloroethylene distillate bottoms will be conducted. As a process alternative, the use of a segmented bed containing Na_2CO_2 in one section and chromic trioxide coated alumina in the following section will be tested if earlier tests result in incomplete combustion.

Corrosion coupons will be placed in the Na_2CO_3 bed near the exit only for observing gross effects, if any.

The apparatus has been constructed and leak tested. Chemicals are on order.

Fig. 3.3-5. Perchloroethylene bottoms combustion laboratory scale test apparatus

REFERENCES

- 3.3-1. "HTGR Fuel Recycle Program Quarterly Progress Report for the Period Ending August 31, 1978," DOE Report GA-A14583, General Atomic Company, September 1977.
- 3.3-2. "HTGR Fuel Recycle Program Quarterly Progress Report for the Period Ending February 28, 1978," DOE Report GA-A14878, General Atomic Company, March 1978.

3.4. DRY SOLIDS HANDLING (SECONDARY SUBTASK 314)

3.4.1. Summary

A series of 300 separate tests on the effect of conveying line geometry on material transport properties were conducted. The data are presently being evaluated.

Several components (weigh systems and level detection systems) have been ordered for evaluation in the cold engineering pilot line.

The transport control affected by recent modifications has been checked out, and the total control philosophy is being reviewed and updated.

The solids handling interim design report is being prepared for publication.

3.4.2. Conveying Line Geometry Test Rig

A series of tests were run using the solids handling test rig (Fig. 3.4-1) to determine the effect of conveying line geometry on transport properties and product degradation.

Tests were performed using the following feed materials while varying the bend radius R , acceleration length L , and the conveying velocities:

<u>Test</u>	<u>Material</u>
1	Crushed graphite
2	Crushed graphite
3	Crushed graphite and TRISO kernels
4	PSC TRISO fissile
5	LHTGR BISO fertile
6	Crushed graphite and LHTGR TRISO particles

Fig. 3.4-1. Conveying line geometry test rig

The data from these test runs, approximately 300 in all, are now being correlated and will be reported in the next quarterly report.

3.4.3. Upgraded Components

Several components for testing in the engineering-scale pilot line have been purchased or are on order.

3.4.3.1. Weigh Bars. An order has been placed for a weighing system for the primary burner product bunker. This system is a tension rather than a compression system like those now in use in the pilot line. This should eliminate the critical alignment problems now experienced with the present system and make the system more adaptable to remote operations.

3.4.3.2. Level Sensors. Two types of level sensors have been ordered for evaluation in the pilot line. A vibrating rod sensor will be evaluated in the primary burner feed bunker. A high temperature level detector, which detects the presence of finely divided, cohesive materials, was ordered for installation and evaluation in the primary burner fines bunker.

3.4.4. System Modifications

Several of the transport system control systems have been modified because of the upgrading of the secondary burner product removal system. Considerable time has been spent in checking out these modifications. In addition, the total control philosophy for the solids handling system and the operating procedures are being reviewed and updated.

3.4.5. Solids Handling System Interim Design Report

The results of all of the solids handling system tests prior to and including the FY-77 sequential operation were compiled into a single report: "Interim Design Report: Engineering-Scale HTGR Fuel Solids Handling System." This report is being prepared for publication.

3.5. DISSOLUTION SYSTEMS (SUBTASK 330)

3.5.1. Summary

Calibration of process vessels for the 0.50-m (20-in.) dissolver-centrifuge system has been completed. Initial shakedown of the equipment using water as the simulated feed was completed. The equipment performed satisfactorily throughout the shakedown testing.

Modifications were made to the 0.13-m (5-in.) dissolver system in preparation for iodine and ruthenium volatility studies using radioactive tracers. Preliminary results from initial iodine volatility tests reveal that greater than 98% of the total iodine charged to the dissolver was vaporized into the overheads. Complete data reduction is underway and the final results will be reported in the next quarterly progress report.

Drying tests on insols containing residual salts were completed on February 28, 1978, meeting the 189 milestone. One water rinse of about 30 wt % SiC slurry is sufficient to reduce the thorium content in the insols to a safe level for smooth fluidized bed drying. Since the use of steam jet transfer planned for the engineering-scale repulp operation requires a more dilute slurry (about 10 wt %), the planned repulp volume for the 0.50-m dissolver-centrifuge system will encounter no drying problem. The dryer can tolerate up to about 0.3 wt % of residual thorium content in the dried SiC hulls without excessive agglomeration and caking.

A conical distributor appears to work as well as a flat distributor for drying insols, but with the added advantage of simplicity and the potential for combining repulping and drying in one vessel. It is recommended that a new conical distributor, equipped with a bottom product removal valve, be tested.

3.5.2. Dissolution Studies

3.5.2.1. 0.50-m Dissolver-Centrifuge System. Calibration of the dissolver-centrifuge vessels has been completed. Pressure test of the instrumentation lines revealed leaks, which have since been corrected. To allow checkout of components, electrical power was supplied to valves, the centrifuge, and pumps through the local control panel. Calibration of electronic instrumentation, e.g., load cells, pressure transducers, and recorders, will not commence until the control room expansion is complete. A portable recorder will be employed for system checkout until the control consoles are ready.

The process steam piping and the dissolver heating jackets were successfully pressure tested at 515 kPa (60 psig) steam. Then a shakedown run was made in the dissolver using water to simulate feed, heatup, cool-down, and slurry jet transfer to the centrifuge. All operating conditions were satisfactory.

The centrifuge operation was initially plagued with noisy seals, which has since been corrected by reducing seal coolant pressure.

In the centrifuge test performed with water as the simulated slurry, the feed velocity through the centrifuge vertical feed tube was found to be too low. Not all slurry feed had enough velocity to impact the spreader cone, which distributed the slurry radially under the centrifugal force. Some simply fell by gravity down the side of the feed tube into the repulp vessel below. The liquid carryover rate to the solids discharge end was estimated to be around 1.9 l/min (1/2 gpm). This problem will be resolved by either increasing the slurry feed rate using a larger steam jet or reducing the feed nozzle diameter to boost feed velocity.

3.5.2.2. Iodine and Ruthenium Volatility During Pilot Plant Scale Dissolution

3.5.2.2.1. Introduction

Iodine and ruthenium are potentially volatile fission products contained in ThO_2 kernels. The behavior of these radioactive elements during dissolution is important for several reasons. First, the off-gas requirements from the dissolver must be defined. Iodine will volatilize throughout the process system unless it can be driven off at one point, such as the dissolver. This will eliminate the problem of treating iodine in a wide variety of off-gas streams. Finally, ruthenium, which is highly radioactive and volatile under some conditions, should be contained in solution until it is removed in the solvent extraction process. Methods of promoting iodine volatility while suppressing ruthenium volatility during ThO_2 dissolution are the developmental objectives of this effort.

3.5.2.2.2. Experimental

The 0.13-m dissolver system, shown in Fig. 3.5-1, was used for the iodine and ruthenium volatility tests. The dissolver system was modified to include a five-stage iodine trap in the off-gas line downstream of the overhead condenser. The sampling port for the dissolver solution has been partially enclosed with a transparent bag that vents to the off-gas header system. The vent line includes a small, in-line charcoal filter to prevent iodine release to the off-gas header. The entire dissolver system was pressure checked for leaks at 48 kPa (2 psig).

3.5.2.2.3. Results and Discussion

Preliminary test results reveal that greater than 98% iodine volatility can be expected during ThO_2 dissolution when sparging with nitric oxide (NO) gas. Ruthenium volatility work has begun, but complete results are not yet available. Data reduction of iodine and ruthenium volatility tests in the 0.13-m dissolver is underway and results will be given in more detail in the next quarterly.

Fig. 3.5-1. 0.13-m dissolver system

3.5.3. Drying of SiC Hulls Containing Residual Salts

3.5.3.1. Introduction. Insols drying tests of SiC hulls containing 1.0 M $\text{Th}(\text{NO}_3)_4$ dissolver solution to simulate the maximum salt residue conceivable on the insols resulted in badly caked and agglomerated product in the dryer. It was necessary, therefore, to perform a series of tests at lower salt concentrations to define a maximum allowable salt content in the insols and to establish the minimum wash volume required.

Residual salts present in the insols include nitrates of thorium, uranium, and cadmium (a soluble neutron poison) as well as fission products. In this series of drying tests, only thorium nitrate was used. Uranyl nitrate has very similar solubility and, therefore, is expected to behave similarly.

Prior tests have established that the expected cadmium concentration of 5.7 g/l in the approximately 10 wt % moisture content will present no drying problem. In addition, these tests indicated the residual salt limit to be around a specific gravity of 1.05 to 1.1. The current series of tests (1) simulate a drying of insols separated from the dissolver solution and repulped with the estimated minimum wash volume, and (2) define the allowable limit of salt content in the insols before the onset of severe caking and agglomeration.

