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HTGR FUEL REPROCESSING - EFFECTS OF SOME FUEL
DESIGN CHANGES ON REPROCESSING COSTS

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1. INTRODUCTION

The recent cost studies^(1,2,3) made by Gulf General Atomic on the reprocessing of HTGR fuels in central plants are based on fuels designed for (1) a C/Th = 200, (2) a two-particle, once-through recycle mode, and (3) void-diluted fissile particles. More recently, minor changes in the fuel design were proposed. These changes include (1) reducing the thorium loading to a C/Th = 250 in the first few large reactors, (2) the use of the bred-uranium fuel cycle, and (3) buffer-diluted fissile particles. The basic geometry of the fuel element remains the same (hexagonal graphite blocks, 14.17 inches across the flats and 31.22 inches long) as does the basic composition of the fuel particles.

In the base case study⁽¹⁾, Case III A, the thorium fuel particles have only carbon coatings but the uranium fuel particles have a SiC coating added. Case III A considers processing only thorium particles; the uranium particles are packaged and stored for eventual disposal or for possible future processing. Case III A3 is based on the same fuel as Case III A but the facilities for processing the uranium particles are included in the plant. Cases III B and III B1 are similar in processing capability to Cases III A and III A3, respectively, but the thorium fuel particles were modified to include a SiC coating.

The above four studies were redone to obtain the estimated costs associated with reprocessing HTGR fuels incorporating the above-mentioned proposed changes. The new Cases III C and III C1 correspond to Cases III A and III A3 (only carbon coatings on the thorium particles) and Cases III D and III D1 correspond to Cases III B and III B1 (SiC coating on all of the fuel particles).

One additional case was studied (Case III E) in which the fuel design and quantities are similar to those of Case III A but the uranium particles are buffer diluted rather than void diluted. Table 1 lists the assumptions essential to each of the various case studies.

This report summarizes the costs associated with all of the above cases.

TABLE 1

CASE STUDY DEFINITIONS

	Case Number								
	<u>III A</u> once- through	<u>III A3</u> once- through	<u>III B</u> once- through	<u>III B1</u> once- through	<u>III C</u> bred-U	<u>III C1</u> bred-U	<u>III D</u> bred-U	<u>III D1</u> bred-U	<u>III E</u> once- through
Fuel cycle									
Carbon-to-thorium ratio	200	200	200	200	250	250	250	250	200
Uranium particle dilution	void	void	void	void	buffer	buffer	buffer	buffer	buffer
Uranium particle processing	no	yes	no	yes	no	yes	no	yes	no
SiC coating on thorium particles	no	no	yes	yes	no	no	yes	yes	no

2. STUDY ASSUMPTIONS

To obtain a comparison on the relative costs of processing the HTGR fuels of various designs, the following assumptions and criteria were used for all the cases studied:

1. The reprocessing plant is self-sufficient.
2. Reprocessing capability is limited to HTGR fuel elements.
3. The plant is sized to process the fuel from fifteen 1000 Mw(e) HTGRs.
4. The plant operates at its design capacity 274 days per year (75 percent on-line operating efficiency).
5. A basic burn-leach head end process is used but modified to include grind-burn-leach operations when SiC coated particles are processed.
6. A solvent extraction process is used for separation and decontamination of the fuel material. A separate solvent extraction processing line is included when the uranium in the uranium particles is also recovered.
7. The recovered thorium is kept in long term (15 year) storage as a thorium nitrate solution for Th-228 decay.
8. A 15-year amortization period is used.
9. The plant has a fuel element storage capacity equivalent to 90 days of operation at the design processing rate.
10. The radioactive wastes are solidified, placed in interim storage and, after 15 years, shipped to a permanent disposal area.

The fuel element parameters for the various cases are contained in Table 2.

