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by

Thomas H. Gould, Jr.

E. I. du Pont de Nemours & Company
Savannah River Laboratory
Aiken, South Carolina 29808

James B. Dunson, Jr., Arnold M. Eisenberg, H. Granville Haight, Jr., Victor E. Mello, Roy L. Schuyler, III

E. I. du Pont de Nemours & Co.
Engineering Department
Newark, Delaware 19711

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ABSTRACT

A quantitative merit evaluation, or processability analysis, was performed to assess the relative difficulty of remote processing of Savannah River Plant high-level wastes for seven alternative waste form candidates. The reference borosilicate glass process was rated as the simplest, followed by FUETAP concrete, glass marbles in a lead matrix, high-silica glass, crystalline ceramics (SYNROC-D and tailored ceramics), and coated ceramic particles. Cost estimates for the borosilicate glass, high-silica glass, and ceramic waste form processing facilities are also reported.

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INTRODUCTION

Approximately 27 million gallons of high-level waste containing about 740 million curies of radioactivity have accumulated at the Department of Energy's (DOE) Savannah River Plant (SRP) from the production of defense nuclear materials and other radionuclides. The DOE plan for permanent disposal of SRP defense high-level waste involves: (1) the immobilization of the waste into durable solid forms, and (2) the permanent storage of these forms in a deep geologic repository. A defense waste processing facility (DWPF), scheduled for startup by 1990, is being designed to immobilize the defense waste at SRP into a solid waste form that will meet federal requirements for safe transport and repository disposal. Based on earlier studies, borosilicate glass was chosen in 1977 as the reference waste form for process development and DWPF design studies.

Since 1979 the DOE Savannah River Operations Office, with technical assistance from the Savannah River Laboratory, has carried out a multi-laboratory program to develop and evaluate alternative waste forms for SRP and other high-level wastes. In 1980, seven waste forms, including borosilicate glass, were selected for further development and evaluation based on their product performance potential and conceptual processes. The waste forms and their primary developers are shown in Slide 1.

As discussed in accompanying papers by D. E. Gordon and T. A. Bernadzikowski, these waste forms underwent further development, characterization and evaluation in FY-1981 to provide a data base for a screening assessment at the end of FY-1981. From this assessment, borosilicate glass and a crystalline ceramic based on the Synroc-D concept were selected for continued development for SRP waste. Two of the major considerations in this waste form assessment were product performance, described in the previous paper, and processability evaluated in a study by the Du Pont Engineering Department. The processability study, the subject of this presentation, was performed to rate the effectiveness of the various processes for manufacturing the seven candidate waste forms in a remotely operated DWPF. Processability is important because it affects waste form quality, facility cost, operating cost, and safety.

DISCUSSION

Processes Evaluated

Six waste form processes were evaluated (Slide 2). They were: borosilicate glass made by slurry fed melting; glass marbles in a lead matrix, also by slurry fed melting; high-silica glass by a rising level, in-can sintering process; concrete formed under elevated temperature and pressure (FUETAP); crystalline ceramic made by hot isostatic pressing; and coated ceramic particles made by the sol-gel process with chemical vapor deposition of pyrolitic carbon and silicon carbide coatings. The Synroc and tailored

ceramic waste forms were combined into a single generic ceramic process, because both forms have essentially identical process steps and differ primarily in chemical composition.

Because of time constraints, only the reference borosilicate glass process and the crystalline ceramic process will be illustrated. The borosilicate glass process, summarized in Slide 3, centers around a continuous slurry-fed, ceramic-lined melter. Washed high- level waste sludge from SRP waste tanks (28 wt %) and glass frit (72 wt %) are mixed as a slurry and fed to a joule-heated melter. Homogenized molten glass exiting the melter is cast and sealed in a stainless steel canister, 0.61 m in diameter and 3.0 m high.

In the ceramic waste form process (Slide 4), washed sludge (60 wt %) and ceramic additives are milled and spray calcined. The dry calcine powder is tamped into a stainless steel canister, which is sealed and heated under vacuum. The canister of waste is then hot isostatically pressed at high temperature and high pressure into a compact form 0.46 m in diameter and 1.1 m high.

Procedure

The processability study involved two tasks. In the first (Slide 5), detailed process flowsheets for the candidate processes were developed by the Engineering Department in collaboration with SRL and the waste form developers. The flowsheets were used to define equipment requirements and to develop process cell arrangements. This information was reviewed with the developers, and then

used to rate each process via quantitative processability criteria. An example process cell arrangement plan is shown in Slide 6 for the reference glass process. All of the processing operations are performed remotely. Maintenance is carried out by removing the defective piece of equipment with an overhead crane and replacing it with new or repaired equipment. The defective equipment is decontaminated remotely and then repaired by contact maintenance or discarded. The process cells and equipment for the other candidate processes were also conceptually designed for remote operation and maintenance.