3.5.3.2. Experimental. Six kg of FSV fertile secondary burner ash were leached in the 0.20-m dissolver to produce approximately 18 liters of 1 M $\text{Th}(\text{NO}_3)_4$ and to recover 1.2 kg of SiC hulls for use in the insols dryer. The burner ash was taken from Run 1 of the 0.20-m secondary burner operation (Ref. 3.5-1). The dissolver product (Run 178) was then clarified through the basket centrifuge at 500 rpm for 10 min and the SiC hulls retained were sampled for moisture and thorium content. The repulp volume required to reduce the SiC thorium content to the desired level was estimated to be around 30 wt % SiC (in the repulp slurry). The slurry was

thoroughly mixed with a stirrer and again filtered through the basket centrifuge at 500 rpm for 10 min. The repulped insols were then fed to the insols dryer for Run 85.

Runs 86 and 87 were performed to duplicate conditions and to confirm previous drying test results which roughly defined marginal caking conditions to be around a specific gravity of 1.05 to 1.1 dissolver solution. Feed for Runs 86 and 87 was prepared by repulping with diluted solutions of 1.07 and 1.1 specific gravity, respectively, but then centrifuging to a similar moisture content before drying. The run parameters and insol properties for Runs 57 and 71 (earlier tests) are included here for comparison purposes.

One run was made without the flat distributor plate to simulate conical distribution in the fluidized bed.

Measurement of the thorium content in the SiC hulls was by leaching a sample with Thorex acid and titrating the leachate.

The dryer operating parameters for these tests are given in Table 3.5-1.

3.5.3.3. Results and Discussion: Table 3.5-2 is a tabulation of the effect of thorium content on the drying characteristics of SiC hulls. Wetting solution properties and moisture and thorium contents of SiC hulls are presented together with the corresponding drying characteristics.

3.5.3.3.1. Simulated Repulping and Drying of SiC Hulls with Residual Thorium Content

Dissolver Run 178 represents the centrifuged insols from the dissolver. The hulls are still wetted with the original dissolver solution. Although unwashed insols were not dried in this series of tests, two

TABLE 3.5-1
FLUIDIZED BED DRYER OPERATING PARAMETERS

Run No.	N ₂ Flow (slpm)	Inlet Gas Temp Below Distributor (°C)	Charge of SiC Hulls (g)	SiC Feed Liquid Content (wt % dry basis)	Solution Used
57	396	122	2000	20.5	1.62 sp gr dissolver product (0.966 <u>M</u> thorium)
71	436 ^(a)	77	2000	10.5	1.05 sp gr diluted dissolver (0.064 <u>M</u> thorium)
83	300	100	1941	50.0	Water
85	210	100	1075	18.8	1.03 sp gr diluted dissolver solution (0.046 <u>M</u> thorium)
86	210	100	1938	10.5	1.07 sp gr diluted dissolver solution (0.092 <u>M</u> thorium)
87	250	115	1800	14.0	1.1 sp gr diluted dissolver solution (0.123 <u>M</u> thorium)

(a) Flow rate was taken before dryer leaks were repaired and, therefore, is expected to be on the high side.

TABLE 3.5-2
 DRYING CHARACTERISTIC OF INSOLS AS A FUNCTION OF THORIUM CONTENT IN THE SiC HULLS

Item	Run No.	Description	Drying Time (h)	Residual Thorium Content in SiC (Wt % dry basis)	Drying Characteristics
1	57	Dissolver effluent	2.17	2.8	Insols caked badly into a ball
2	85	First repulp of SiC hulls separated from dissolver Run 178 (repulp in 28.5 wt % slurry)	1.15	0.2	Smooth and troublefree drying with free flowing products. A white powder of thorium nitrate of negligible weight was observed coating the glass column.
3	71	SiC hulls wetted with 1.05 sp gr diluted dissolver solution	1.25	0.15	Smooth drying
4	86	Repulped SiC hulls in 1.07 sp gr diluted dissolver solution and then centrifuged	2.63	0.3	A few clumps of -0.3 cm (-1/8 in.) size were observed; patches of thin cake coating formed covering 15 cm ² of glass wall near bottom; product still free flowing.
5	87	Repulped SiC hulls in 1.1 sp gr diluted dissolver effluent and then centrifuged	2.42	0.8 ^(a) (0.4)	Agglomerated into a ball above the distributor; 50% distributor holes plugged around the periphery; above distributor pressure tap purge line was plugged causing pressure gage rupture.

(a) The thorium content of this run is much higher than it should be due to insufficient rinsing of the SiC hulls, which had been used repeatedly for previous runs. The estimated value, based on the thorium concentration in the wetting solution and the moisture content, is included in parentheses.

previous drying tests (Runs 56 and 57) had shown that severe caking resulted. The 2.8 wt % thorium content in the dried SiC hulls simulates the maximum conceivable salt residue that would be present on the insols if no repulping of the insols were made. It is obvious that if the moisture content of the insols is halved (e.g., centrifuged at a higher g-force) the residual thorium content is reduced by a factor of 2. The 20% moisture content, however, represents a very conservative limit.

A continuous centrifuge, on the other hand, can produce a more consistent solids discharge. Drying tests should be performed in conjunction with the vertical centrifuge tests and repulping studies in the engineering-scale system.

Insols from dissolver Run 178 were repulped in water to make a 28.5 wt % SiC slurry. If the repulped slurry had been transferred by steam jet (as in the engineering-scale equipment), the slurry concentration would be even lower (perhaps 10 to 20 wt % solids in slurry). Therefore, the salt content measured here in the repulped insols is conservative and representative of the operation to be expected in the 0.50-m dissolver-centrifuge system.

Subsequent drying of the repulped insols in the fluidized bed dryer was smooth and trouble free. No agglomeration of SiC hulls was observed. However, a thin layer of thorium nitrate powder and insols coating was observed in the upper section of the glass column, where the abrasive hulls did not reach to scrub the wall surface. The layer of powder was negligible in weight.

3.5.3.3.2. Maximum Allowable Residual Salt Content in SiC Hulls

Items 3 through 5 in Table 3.5-2 serve to define the maximum allowable residual thorium content in the SiC hulls without causing caking during

fluidized bed drying. Prior drying tests showed that the specific gravity limit falls between 1.05 and 1.1 diluted dissolver solutions, which are equivalent to 0.15 wt % and 0.4 wt % residual thorium in the hulls, respectively. Run 86 (item 4) further narrowed the gap to a 1.07 specific gravity solution at a residual thorium content of 0.3 wt %, at which point a few -0.3 cm (-1/8 in.) clumps and minor caking on the lower section of the glass column were visible. However, a free flowing product was still obtained.

Run 87 depicted severe agglomeration and caking at high residual thorium content. Fifty percent of the distributor holes were plugged, especially around the periphery of the plate. The pressure tap purge above the distributor was plugged, causing pressurization of the purge line and gage. Product removal through the Volkswagen valve was impossible. The dryer had to be disassembled in order to remove the caked insols. In the engineering-scale dryer design, provision to remove potential caked insols (for example, due to failure of a rinse) should be considered.

It is believed that the residual thorium content in the final dried SiC hulls alone determines caking and agglomeration. Therefore, a number of combinations of wetting solution concentration and mixture content can still produce the same drying characteristics, as long as the final residual thorium content in the dried insols remains the same. An acceptable criterion for a smooth drying operation would be to keep the allowable residual thorium in dried insols below 0.3 wt %. Knowing the thorium concentration of the wetting solution and the residual moisture content in the wet insols before drying, the final residual thorium content can be computed before a drying run.

3.5.3.3.3. Conical Distributor for Dryer

In Run 83, a conical distributor was used. During the initial phase, wet insols were observed to stick to the side wall and cone. Considerable channeling was observed through the center. No fluidization was evident.

As drying progressed, more and more insols rose through the center of the dryer and came down the side wall. It was found that the sweep tube located just above the cone helped to dislodge wet insols from the side of the cone and prevented the formation of a central "rate-hole." A drying time of 2.67 h was required for Run 83.

No stationary wet slug was observed with conical distributor drying. The slug is a form of bridging and is normally observed in the dryer with a flat distributor. The formation of such a slug lessens the advantage of fluidized bed drying because the slug behaves as a packed bed. Most of the drying gas bypasses the slug through channels between the slug and the wall. Although the wet slug eventually breaks up after 1 to 2 h as drying progresses, the efficiency of the dryer is greatly compromised.

A conical distributor eliminates the potential residual salts plugging problem associated with a flat distributor plate. It also facilitates repulping of the insols in the dryer, without the operational complication associated with preventing water and insols from seeping through the distributor holes while repulping. The disadvantage of the conical distributor would be a potential channeling problem with the wet insols at the vertex gas inlet. This problem, however, can possibly be resolved by a strategically located sweep tube to agitate the wet insols, and by keeping the cone surface hot enough to prevent wet insols from sticking to the cone slopes.