TABLE 2
FUEL ELEMENT CHARACTERISTICS

Case number	III A and <u>III A3</u>	III B and <u>III B1</u>	III C and <u>III C1</u>	III D and <u>III D1</u>	<u>III E</u>
Weights at discharge (kg/element)					
Graphite fuel block	97.46	97.46	98.13	98.13	97.46
Carbon binder	4.94	6.93	6.94	6.94	4.94
Thorium particle components					
Thorium	10.48	10.48	8.91 ⁽¹⁾	8.91 ⁽¹⁾	10.48
Uranium	0.30	0.30	0.33	0.33	0.30
Fission products	0.41	0.41	0.46	0.46	0.41
Oxygen (oxide)	1.55	1.55	1.34	1.34	1.55
Carbon outside of SiC coating	10.90	5.09	7.22	3.25	10.90
SiC coating	---	1.86	---	2.15	---
Carbon inside of SiC coating	---	1.40	---	2.50	---
Uranium particle components					
Uranium	0.15	0.15	0.10	0.10	0.15
Fission products	0.42	0.42	0.30	0.30	0.42
Oxygen (oxide)	0.08	0.08	0.05	0.05	0.08
Carbon outside of SiC coating	2.22	2.22	2.67	2.67	3.83
SiC coating	0.36	0.36	2.16	2.16	3.10
Carbon inside of SiC coating	0.30	0.30	2.46	2.46	3.53
Total fuel element weight ⁽²⁾	129.57	129.01	131.07	131.85	137.15
Particle diameters (microns)					
Thorium particles					
Kernel	350	400	400	400	350
With buffer carbon coating	410	500	500	500	410
With inner PyC coating	---	---	---	540	---
With SiC coating	---	535	---	580	---
With outer PyC coating	610	655	660	660	610

TABLE 2 (Cont'd)

Case number	III A and <u>III A3</u>	III B and <u>III B1</u>	III C and <u>III C1</u>	III D and <u>III D1</u>	<u>III E</u>
Uranium particles					
Kernel	200 ⁽³⁾	200 ⁽³⁾	100	100	100
With buffer carbon coating	260	260	300	300	300
With inner PyC coating	---	---	340	340	340
With SiC coating	280	280	380	380	380
With outer PyC coating	400	400	440	440	440
9 Volume of SiC-coated uranium particles, $\frac{\text{liters}}{\text{block}}$	0.578	0.578	2.42	2.42	3.47
Number of elements per 1000 Mw(e)					
HTGR core	3750	3750	3560	3560	3750

NOTES: 1) These cases have two types of thorium particles. Initially one of the particle types contains all of the recycle U-233 at a Th/U of 4.25. The other particle contains the remainder of the thorium.

2) Burnable poison particles not included.

3) 70 percent voids.

3. DISCUSSION

The costs associated with Cases III A3, III B and III B1 were derived from modifications to the plant and processes developed for Case III A. Since the proposed fuel element changes are relatively minor, the costs for the new cases were developed in the same manner. Thus the detailed process, plant, and equipment descriptions contained in the reports^(1,2,3) on the earlier cases are applicable to the corresponding new case. Because of the differences in fuel makeup, some changes in plant layout, equipment size, and operating costs did result. Most of these changes are relatively minor. With the newer fuel, there are fewer fuel elements per 1000 Mw(e) HTGR core (3560 versus 3750) and slight differences in the fuel storage area result. Also, the difference in the thorium loading affects the size of the thorium processing equipment and storage tanks.

The biggest difference occurs in the area of uranium particle handling, particularly in waste storage and disposal. This is attributable to the differences in the uranium particle geometry (see Table 2). The newer buffer-diluted uranium particle kernel is only one-half the diameter (one-eighth the volume) of the older void-diluted uranium kernel but for an individual particle with its SiC coating, the newer particle is larger by a factor of 2.5 in volume. Taking into account kernel density differences and the larger quantity of uranium in the once-through cycle uranium particles, the volume of the newer particles (with SiC coats) processed annually is more than four times greater. In Case III E, (buffer-diluted, once-through cycle), the relative volume of the SiC coated uranium particles processed annually is a factor of six greater. In the cases where the uranium particles are not processed, but treated as a high-level waste (Cases III C, III D, and III E), this increased particle volume significantly increases costs associated with high-level waste storage and disposal. In cases where the uranium particles are processed (Cases III C1 and III D1), the waste disposal costs are also increased because the volumes of SiC

residues requiring disposal are greater. Work on diluent particle development is continuing and future particle definitions could well indicate less difference between void and buffer diluted particles.

The waste disposal costs are not directly proportional to the volume of the uranium particles, because the quantity of alumina in the uranium particle waste streams is increased only slightly and because the lower volumetric heat generation rate in the more voluminous particles permits the use of larger disposal containers. Increasing the container size reduces the container cost per unit volume of waste. The storage basin size requirements and shipping costs, however, are directly proportional to the container diameter.