In the second task, the processes were rated in four major categories (Slide 7): (1) complexity/reliability, weighted 40%; (2) personnel safety, weighted 20%; (3) quality control and assurance, weighted 15%; and (4) resource requirements, weighted 25%. Following selection of the major criteria categories, specific criteria were defined within each category through a consensus process involving professionals from the Engineering Department, SRL, and SRP with broad-based experience in radioactive waste management, nuclear facility design and radioactive materials processing. A total of 21 quantitative criteria were defined and then value rated for assessing the relative merits of the waste form processes. These criteria are listed in Slide 8 in descending order of their relative weights. (The letters A through D designate the major criteria categories given in the previous slide). Criteria having the greatest influence on the process ratings were the number of critical control parameters, the number of radioactive

high maintenance equipment pieces, process cell space, and capital cost.

A merit rating for each process was determined by the Figure of Merit approach illustrated in Slide 9. The individual process scores were normalized for each of the 21 criteria by dividing the best process score for a given criterion (e.g. process with fewest number of steps) by the score for the process of interest; then each normalized score was multiplied by the relative weighting factor of the criterion; and finally, the resulting weighted, normalized scores were summed for each process. A process receiving the highest normalized value for each of the 21 criteria would have received a merit rating of 100.

Processability Ratings

The final ranking of the six alternative processes and their associated merit ratings by major category are shown in Slide 10.

The final ratings suggest four general groupings of the processes. Borosilicate glass, the simplest and highest overall rated process of those evaluated, and FUETAP concrete can be categorized as relatively simple processes; glass marbles in a lead matrix and high-silica glass as moderately complex; crystalline ceramic (SYNROC-D and tailored ceramic) as complex; and coated ceramic particles as very complex.

The highest rating in each major category is underlined. The borosilicate glass process ranked highest (best) among the six processes evaluated in the major categories of

complexity/reliability and resource requirements (costs), and ranked second to FUETAP concrete in the categories of personnel safety and quality control/assurance. The ceramic process ranked fifth in complexity/reliability and personnel safety, sixth in quality control/assurance, and fourth in resource requirements. The crystalline ceramic form was selected as the primary alternative to borosilicate glass in the recent waste form evaluation, because its excellent product performance properties compensated for its relatively high process complexity.

Cost Appraisal

Development of the equipment concepts and conceptual process cell designs in the processability analysis permitted cost estimates of the processing facilities to be made. Because of time and funding restrictions, cost estimates were made for only the borosilicate glass, high-silica glass, and ceramic waste form processes. These estimates are shown in Slide 11 along with the process cell sizes for all six waste form processes. Comparison of the process cell sizes gives a rough indication of the relative costs of the processes.

Conclusions

All six of the processes evaluated in this study could be designed to produce waste forms in a fully remote DWPF, although the size and complexity of the processing facilities would differ greatly. The borosilicate glass process was judged to be the least

complex and require the smallest processing facility of the processes evaluated. The FUETAP concrete process was rated second to borosilicate glass in terms of overall processability, followed by glass marbles in a metal matrix, high-silica glass, crystalline ceramics, and coated ceramic particles.

SLIDE 1.

Seven Candidate Waste Forms Evaluated in Processability Study

Waste Form	Developer/Contractor
Borosilicate Glass	Pacific Northwest Laboratory Savannah River Laboratory
SYNROC	Lawrence Livermore National Laboratory Argonne National Laboratory North Carolina State University
Tailored Ceramic	Rockwell International Pennsylvania State University
High-Silica Glass	Catholic University of America
FUETAP Concrete	Oak Ridge National Laboratory
Coated Sol-Gel Spheres	Oak Ridge National Laboratory
Glass Marbles in a Lead Matrix	Pacific Northwest Laboratory