3.5.3.4. Conclusions.

1. One water rinse (about 30 wt % SiC slurry) is sufficient to reduce the thorium content in the insols to a safe level for smooth fluidized bed drying. The use of a steam jet transfer device for the engineering-scale repulp operation dictates a more dilute slurry (10 wt %). Therefore, the planned repulp volume for the 0.50-m dissolver-centrifuge system will reduce thorium content in the insols low enough to give no problem in drying.

2. The residual thorium content in the insols determines the drying characteristics. The dryer can tolerate up to 0.3 wt % residual thorium content in the dried SiC hulls without excessive agglomeration and caking. By knowing the moisture content of the insols and by sampling the rinse solution salt concentration, the residual thorium content can be predicted before a drying run, therefore assuring smooth drying as well as maximum recovery of thorium or uranium.
3. A conical distributor appears to work as well as a flat distributor for drying insols. However, the conical distributor has the added advantages of simplicity and the potential for combining repulping and drying operations in one vessel.

REFERENCE

- 3.5-1. Rickman, W. S., "Process Development Report - 0.2 m Secondary Burner System," ERDA Report GA-A14542, General Atomic Company, September 1977, p. 2-18.

3.6. OFF-GAS TREATMENT AND RETENTION PROCESSES (SUBTASK 340)

3.6.1. Summary

An overall procurement and installation schedule has been developed that will constantly be updated to keep track of all activities. The detailed design of the engineering-scale off-gas system, including all the adsorption and catalytic reaction vessels and the CO/HT oxidizer, has been completed as scheduled. The fabrication of the vessels and CO oxidizer is in progress. Purchase requisitions for all the heat exchangers, heaters, controllers, recorders, meters, piping, and corresponding fittings have been sent out.

A preliminary hazard analysis and a fault tree analysis were completed for the burner off-gas and dissolver off-gas pilot plant.

3.6.2. Procurement Schedule

An overall work schedule has been produced. It shows all design, procurement, and installation activities required for the completion of the installation of the system by October 1, 1978. This schedule (Fig. 3.6-1) will constantly be updated to track all relevant activities.

3.6.3. Fabrication and Installation

The detailed design of the engineering-scale off-gas system (including that of the CO/HT oxidizer) has been completed as scheduled. Detailed fabrication and assembly drawings of all the vessels (adsorbers and catalytic reactors) have been finalized. Fabrication of the vessels is in progress. Their completion has been scheduled for June 1, 1978. Figure 3.6-2 shows the general arrangement of the equipment on the platform. Figures 3.6-3 and 3.6-4 show typical adsorber designs, namely the Radon holdup bed and the SO₂ adsorber, respectively.

Fig. 3.6-1. Installation schedule for off-gas system

NOTES:
 UNISTROT CORP.
 4118 SO. WAYNE CO.
 WAYNE, MICH. 48184
 PHILLIPS DRILL CO.
 MICHIGAN CITY, INDIANA.

ITEM	PART NO.	DESCRIPTION	QTY	UNIT	REMARKS
1	44	14000	2	DO NOT COOL	
1	45	14000	2	DO NOT COOL	
2	46	14000	2	DO NOT COOL	
3	47	14000	2	DO NOT COOL	
4	48	14000	2	DO NOT COOL	
5	49	14000	2	DO NOT COOL	
6	50	14000	2	DO NOT COOL	
7	51	14000	2	DO NOT COOL	
8	52	14000	2	DO NOT COOL	
9	53	14000	2	DO NOT COOL	
10	54	14000	2	DO NOT COOL	
11	55	14000	2	DO NOT COOL	
12	56	14000	2	DO NOT COOL	
13	57	14000	2	DO NOT COOL	
14	58	14000	2	DO NOT COOL	
15	59	14000	2	DO NOT COOL	
16	60	14000	2	DO NOT COOL	
17	61	14000	2	DO NOT COOL	
18	62	14000	2	DO NOT COOL	
19	63	14000	2	DO NOT COOL	
20	64	14000	2	DO NOT COOL	
21	65	14000	2	DO NOT COOL	
22	66	14000	2	DO NOT COOL	
23	67	14000	2	DO NOT COOL	
24	68	14000	2	DO NOT COOL	
25	69	14000	2	DO NOT COOL	
26	70	14000	2	DO NOT COOL	
27	71	14000	2	DO NOT COOL	
28	72	14000	2	DO NOT COOL	
29	73	14000	2	DO NOT COOL	
30	74	14000	2	DO NOT COOL	
31	75	14000	2	DO NOT COOL	
32	76	14000	2	DO NOT COOL	
33	77	14000	2	DO NOT COOL	
34	78	14000	2	DO NOT COOL	
35	79	14000	2	DO NOT COOL	
36	80	14000	2	DO NOT COOL	
37	81	14000	2	DO NOT COOL	
38	82	14000	2	DO NOT COOL	
39	83	14000	2	DO NOT COOL	
40	84	14000	2	DO NOT COOL	
41	85	14000	2	DO NOT COOL	
42	86	14000	2	DO NOT COOL	
43	87	14000	2	DO NOT COOL	
44	88	14000	2	DO NOT COOL	
45	89	14000	2	DO NOT COOL	
46	90	14000	2	DO NOT COOL	
47	91	14000	2	DO NOT COOL	
48	92	14000	2	DO NOT COOL	
49	93	14000	2	DO NOT COOL	
50	94	14000	2	DO NOT COOL	
51	95	14000	2	DO NOT COOL	
52	96	14000	2	DO NOT COOL	
53	97	14000	2	DO NOT COOL	
54	98	14000	2	DO NOT COOL	
55	99	14000	2	DO NOT COOL	
56	100	14000	2	DO NOT COOL	
57	101	14000	2	DO NOT COOL	
58	102	14000	2	DO NOT COOL	
59	103	14000	2	DO NOT COOL	
60	104	14000	2	DO NOT COOL	
61	105	14000	2	DO NOT COOL	
62	106	14000	2	DO NOT COOL	
63	107	14000	2	DO NOT COOL	
64	108	14000	2	DO NOT COOL	
65	109	14000	2	DO NOT COOL	
66	110	14000	2	DO NOT COOL	
67	111	14000	2	DO NOT COOL	
68	112	14000	2	DO NOT COOL	
69	113	14000	2	DO NOT COOL	
70	114	14000	2	DO NOT COOL	
71	115	14000	2	DO NOT COOL	
72	116	14000	2	DO NOT COOL	
73	117	14000	2	DO NOT COOL	
74	118	14000	2	DO NOT COOL	
75	119	14000	2	DO NOT COOL	
76	120	14000	2	DO NOT COOL	
77	121	14000	2	DO NOT COOL	
78	122	14000	2	DO NOT COOL	
79	123	14000	2	DO NOT COOL	
80	124	14000	2	DO NOT COOL	
81	125	14000	2	DO NOT COOL	
82	126	14000	2	DO NOT COOL	
83	127	14000	2	DO NOT COOL	
84	128	14000	2	DO NOT COOL	
85	129	14000	2	DO NOT COOL	
86	130	14000	2	DO NOT COOL	
87	131	14000	2	DO NOT COOL	
88	132	14000	2	DO NOT COOL	
89	133	14000	2	DO NOT COOL	
90	134	14000	2	DO NOT COOL	
91	135	14000	2	DO NOT COOL	
92	136	14000	2	DO NOT COOL	
93	137	14000	2	DO NOT COOL	
94	138	14000	2	DO NOT COOL	
95	139	14000	2	DO NOT COOL	
96	140	14000	2	DO NOT COOL	
97	141	14000	2	DO NOT COOL	
98	142	14000	2	DO NOT COOL	
99	143	14000	2	DO NOT COOL	
100	144	14000	2	DO NOT COOL	

Fig. 3.6-2. General arrangement of the equipment

- NOTES**
1. NORMAL OPERATING CONDITIONS:
18.3 PSIA @ 77°F
 2. FABRICATE IN ACCORDANCE WITH SECTION VIII OF ASME B+PV CODE. STAMP IS NOT REQUIRED
 3. PRESSURE TEST WITH 50 PSIG HE LEAK RATE TO CONFORM TO QDI LTH-3801 A
 4. SOLVENT CLEAN AND SEAL OPENINGS PRIOR TO SHIPPING.
 5. VESSEL WT. =
CONTENTS: HYDROGEN MORDENITE ZEOLON 900H = 467 LBS.
GROSS WT. =
 6. POSITION ITEM 5 FOR BOLTS TO CLEAR ITEM 16, MARKED P.
 7. WELD BY GMP OR GTA PROCESS
 8. PENETRANT INSPECT PER QDI-PT3801
 9. DESIGN CONDITIONS, 50 PSIG @ 930°F
 10. SOURCE: LADISH