The costs for the various cases are summarized in Table 3. The table is arranged so that cases with comparable processing requirements are in adjoining columns. Cases III A, III C, and III E deal with fuel having only carbon coatings on the thorium particles, and the uranium particles are not processed. The same fuel is used in Cases III A3 and III C1, but the uranium particles are also processed. In the remaining cases, the thorium particles have SiC coatings, but the uranium particles are processed only in Cases III B1 and III D1.

Differences in the capital, operating, and reprocessing costs between the various comparable cases are not significant (generally less than 5 percent). The one exception is the comparison between Cases III A and III E. Here the cost differences are in the order of 10 percent. The higher Case III E costs are solely attributable to the much higher costs associated with the disposal of the greater volume of uranium particles. As indicated in Table 3, the high-level waste disposal costs in Case III E are 70 percent higher than in Case III A. The inclusion of the first waste storage basin in the plant capital cost accounts for the higher Case III E capital cost. With the newer fuel, the higher waste disposal costs largely offset the cost savings realized elsewhere in the plant because of the fewer number of fuel elements and lower quantity of thorium requiring processing and storage.

TABLE 3
COST SUMMARY

Case number

	<u>III A</u>	<u>III C</u>	<u>III E</u>	<u>III A3</u>	<u>III C1</u>	<u>III B</u>	<u>III D</u>	<u>III B1</u>	<u>III D1</u>
Capital cost, \$10 ⁶	30.8	30.4	33.0	33.7	32.5	32.2	32.6	34.7	34.0
Operating cost, \$10 ⁶ /year	4.46	4.64	5.17	4.97	5.10	4.96	5.22	5.43	5.50
Reprocessing cost, \$10 ⁶ /year	10.32	10.44	11.47	11.38	11.30	11.10	11.43	12.05	12.00
6 High-level waste disposal cost, \$10 ⁶ /year*	0.97	1.23	1.64	1.03	1.22	1.16	1.55	1.24	1.45
kg Th + U/year	165555	134835	165555	165555	134835	165555	134835	165555	134835
Dollar/kg Th + U	62	77	69	69	84	67	85	73	89
Fuel elements/year	14063	13350	14063	14063	13350	14063	13350	14063	13350
Dollars/fuel element	734	782	816	809	846	789	856	857	898
Incremental cost for uranium particle processing, \$/gram	---	---	---	0.50	0.65	---	---	0.45	0.42

* This cost is included in the operating cost.

The differences in reprocessing costs in terms of dollars per kilogram of thorium plus uranium are significant for comparable cases. These differences, with the exception of that between Case III A and Case III E, are due mainly to the difference in the thorium loadings. The lower thorium loading in the C/Th = 250 fuels reduces the quantity of thorium plus uranium processed per year by about 20 percent. Since the reprocessing costs in dollars per year are about the same for comparable cases, costs in dollars per kilogram for the C/Th = 250 fuels are increased proportionally.

Reprocessing cost differences in terms of dollars per fuel element are much less, percentagewise, than the dollars per kilogram. This arises because of the smaller differences in the number of fuel elements processed annually.

In all of the case studies, the incremental cost of processing the uranium particles is sufficiently low (\$0.42 to \$0.65 per gram of recoverable uranium) to justify recovering the uranium for sale.

4. CONCLUSION

The proposed changes in fuel design have little effect on the reprocessing plant capital cost and on the reprocessing costs in terms of dollars per year. Reprocessing costs in terms of dollars per kilogram have an inverse relationship to the quantity of thorium plus uranium in the fuel. Reprocessing costs in terms of dollars per fuel element or mills per kilowatt-hour are less sensitive to the quantity of thorium plus uranium contained in the fuel. Some reduction in reprocessing costs are possible if the quantity of SiC coating material on the uranium particles can be reduced. This reduction could be achieved by increasing the size of the uranium particle kernel or by reducing the thickness of the buffer carbon coating.

5. REFERENCES

1. Shefcik, J. J., "Central Reprocessing Plant for HTGR Fuels," USAEC Report GAMD-8382, General Dynamics, General Atomic Division, (October 16, 1967).
2. Shefcik, J. J., "HTGR Fuel Reprocessing - Recovery of Uranium from Silicon Carbide Coated Fissile Particles," USAEC Report GAMD-8615, Gulf General Atomic Incorporated, (March 15, 1968).
3. Shefcik, J. J., "HTGR Fuel Reprocessing - Effects of Including a Silicon Carbide Coating on the Fertile Fuel Particles," USAEC Report GAMD-8661, Gulf General Atomic Incorporated, (May 10, 1968).