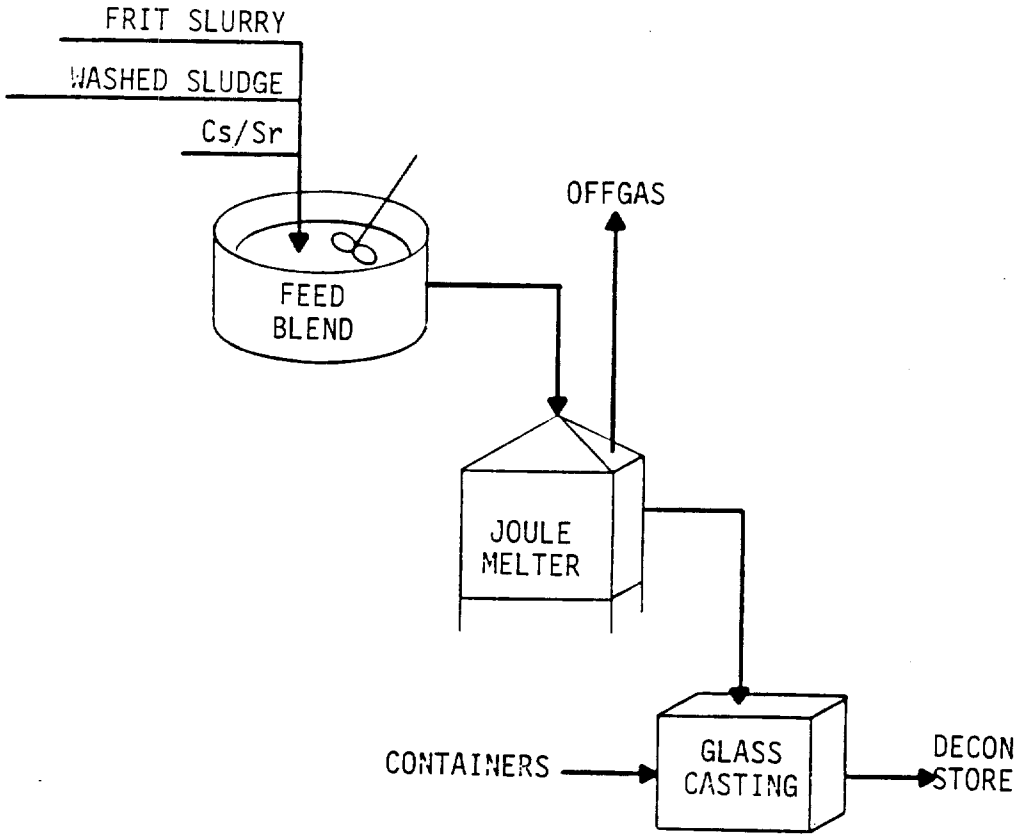
SLIDE 2.

Waste Form Processes Evaluated in Processability Study

- Borosilicate glass made by slurry fed melting
- Glass marbles in a lead matrix, also by slurry fed melting
- High-silica glass made by a rising level, in-can sintering process
- Concrete formed under elevated temperature and pressure (FUETAP)
- Crystalline ceramic made by hot isostatic pressing
- Coated ceramic particles made by the sol-gel process with chemical vapor deposition of PyC and SiC coatings

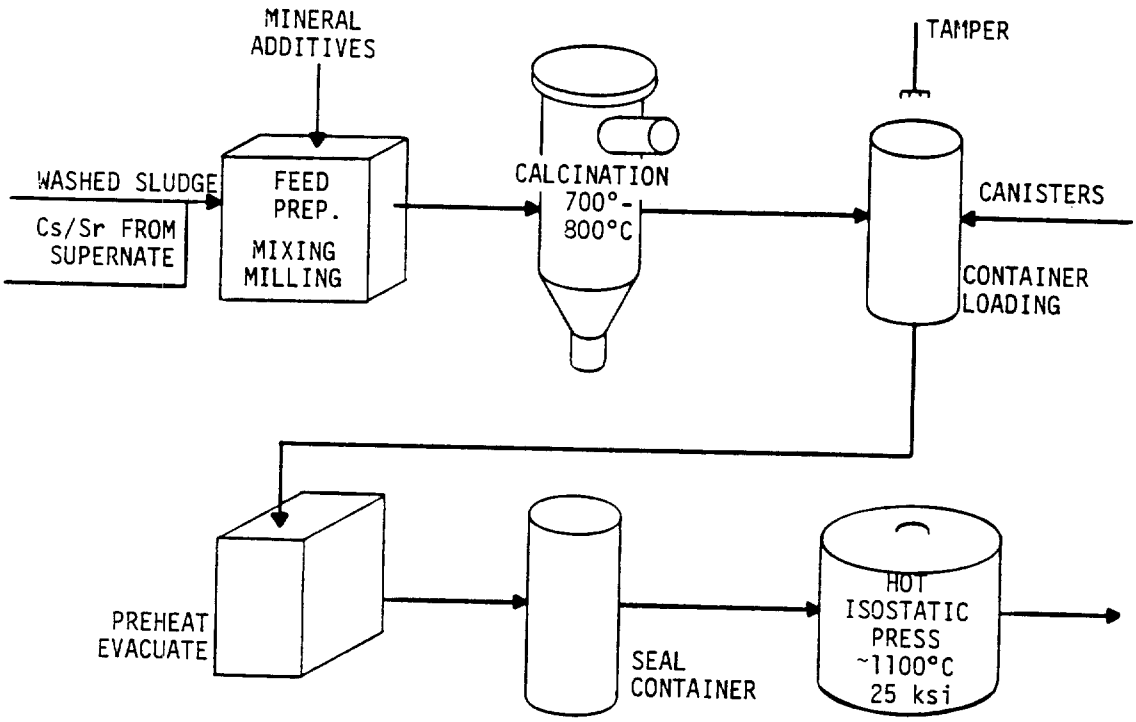
SLIDE 3.