ITEM	PART NO.	DESCRIPTION	MATL	QTY
8	26	3/8-11 HEX NUT	SST 316	SA 194
12	25	1"-8 HEX NUT	SST 316	SA 194
1	24	5650121-17 SCREEN ASS'Y.		
8	23	5/8 LOCKWASHER	SST 316	SA 240
8	22	5/8 PLAINWASHER	SST 316	SA 240
8	21	5/8-11 UNC-2A x 2 7/8 LG. HEX HD	SST 316	SA 193
1	20	GASKET, 1/8 THICK	GRAFOIL	
12	19	1"-8 LOCKWASHER	SST 316	SA 240
12	18	1"-8 PLAINWASHER	SST 316	SA 240
12	17	1"-UNC-2A x 4 1/8 LG. HEX HD	SST 316	SA 193
8	16	ROUND 1 1/2 DIA	SST 316L	SA-479
1	15	BLIND FLANGE 4"	SST 316L	SA-182
2	14	5650121-14 BRACKET, MTG.		
1	13	5650121-8 SCREEN		
1	12	GASKET, 1/8 THICK	GRAFOIL	
1	11	BLIND FLANGE 14"-150"	SST 316L	SA-182
1	10	CAP 14" SCH 10S	SST 316L	SA-122
2	9	PIPE 2" SCH 10S	SST 316L	SA-312
2	8	FLANGE, SLIP-ON 2"-150"	SST 316L	SA-52
1	7	PIPE 4" SCH 10S	SST 316L	SA-312
1	6	FLANGE, SLIP-ON 4"-50"	SST 316L	SA-52
1	5	FLANGE, SLIP-ON 2"-50"	SST 316L	SA-52
1	4	PIPE 14" SCH 10S	SST 316L	SA-312
1	3	5650121-3 SCREEN ASSY		
1	2	3650120-3 BRACKET, SAMPLING ASSY		
1	1	ASSEMBLY		

Fig. 3.6-3. Radon holdup bed

		12	27		1'-8	HEX NUT	SST 316	SA-194
		8	26		5/8-11	HEX NUT	SST 316	SA-194
			25					
		1	24	5650121-16	SCREEN ASSY			
		8	23		5/8 φ LOCKWASHER	SST 316	SA-240	
		8	22		5/8 φ PLAINWASHER	SST 316	SA-240	
		8	21		5/8-11UNC-2A x 2 7/8 LG HEX HD.	SST 316	SA-193	
		1	20		GASKET, 1/16 TH'K.	GRAFOIL		
		12	19		1' φ LOCKWASHER	SST 316	SA-240	
		12	18		1' φ PLAINWASHER	SST 316	SA-240	
		12	17		1'-8UNC-2A x 4 1/8 LG HEX HD.	SST 316	SA-193	
		5	16		ROUND 1 1/2 φ	SST 316L	SA-479	
		1	15		BLIND FLANGE 4"-150"	SST 316L	SA-182	
		2	14	5650121-14	BRACKET, MTG.			
		1	13	5650121-7	SCREEN			
		1	12		GASKET, 1/16 TH'K	GRAFOIL		
		1	11		BLIND FLANGE 14"-150"	SST 316L	SA-182	
		1	10		CAP, 14" SCH 10	SST 316L	SA-182	
		2	9		PIPE, 2" SCH 10S	SST 316L	SA-312	
		2	8		FLANGE, SLIP ON 2"-150"	SST 316L	SA-182	
		1	7		PIPE, 4" SCH 10S	SST 316L	SA-312	
		1	6		FLANGE, SLIP ON 4"-150"	SST 316L	SA-182	
		1	5		FLANGE, S. = 3/4 14"-150"	SST 316L	SA-182	
		1	4		PIPE, 1/2" SCH 10S	SST 316L	SA-312	
		1	3	5650121-2	SCREEN ASSY			
		1	2	5650120-2	GASKET, SAMPLING ASSY			
			1		ASSEMBLY			
		-1						
		ITEM	PART NO	DESCRIPTION				
				LIST OF MATERIAL				

- ALL FLANGES TO BE ASA B16.5 150 LB. RAISED FACE. GASKET FACE TO BE SMOOTH TO 100 MICROINCH AND FLAT WITHIN 1.001.
- GASKET DIMENSIONS TO CONFORM TO REQUIREMENTS OF ASA B16.21 FOR 150 LB. RAISED FACE STEEL FLANGES.

NOTES:

- NORMAL OPERATING CONDITIONS:
21.7 PSIA @ 122°F
- FABRICATE IN ACCORDANCE WITH SECTION VII OF ASME B+PV CODE. STAMP IS NOT REQUIRED.
- PRESSURE TEST WITH 50 PSIG HE LEAK RATE TO CONFORM TO (QDI-111-3401 A)
- SOLVENT CLEAN AND SEAL OPENINGS PRIOR TO SHIPPING
- VESSEL WT = (LATER)
CONTENTS: NORTON BLOON 900 = 70 LBS.
GROSS WT = (LATER)
- POSITION ITEM 5 FOR BOLTS TO CLEAR ITEM 16, MARKED P
- WELD BY GMA OR GTA PROCESS
- PENETRANT INSPECT PER QDI-PT 3801
- DESIGN CONDITIONS, 50 PSIG @ 930°F
- SOURCE: LADISH

1. ALL FLANGES TO BE ASA BIG 5 150 LB. RAISED FACE. GASKET FACE TO BE SMOOTH TO 100 MICROINCH AND FLAT WITHIN 1.001.
2. GASKET DIMENSIONS TO CONFORM TO REQUIREMENTS OF ASA BIG 21 FOR 150 LB. RAISED FACE STEEL FLANGES.

- NOTES:
1. NORMAL OPERATING CONDITIONS: 21.7 PSIA @ 122°F
 2. FABRICATE IN ACCORDANCE WITH SECTION VII OF ASME B+PV CODE. STAMP IS NOT REQUIRED.
 3. PRESSURE TEST WITH 50 PSIG HE LEAK RATE TO CONFORM TO (Q111 L111-3801 A)
 4. SOLVENT CLEAN AND SEAL OPENINGS PRIOR TO SHIPPING.
 5. VESSEL WT. = (LATER)
CONTENTS: NORTON ECLON 900 = 70 LBS.
GROSS WT. = (LATER)
 6. POSITION ITEM 5 FOR BOLTS TO CLEAR ITEM 16, MARKED P
 7. WELD BY GMA OR GTA PROCESS
 8. PENETRANT INSPECT PER QDI - PT 3801
 9. DESIGN CONDITIONS, 50 PSIG @ 930°F
 10. SOURCE: LADISH.

		12	27	1'-8 HEX NUT	SST 316	SA-194
		8	26	5/8-11 HEX NUT	SST 316	SA-194
			25			
		1	24	5650121-16 SCREEN ASSY.		
		8	23	5/8 φ LOCKWASHER	SST 316	SA-240
		8	22	5/8 φ PLAINWASHER	SST 316	SA-240
		8	21	5/8-11UNC-2A x 2 1/8 LG HEX HD.	SST 316	SA-193
		1	20	GASKET, 1/16 TH'K.	GRAFOIL	
		12	19	1' φ LOCKWASHER	SST 316	SA-240
		12	18	1' φ PLAINWASHER	SST 316	SA-240
		12	17	1'-8UNC-2A x 4 1/8 LG HEX HD.	SST 316	SA-193
		5	16	ROUND 1 1/2 φ	SST 316L	SA-479
		1	15	BLIND FLANGE 4'-150"	SST 316L	SA-132
		2	14	5650121-14 BRACKET, MTG.		
		1	13	5650121-7 SCREEN		
		1	12	GASKET, 1/16 TH'K.	GRAFOIL	
		1	11	BLIND FLANGE 14'-150"	SST 316L	SA-132
		1	10	CAP, 14" SCH 10	SST 316L	SA-132
		2	9	PIPE, 2" SCH 10S	SST 316L	SA-312
		2	8	FLANGE, SLIP ON 2"-150"	SST 316L	SA-132
		1	7	PIPE, 4" SCH 10S	SST 316L	SA-312
		1	6	FLANGE, SLIP ON 4"-150"	SST 316L	SA-132
		1	5	FLANGE, S. F. 14"-150"	SST 316L	SA-132
		1	4	PIPE, 14" SCH 10S	SST 316L	SA-312
		1	3	5650121-2 SCREEN ASSY		
		1	2	5650120-2 BRACKET, SAMPLING ASSY		
			1	ASSEMBLY		
		-1				
REQD/ASSEMBLY	ITEM	PART NO	DESCRIPTION	MATL

The CO/HT oxidizer heat exchanger design calculations have been performed for a variety of heat exchanger configurations. The one presenting the lowest pressure drop and best process gas mixing at exit has been selected, and its detailed design completed. June 30, 1978 has been set for completion of the fabrication of the oxidizer. Figure 3.6-5 shows the detailed design configuration for the CO/HT oxidizer.

The remodeling of the platform and the expansion of the control room are in progress. The completion date has been set for May 26, 1978. Figures 3.6-6 and 3.6-7 show the platform and control room undergoing remodeling.

Purchase orders for major control instrumentation and other long-lead items, such as the Diogenes digital process controller, recorders, control valves, flow meters, heaters, heat exchangers, as well as piping, valves, and fittings, have been sent out, and some items have already been received. Other shipments have been scheduled for arrival as late as mid-August 1978.

3.6.4. CO/HT Oxidizer Design

The CO oxidizer is a series of chemical reactors and air-cooled heat exchange units that form six stages. Each stage has a platinum-impregnated alumina/silica catalyst bed followed by a shrouded tube heat exchanger. Oxygen at a controlled rate of flow is to be introduced into a 350°C hot process gas stream, at each stage, immediately before entering the catalyst bed. The exothermic conversion of $\text{CO} + 1/2 \text{O}_2 \rightarrow \text{CO}_2$ takes place at each catalyst bed, producing an outlet temperature of up to 700°C. Then, a counterflow air-cooled heat exchanger cools the outlet stream to 350°C before it enters the next stage.

The heat transfer coefficients for each gas flow were evaluated at small increments along the exchanger tubes from which the overall heat transfer coefficient was computed. Figures 3.6-8 and 3.6-9 show the calculated heat exchanger performance at maximum design flow rates.

2

4

NOTES:

△ SOURCE: SWAGELOCK, SAN DIEGO, CAL.
 △ SOURCE: LADISH, LOS ANGELES, CAL.

3 FABRICATE PER SECTION VII OF ASME B4PV CODE.
 NO STAMP REQ'D.
 DES'GN CONDITIONS:
 50 PSIG @ 1500 °F
 OPERATING CONDITIONS:
 10 PSIG @ 1500 °F

4 PENETRANT INSPECT PER QP1-PT 8501. NO CRACKS ALLOWED.
 5 WELD BY SMA OR STA PROCESS.

ITEM	PART NO.	DESCRIPTION	DATE
112	25	WASHER STD - 3/8	SST 304 FRW 04
1	22	5650125-4 END PLATE	
56	21	WASHER LOCK - 3/8	SST 304 FRW-04
56	20	NUT HEX HD 5/8-10	SST 304 SA193 BN
56	19	SCREW CAP 5/8-10 x 3	SST 304 SA193 BN
7	18	GASKET	
2	17	5650127-6 END ASSY	
1	16	-16 CO OXIDIZER ASSY	
1	15	5650126-1 BELLOW ASSY	
1	14	5650125-11 SHIELD TUBE	
1	13	5650125-2 COVER	
1	12	5650127-1 COOLANT TUBE ASSY	
1	11	34415 HEX HD FLG-1 INPT, 150°	SST 304 SA 182
1	10	34415 HEX HD FLG-1 1/2 INPT, 150°	SA 182
2	9	55 200 x 25 T/C CONNECTOR	
5	8	55-400-142T GAS EXHAUST CONNECT	SST 304
2	7	5650127-7 REPLICATED RATE	
1	6	5650125-1 TUBE ASSY	
1	5	5650126-4 LOWER HOUSING	
1	4	5650126-2 UPPER HOUSING	
1	3	5650126-1 UPPER HOUSING	
1	2	-2 ASSY (G BEO)	
5	1	-1 ASSY (S BEO)	
1	0	-0 ASSY (S BEO)

Fig. 3.6-6. Remodeled platform for off-gas system installation. (Upper arrow shows the expansion in control room and the lower arrows show an area for gas bottles and a recess to accommodate tall adsorption vessels)

Fig. 3.6-7. Platform for the off-gas system installation. (The arrow shows a cut out in the platform to accommodate tall adsorption vessels. The partially completed expanded control room for the off-gas system is seen at center)

Fig. 3.6-8. Shrouded tube heat exchanger temperature profile

Fig. 3.6-9. Shrouded tube heat exchanger pressure drop

3.6.5. Flowsheets

Process flow diagrams for both the burner off-gas (BOG) and the dissolver off-gas (DOG) systems are being revised to incorporate the modified CO/HT oxidizer arrangement and situation, two new heat exchangers, and an updated material balance.

The piping and instrumentation diagrams (P&Is) are also being updated to include all the added instrumentation as well as show the changes made in process flow diagrams.

3.6.6. Utilities

Three new heat exchangers have been added to the system: two to BOG and one to the utility system. The one serving the utility system will produce 10°C chilled cooling water to be used in other process coolers. The other two will use 25°C cooling water from the cooling tower.

The total cooling water required has been estimated to be 1336 kg/h for BOG and 118 kg/h for DOG systems. Three kinds are needed: -4°C chilled 50% water 50% ethyleneglycol mixture, 10°C chilled cooling water, and 25°C cooling water.

The existing cooling water system is scheduled to be upgraded to provide an additional 30 tons of capacity. This will be accomplished by installation of an additional cooling tower, circulating pumps, fan dampers, and the extension of cooling water piping.

To obtain the -4°C chilled 50% water 50% ethyleneglycol mixture, a 5-ton chilled water unit has been ordered.

Total electrical consumption has been estimated to be 35 kW for BOG and 18 kW for DOG.

3.6.7. Safety Analysis

A preliminary hazard analysis and fault tree analysis were completed for the BOG and DOG pilot plant. Recommendations have been made, reviewed, and incorporated into the system design. Special emphasis was placed on the specification of additional instrument and control equipment requirements to allow the prompt development and release of purchase orders for those items.

3.7. SEPARATION PROCESSES (SUBTASK 350)

3.7.1. Summary

There was no activity on solvent extraction feed adjustment during this quarter.

One solvent extraction run made last quarter is reported herein. The modified Purex process demonstrated for fissile particle uranium recovery gave satisfactory operational performance even with exaggerated amounts of DBP added to the first cycle system.

3.7.2. Solvent Extraction

3.7.2.1. Introduction and Discussion. A modified Purex process will be used in the HRRF to separate unburned fissile particle uranium from fission products. As in the Acid-Thorex process, 30% TBP in NPH will be used for the separation. The Purex process uses an acidic feed (H^+ = about 2 M). The uranium concentration in the feed solution (from dissolver operations) is limited by fission product content and handling requirements and is expected to be about 12 g/liter.

Due to proliferation and operational considerations, plutonium will not be separated in a partition column (5PU). Rather, plutonium will be reduced in the second extraction column (6A) with ferrous ion and removed in the aqueous waste stream (6AW), which also contains fission products.

The ultimate use of recovered uranium will depend on the amount of U-236 present in the product. U-236 is a neutron poison and, therefore, may prohibit use of recovered uranium in fuel manufacturing operations unless isotopic separation methods are perfected.

3.7.2.2. Experimental and Results. Four 0.05-m (2-in.) diameter columns were used in the pilot plant to test the Purex flowsheet. Extraction sections of 4 m (13 ft) were used in the 5A and 6A columns with scrub sections of 3 m (9 ft) and 1.2 m (4 ft), respectively. The 5B and 6B stripping lengths were 4.6 m (15 ft) and 5.2 m (17 ft), respectively. Stream samples were removed during the run for wet chemical analyses. Figure 3.7-1 shows the flowsheet for the Purex process.

Table 3.7-1 contains a description of the pulsed columns and column cartridges used. Table 3.7-2 contains the stream and analytical data. Table 3.7-3 contains height equivalent to a theoretical stage (HETS), percentage loss, and flooding data. A comparison of data from the SEPHIS computer code with analytical stream values is given in Table 3.7-4. Uranium and H^+ material balances are given in Table 3.7-5.

3.7.2.3. Conclusions. Pilot plant operation demonstrated acceptable column performance and capacities.

The use of a longer 6B stripping column and/or increased 6BX flow is suggested to reduce uranium inventory in the 6B column (as indicated from the SEPHIS profile).

The effect of DBP is readily apparent in the first stripping column (5B). Significant uranium losses via the 5BW waste stream occurred as a result of DBP in the 5B column. However, the exaggerated amount of DBP added (0.3 g/liter in 5BW) did not cause significant operational problems. Fission product/uranium decontamination factors (DFs) were not calculated for Run 106 due to the unavailability of Zr-95 tracer.

Stream compositional predictions obtained from SEPHIS analysis compared well with wet chemical analytical values (see Table 3.7-4) and demonstrate the usefulness of the computer code in run characterizations.