Borosilicate Glass Process Summary Diagram



SLIDE 4.

Crystalline Ceramic Process Summary Diagram



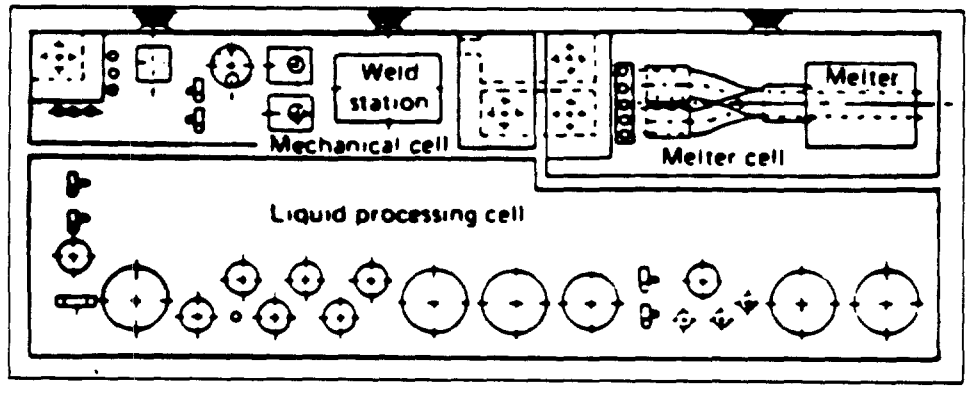
SLIDE 5.

Procedure Used in Processability Analysis

- Process details from developers
- Development of detailed flowsheets
- Definition of equipment requirements
- Development of process cell arrangements
- Review by developers and SRL
- Application to processability ratings

SLIDE 6.

Schematic of the Process-Cell Floor Plan for Borosilicate Glass



SLIDE 7.

Major Processability Categories

	Relative Weight, %
A. Complexity/Reliability	40
B. Personnel Safety	20
C. Quality Control and Assurance	15
D. Resource Requirements	25

SLIDE 8.

Processability Criteria Ranking

		Weight, %
A1	Critical Control Parameters	10
B1	Radioactive High Maintenance Equipment Pieces	10
A2	Process Cell Requirements	8
C1	Product Tolerance to Process Variations	7.5
D1	Capital Cost	7.5
D2	Development Items	7.5
A3	Process Steps	6
B2	Process Steps at High Temperature or Pressure	5
B3	Other Hazardous Materials	5
A4	Equipment Pieces at High Temperature or Pressure	4
A5	Unusual Service Facilities	4
D4	Decontamination and Disposal	3.75
D5	Lag Storage	3.75
C2	Dry Particle Processing Steps	3
C3	Steps to Prepare and Test Sample	3
D3	Raw Materials	2.5
A6	Recycle Loops	2
A7	Equipment Pieces in Covered Cells	2
A8	Chemical Additions Through Walls	2
A9	Dry Radioactive Materials Transfer Steps	2
C4	Quality Control Sampling Points	1.5
		100

SLIDE 9.

Processability Merit Rating Calculation

$$R = \sum_{i-1}^{21} W_i \left(Y_i/X_i\right)$$

where for the ith criterion

W_i = weighting factor

(Y_i/X_i) = normalized value function

X_i = value of process being rated

Y_i = value for the best process

SLIDE 10.

Merit Ratings for Waste Form Processes

Primary Process Category	Alternative Waste Forms: Boro-silicate Glass	FUETAP Concrete	Glass Marbles in Lead Matrix	High-Silica Glass	Crystal-line Ceramic	Coated Particles via Sol Gel
Complexity/Reliability	38*	31	25	23	17	11
Personnel Safety	15	20	12	12	7	6
Quality Control/Assurance	9	11	7	4	4	6
Resource Requirements	21	14	13	12	14	9
Figure of Merit	83	77	58	51	42	32
Ranking	1	2	3	4	5	6

* Maximum Scores Underlined.

SLIDE 11.

Cost and Facility Size Comparison of Alternative Waste Form Processes

Waste Form	3Q FY-80 Cost Estimate*	Process Cell Size,** ft
Borosilicate Glass	585	187
Glass Marbles	-	216
High-Silica Glass	797	248
FUETAP Concrete	-	287
Crystalline Ceramic	958	390
Coated Ceramic Particles	-	551

* In Millions. Includes 15% contingency for borosilicate glass and 35% contingencies for high silica glass and ceramic.

** Length of process cell; cross sections were equal for all processes.