STREAM	STREAM NO.	RELATIVE FLOW	U (G/L)	HNO ₃ M
5AF	1	100	12	2.0
5AX	2	64	[30% TBP]	
5AS	3	25		1.0
(5A DBP)	(4)	(1)	[30% TBP]	[DBP = 25 G/L]
5AW	5			
5AP	6			
5BX	7	67		0.01
5BW	8			
5BU	9			
6AA	10	2		13
6AF	11			
6AS	12	20	[Fe ⁺⁺ = 0.05 M]	2.5
6AX	13	46	[30% TBP]	
6AW	14			
6AP	15			
6BX	16	39		0.01
6BW	17			
6BP	18			

Fig. 3.7-1. Purex two-cycle fissile particle HRRF flowsheet

TABLE 3.7-1
CARTRIDGE DESCRIPTION FOR PUREX TWO-CYCLE FISSILE PARTICLE HRRF FLOWSHEET

Column	Column Diameter (cm) (in.)	Cartridge Height (m) (ft)	Plates		% Free Area	Plate Spacing (cm) (in.)	Pulse Amplitude (cm) (in.)
			Nozzle Direction	Hole Size (mm) (in.)			
5A extraction	5.1(2)	4.0(13)	Down	3.2(1/8)	23	5.1(2)	2.5(1)
5B scrub	5.1(2)	2.7(9)	Down	3.2(1/8)	23	5.1(2)	2.5(1)
5B stripping	5.1(2)	4.6(15)	Up	4.8(3/16)	23	5.1(2)	2.5(1)
6A extraction	5.1(2)	4.0(13)	Down	3.2(1/8)	23	5.1(2)	2.5(1)
6B scrub	5.1(2)	1.2(4)	Down	3.2(1/8)	23	5.1(2)	2.5(1)
6B stripping	5.1(2)	5.2(17)	Up	4.8(3/16)	23	5.1(2)	2.5(1)

TABLE 3.7-2
STREAM AND ANALYTICAL DATA FOR PUREX TWO CYCLE FISSILE PARTICLE HRRF FLOWSHEET

Stream	Stream No.	U (g/l)	HNO ₃ (M)	Zr (g/l)	Flow (ml/min)	Relative Flow	Other
5AF	1	13.0	2.30	7.5×10^{-3}	708	100	
5AX	2	--	[30% TBP]		460	65	29.48% TBP
5AS	3	--	1.28		165	23	
5A DBP	4				6	0.8	23 g/l DBP
5AW	5	3.2×10^{-3} $<0.4 \times 10^{-3}$	1.84 1.85	$<2.0 \times 10^{-3}$ $<2.0 \times 10^{-3}$	873	123	
5AP	6	20.0 20.1	0.198 0.214		466	66	0.3 g/l DBP 0.5 g/l DBP
5BX	7		0.01		564	80	
5BW	8	$<0.4 \times 10^{-3}$ 0.21	0.011 0.011		466	66	0.02 g/l (DBP; 29.38% TBP) 0.03 g/l (DBP)
5BU	9	16.0 16.3	0.165 0.198	5.0×10^{-3} 5.0×10^{-3}	564	80	
6AA	10				22	3.1	
6AF	11				586	82	
6AS	12		2.24		168	24	0.025 M Fe ⁺²

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TABLE 3.7-2 (Continued)

Stream	Stream No.	U (g/l)	HNO ₃ (M)	Zr (g/l)	Flow (ml/min)	Relative Flow	Other
6AX	13				337	48	
6AW	14	4.0 x 10 ⁻³ 0.02	0.918 0.786		754	106	
6AP	15	29.7 26.6	0.366 0.366		337	48	
6BX	16				303	43	
6BW	17	<0.4 x 10 ⁻³ <0.4 x 10 ⁻³	0.011 0.011		337	48	29.48% TBP
6BP	18	28.1 29.2	0.428 0.428		303	43	

TABLE 3.7-3
HETS, PERCENTAGE LOSS, AND FLOODING DATA FOR PUREX TWO-CYCLE FISSILE PARTICLE HRRF FLOWSHEET

Column	HETS (m) (ft)	Volume ^(a) Velocity (gal/hr/ft ²)	$\bar{V}_a$ (cm/s)	$\bar{V}_o$ (cm/s)	Flooding Frequency (cpm)	Continuous Phase	Aqueous to Organic Ratio	% Loss U	% Flooding Frequency	Temperature (°C)
5A	1.16(3.80)	973.5	0.718	0.383	131	Organic	1.87	0.025	67	Ambient
	0.99(3.26)							0.003		
5B	1.26(4.13)	748.8	0.464	0.383	119	Aqueous	1.21	0.002	72	50
	1.63(5.36)							1.05		
6A	0.85(2.79)	793.2	0.620	0.277	103	Organic	2.24	0.026	83	Ambient
	0.70(2.30)							0.127		
6B		465.3	0.249	0.277	77	Aqueous	0.90	0.001	94	50
								0.002		

^(a) Metric equivalents are in the two columns to the right ($\bar{V}_a$ and $\bar{V}_o$)

TABLE 3.7-4
COMPARISON OF SEPHIS CALCULATIONS FOR PUREX TWO-CYCLE
FISSILE PARTICLE HRRF FLOWSHEET

Output Stream	Analytical Value		SEPHIS Prediction	
	U (g/l)	H ⁺ (M)	U (g/l)	H ⁺ (M)
5AP	20.0	0.198	20.0	0.31
	20.1	0.214		
5AW	3.2×10^{-3}	1.84	2.8×10^{-5}	1.93
	$<0.4 \times 10^{-3}$	1.85		
5BU	16.0	0.165	16.5	0.29
	16.3	0.198		
5BW	$<0.4 \times 10^{-3}$	0.011	8.2×10^{-11}	4×10^{-5}
	0.21	0.011		
6AP	29.7	0.366	27.6	0.42
	26.6	0.366		
6AW	4×10^{-3}	0.918	8×10^{-3}	0.97
	0.02	0.786		
6BU	28.1	0.428	29.6	0.48
	29.2	0.428		
6BW	0.4×10^{-3}	0.011	9.3×10^{-1}	5.1×10^{-4}

TABLE 3.7-5
MATERIAL ACCOUNTABILITY FOR PUREX TWO-CYCLE FISSILE
PARTICLE HRRF FLOWSHEET

Column	Material In		Material Out		% Accounted For	
	U (g/min)	H ⁺ (mol/min)	U (g/min)	H ⁺ (mol/min)	U	H ⁺
5A	9.20	1.84	9.34	1.71	102	93
5B	9.34	0.102	9.16	0.107	98	105
6A	9.29	0.869	9.49	0.776	102	88
6B	9.49	0.126	8.68	0.133	92	106

3.8. REWORK AND RECYCLE (SUBTASK 360)

3.8.1. Summary

The detailed design effort on the nitric acid fractionator has been postponed indefinitely for budgetary reasons. The corrosion tests underway to aid in the determination of materials of construction for the acid fractionator will be completed.

3.8.2. Nitric Acid Fractionator

Work on the conceptual design of the nitric acid fractionator was completed, and the detailed design effort was initiated before being postponed indefinitely for budgetary reasons. Design work to date will be summarized and documented. Correspondence with outside vendors will continue until all inquiry requisitions have been answered.

Bench-scale corrosion work designed to evaluate corrosion rates of candidate metals in the HNO_3 -HF systems will continue as planned. Tests are being performed to evaluate SS-316L, Nitronic 50, and Hastelloy C-4 in 13.5 M HNO_3 and 10^{-4} M to 5×10^{-3} M HF at 60° to 100°C. Preliminary results indicate that Hastelloy C-4 is apparently the least likely candidate metal. Corrosion rates were found to be higher for coupons in solution than for similar coupons in the equilibrium vapor space of the test apparatus.

4. GENERAL SUPPORT (TASK 800)

4.1. FUEL IRRADIATION TESTING AND EXAMINATION (SUBTASK 880)

Thermal conductivity measurements of three blend 12 driver fuel rods are above the 0.0165 cal/cm sec °C value used in design calculations. The standard deviation for these three rods is $\pm 15\%$.

Four hundred rods from Peach Bottom test elements FT-5 and FT-6 were shipped to ORNL on May 1 for use as recycle head-end material.

5. MAJOR FACILITIES

5.1. HOT ENGINEERING TEST FACILITY

5.1.1. Summary

Because of the HTGR Recycle Fuel Development Program Office's deferment for FY-78 of the HET reprocessing system equipment design and shipping system tasks, no activities on these tasks occurred during this report period.

All assigned sections to the Conceptual Design Report (CDR) Addenda II document for MEU fuel reprocessing were completed. The compiled document, prepared by RMPCo, was reviewed and comments were transmitted to UCC-ND to be incorporated into the DOE/UCC-ND approved document.

The input sections for all assigned parts of the reprocessing system design requirement review documents were completed and forwarded to the HET project leader's office.

5.1.2. Project Management

5.1.2.1. Introduction. The HET project activity originally planned for FY-78 included the engineering and design of the reprocessing systems and the HET shipping system. The planned tasks would have developed the system designs from the CDR to the detail design scheduled for completion about mid-FY-84. During the first half of FY-78, supportive activities were scheduled including the preparation of system work package and design requirement review documents and contributions to the Reprocessing Facility CDR addenda for MEU fuel processing capability. Preliminary design

activities for the systems and equipment were scheduled to begin in mid-FY-78 and continue through the balance of the year. The conceptual design and cost estimate for the MEU updated HET shipping system was originally scheduled to start during the second quarter of FY-78 and be completed by the fourth quarter of the year.

During the preceding report period, DOE directed that the HET support facilities funding authorization be deferred from FY-79 to FY-81. In response to this directive the HTGR Recycle Fuel Development Program Office deferred the reprocessing equipment preliminary design and the HET MEU shipping update activities for FY-78. The support activities, including the preparation of the System Design Requirement Review documents and Addenda II to the Reprocessing Facility CDR, were scheduled to be completed by mid-May 1978.

5.1.2.2. Activity

5.1.2.2.1. Meetings

On March 30, 1978, and April 4, 1978, the Recycle Development Department cognizant engineers conducted an overall technical review of the HETE-Reprocessing information prepared for the System Design Requirements Review documents and the CDR Addenda II for MEU fuel processing. The review meetings provided an overall recap of the reprocessing systems as presented in the CDR for HEU fuel processing and as revised to include the MEU fuel processing capability.

The HRRF/HETP program manager held a review meeting on program subtask 920 (HETP) and 930 (HRRF) at General Atomic Company April 10-14. Meeting sessions concerning the HETP included a general wrapup on the HETE-Reprocessing tasks for FY-78 and a review of the status of the ORNL-prepared HETP Quality Assurance Program Plan (QAPP). As an action item from the meeting sessions, the GA Quality Assurance coordinator will work with the ORNL coordinator to review the draft QAPP for final issuance.

5.1.2.2.2. CDR Addenda II for MEU Fuel Processing

Assignments and schedules were made to GA, ORNL, UCC-ND, and RMPCo for the preparation of Addenda II to the HET Reprocessing Facility CDR. The addenda sections assigned to GA, completed and transmitted March 17, included:

<u>Section</u>	<u>Title</u>
3.1	Safety and Environmental Considerations - Reprocessing Facility
5.1	Impact on Research and Development - Reprocessing Facility
7.1	Impact on Support Facility (equipment for facility interfaces for spent fuel, scrap, waste, and samples)
7.2	Impact on Reprocessing Facility
7.2.1	MEU Operating Plan
7.2.2 through 7.2.9	Detailed system process and equipment descriptions, maintenance requirements, and Title I TBD items covering reprocessing systems 1100 through 1800 and subsystems 1921 and 1931.

The compiled addenda was prepared by RMPCo as document X-OE-60 and was distributed to the contractors for final review and comment. GA review comments were prepared and transmitted to the UCC-ND project engineer's office on May 1 for incorporation into the DOE/UCC-ND approved comment transmittal to RMPCo. Publication of the Addenda II document is currently scheduled by May 19.

5.1.2.2.3. HET-Reprocessing System Design Requirements Review

The assigned HETE-Reprocessing Design Requirements Review sections were completed for systems 1200, 1300, 1400, 1500, 1600, and 1800 and for subsystems 1921 and 1931. The document sections included were:

<u>Section</u>	<u>Title</u>
2.0	Physical and Design/Research and Development Interfaces
4.0	Sampling
5.0	Cost
6.0	Schedule
7.0	Requirements

Review comments on the UCC-ND prepared DRR draft for system 1100 were completed and included the preparation of Section 2.0, Physical and Design/Research and Development Interfaces, and the Level 2 Requirements Review Table (7.1) for Section 7.0.

The original materials for each of the DRR sections were transmitted to the HET project leader's office on March 20. They will be combined with ORNL and UCC-ND contributions for issuance as complete documents.

5.1.3. Reprocessing Equipment Design

5.1.3.1. Introduction. The engineering and design of the HET-Reprocessing system equipment is scheduled to be carried out in three stages: preliminary design, detail design, and vendor design. Originally, this effort was to be initiated by mid-FY-78 and continue into FY-84. The FY-78

preliminary design activities were to be principally involved with the head-end reprocessing systems' equipment.

During the preceding report period, the HTGR Fuel Recycle Development Program Office directed that all planned equipment design activities be deferred for FY-78.

5.1.3.2. Activity. No equipment design effort was initiated during this report period. All effort planned has been deferred by the Program Office for FY-78.

5.1.4. HET Shipping System

5.1.4.1. Introduction. The design concept for using the Peach Bottom cask to ship FSV spent fuel elements for HET reprocessing was planned to be updated to cover the MEU proliferation-resistant fuel shipping. The task effort was to identify required design modifications, perform a preliminary licensing assessment, and update the conceptual design and cost estimate.

During the preceding report period, the HTGR Fuel Recycle Development Program Office directed that all planned activities for the shipping system be deferred for FY-78.

5.1.4.2. Activity. No activity was initiated during this report period. All effort planned for FY-78 has been deferred by the Program Office.

5.2. HTGR RECYCLE REFERENCE FACILITY (HRRF)

5.2.1. Summary

Updated MEU fuel recycle reprocessing flowsheets were issued, and preparation of the HRRF-Reprocessing head-end material balance was completed. All deliverable end items under the RMPCo subcontract to update the TRP cost data base are on schedule. Breakdown of piping, electrical, and instrumentation costs to the system level is in progress. Work continued on the HRRF remote maintenance systems activity to develop a remote maintenance philosophy and concept for the HRRF-Reprocessing facility. Requirements for integrated remote maintenance handling and support equipment and facilities were established. An engineering support study subcontract was let to Norman Engineering Company to assist GA in the design development of HRRF-Reprocessing head-end remote maintenance equipment systems and facilities. This effort was activated on May 5, 1978, when a briefing was held at GA to acquaint Norman Engineering personnel with the design, operational, and maintenance aspects of head-end process systems.

Several previously proposed spent fuel storage concepts were reviewed for applicability to the HRRF Feasibility Study. Review of the present HTGR spent fuel storage facility design integral to a reprocessing plant identified several potential design improvements. A major design issue is the choice between water- and air-cooled storage. Information derived from revised ORNL (K. H. Lin) waste treatment system flowsheets is being integrated into a GA update of reprocessing waste treatment process flowsheets that are sufficiently detailed for application to TRP data base/HRRF system allocation cost studies.

5.2.2. Introduction

The objectives of this subtask are to perform engineering feasibility studies and to develop and evaluate preliminary HRRF Reprocessing Facility concepts leading to the definition of HRRF design requirements. The

objectives include updating of prior HRRF Reprocessing Facility concepts to MEU fuel recycle.

During the preceding quarter, drafts of HRRF reprocessing flowsheets for head-end, solvent extraction, and off-gas treatment were completed in accordance with the approved MEU fuel recycle base case. Update of the FY-77 Reprocessing Remote Maintenance Study information was started, with initial emphasis on head-end system/remote maintenance interface concepts. The HRRF "system allocation to functional areas" was revised and expanded to a system breakdown to lower levels to facilitate changeover of the TRP cost data base for application to HRRF feasibility studies.

5.2.3. Activity

5.2.3.1. HTGR/MEU Reprocessing Flowsheet. Updated MEU fuel recycle reprocessing flowsheets were issued as an interim reference and informally transmitted to ORNL. Calculation of HRRF-Reprocessing head-end material balance data was completed, and preparation of the material balance update for solvent extraction was started. A reprocessing flowsheet schematic for the HTGR/MEU fuel recycle base case is shown in Fig. 5.2-1. Tables 2.2-4 and 2.2-5 summarize the spent fuel definitions for spent U-233 recycle and spent denatured U-235 makeup fuel elements, respectively. These spent fuel definitions form the basis for the reprocessing material balance update currently in progress.

5.2.3.2. Reprocessing Facility Configuration and Cost Basis. Working sessions were held at RMPCo to (1) discuss process flowsheet changes for their update of the TRP cost data base for application to HRRF feasibility studies and (2) identify the quality assurance level assignment philosophy. All deliverable end items under this subcontract are on schedule except for the equipment reconditioning cell designs. Final RMPCo design and cost estimate documents on C-14 fixation, thorium solidification, and waste vitrification systems have been received. The GA cost development department is preparing a breakdown of piping, electrical, and instrumentation

Fig. 5.2-1. HTGR/MEU fuel recycle base case reprocessing flowsheet

costs to the system level. The breakdown is being derived from the lumped cost estimate previously furnished by RMPCo for the 1975 TRP conceptual design study.

5.2.3.3. HRRF Remote Maintenance Systems. Work continued on the HRRF remote maintenance systems activity to develop a remote maintenance philosophy and concept for the HRRF-Reprocessing facility. Requirements for integrated remote maintenance handling and support equipment and facilities were established and are summarized in Table 5.2-1. Figure 5.2-2 illustrates the functional relationship between remote maintenance and a typical processing system. Two examples of interface concepts between remote maintenance and process systems are shown in Figs. 5.2-3 and 5.2-4, respectively. For ease of remote maintainability, the relative merits of a head-end single process cell versus double process cell layouts have been investigated. The two concepts are illustrated in Fig. 5.2-5, which also lists the advantages and disadvantages of the two process cell layout concepts. Figure 5.2-6 is a more detailed remote maintenance/process interface concept sketch for the single process cell layout. As shown in this figure, the single cell would handle the entire 20,000 fuel element throughput projected for HRRF per year. The double cell concept, illustrated in Fig. 5.2-7, would process 10,000 spent fuel elements per year in each of the two process cells. A reprocessing facility layout concept sketch, also including the spent fuel receiving and storage area, is presented for preliminary consideration and is shown in Fig. 5.2-8.

An engineering support study subcontract was let to Normal Engineering Company (NEC) to assist GA in the design development of HRRF-Reprocessing remote maintenance equipment systems and facilities. In particular, this study will develop a conceptual arrangement of the head-end process cell, associated remote maintenance equipment, and remote maintenance facilities. A data package was prepared for use by NEC, including process flowsheets, process equipment lists and equipment outline specifications, a functional description of head-end process equipment, and other supporting documentation. The NEC support study started on May 5, 1978, with a meeting at GA,

TABLE 5.2-1
HRRF REMOTE MAINTENANCE REQUIREMENTS

1. Equipment within the process cell will be maintained remotely for total replacement; minor repair in place; and to remove, repair, and reinstall.	11. Install all head-end process equipment in either a single cell or double cell. Example: Incorporate two separate process systems at 10,000 elements/yr each - 50%/system.
2. Provide alpha-tight facility to prevent contamination spread.	12. Centralize maintenance equipment and facilities to serve reprocessing system.
3. Transfer equipment horizontally via aisle to single access port in roof.	13. Provide means to diagnose failures and test after repairs.
4. Incorporate gas-tight liner; no roof slabs.	14. Maximize use of floor access ports rather than using sealed doors.
5. Install equipment in tiers to allow effective use of gravity feed.	15. Standardize and modularize components.
6. Provide facilities to remotely repair, decontaminate, store, and ship process equipment.	16. Match interfaces to installation fixtures and gages.
7. Don't skimp on quality of maintenance equipment. Use best tools available to assure high equipment availability.	17. Perform maintenance operations in a criticality-safe manner.
8. Incorporate bilateral servo force-reflecting manipulator system with high-resolution TV.	18. Provide capability to remove and replace all reprocessing equipment.
9. Over-design remote handling equipment.	19. Locate pumps, valves, motors, etc., in adjacent limited-access cells.
10. Provide viewing equipment to observe all components and cell areas including windows, periscopes, TV, and lighting.	20. Completely check out all components and maintenance operations in mockup facility prior to final installation.

Fig. 5.2-2. Functional areas

Fig. 5.2-3. Floor-mounted translator

Fig. 5.2-4. In-cell telescoping translator

O = Operating Gallery LA = Limited Access
P = Process Cell H = Induction Htg
S = Sampling Cell = Window

SINGLE PROCESS CELL

- o LEAST COSTLY
- o SHORT LINE TO ADJACENT SYSTEM
- o ONE MANIPULATOR SYSTEM
- o FIRE, EXPLOSION COULD AFFECT OTHER SYSTEM
- o TWO MAINT. SYSTEMS FOR LA AREAS
- o MAJOR MODIFICATIONS TROUBLESOME
- o HIGHEST RADIATION LEVEL
- o ONE ACCESS DOOR REQ.
- o ALL REMOTE VIEWING
- o MORE LIKELY TO DAMAGE OTHER EQUIP
- o ONLY ONE PROCESS LINE MAINTAINED AT A TIME
- o LOWEST AVAILABILITY

DOUBLE PROCESS CELL

- o HIGHER CAPITAL COST
- o LONGER LINE TO ADJACENT SYSTEM
- o TWO MANIPULATOR SYSTEMS
- o EACH SYSTEM INDEPENDENT ALL TIMES
- o ONE MAINT SYSTEM FOR LA AREA
- o MODIFICATIONS EASIER TO IMPLEMENT
- o 1/2 RADIATION LEVEL
- o 2 ACCESS DOORS REQ.
- o DIRECT VIEW INTO PROCESS CELL
- o LESS CHANCE OF ACCIDENTS DURING MAINT.
- o BOTH PROCESS LINES MAINTAINED AT A TIME
- o HIGHEST AVAILABILITY

Fig. 5.2-5. Single and double process cells

Fig. 5.2-6. Single cell

Fig. 5.2-7. Double cell

Fig. 5.2-8. Reprocessing facility layout concept

where Recycle Development Department cognizant personnel briefed NEC on design, operational, and maintenance aspects of head-end process systems. Output from this engineering support study is expected to aid in the definition of the HRRF requirements, as part of the overall HRRF Feasibility Study.

5.2.3.4. Spent Fuel Receiving, Storage, and Handling. This activity has the objective of preparing a design concept for MEU spent fuel receiving, storage, and handling. A number of spent fuel storage concepts previously proposed were briefly reviewed to glean information applicable to our current study, and an internal memo report was issued. Spent fuel storage concepts surveyed included (1) accessible water-cooled storage, (2) remote-operation water-cooled storage, (3) remote or accessible air-cooled storage, and (4) dry-well storage concepts. Typical concept layouts are shown in Figs. 5.2-9 through 5.2-12. A summary of prior HTGR spent fuel storage cost estimates is given in Table 5.2-2.

The present HTGR spent fuel storage facility design integral to a reprocessing plant was reviewed, and several potential design improvements were identified. A major design issue is the choice between water and air-cooled storage.

5.2.3.5. Reprocessing Waste Treatment Requirements. Revised and updated reprocessing waste treatment system flowsheets, prepared by K. H. Lin of ORNL, were received at GA and further discussed in a number of telecons between K. H. Lin and GA Recycle Development Department personnel.

Information derived from the ORNL system flowsheet revisions and discussions is currently being integrated into a GA update of reprocessing waste treatment process flowsheets. The process flowsheet update is approximately 50% complete and contains sufficient design detail for subsequent application to the TRP data base/HRRF system allocation cost study.

Fig. 5.2-9. Accessible water-cooled storage, stacked containers

Fig. 5.2-10. Remotely operated water-cooled storage, container closure above water

Fig. 5.2-11. Remote or accessible air-cooled storage

TABLE 5.2-2
SUMMARY OF HTGR SPENT FUEL STORAGE ESTIMATES

Facility	Storage Capacity	Cost/FE	Comments
Idaho FSV facility	2,600 FE	\$1000 (1971)	Nonlicensable; uses available support services
Target recycle plant concept	15,600 FE	\$3200 (1975)	Including support facilities; assumed licensable
Stand-alone concept	15,000 FE	\$3400 (1975)	No provision for removing fuel
HRDF integral concept	10,000 FE	\$7500 (1977)	RMPCo estimate for RAMCO study: includes 100% rail, 100% truck receiving
Passive storage concept (dry well)		\$730 (1977)	No handling or support service facilities

REFERENCE

- 5.2-1. Henry, K. H., and D. A. Turner, "Storage of Spent Unreprocessed Fuel," DOE Report RHO-SA-40, Rockwell International Atomix International Division, March 1978.

APPENDIX A
TOPICAL REPORTS PUBLISHED DURING THE QUARTER

Richards, P. C., and E. J. Cook, "Pneumatic Conveying in HTGR Fuel Reprocessing," General Atomic Report GA-A14705, April 1978.

Benedict, G. E., et al., "Alternate Fuel Cycle Technology. Quarterly Progress Report for the Period Ending December 31, 1977," DOE Report GA-A14797, General Atomic Company, January 1978.

"HTGR Fuel Recycle Development Program. Quarterly Progress Report for the Period Ending February 28, 1978," DOE Report GA-A14878, General Atomic Company, March 1978.

Young, D. T., "Process Development Report: 0.40-m Primary Burner System," DOE Report GA-A14816, General Atomic Company, April 1978.

APPENDIX B
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