Recovery of Fissile Materials from Plutonium Residues, Miscellaneous Spent Nuclear Fuel, and Uranium Fissile Wastes

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ABSTRACT

A new process is proposed that converts complex feeds containing fissile materials into a chemical form that allows the use of existing technologies (such as PUREX and ion exchange) to recover the fissile materials and convert the resultant wastes to glass. Potential feed materials include (1) plutonium scrap and residue, (2) miscellaneous spent nuclear fuel, and (3) uranium fissile wastes. The initial feed materials may contain mixtures of metals, ceramics, amorphous solids, halides, and organics.

I. INTRODUCTION

A new process is proposed to recover uranium and plutonium from complex mixtures of metals, ceramics, amorphous solids, halides, and organics. Potential feed-materials include (1) plutonium scrap and residue, (2) miscellaneous spent nuclear fuel (SNF), and (3) uranium fissile wastes. These materials are often referred to as miscellaneous fissile materials (MFMs). In the United States, there are more than a hundred specific types of such materials. The quantity of any specific type of material is small, but in total >1000 t of such materials exist.

Recovery of the fissile content from such feed materials is not economical with current technologies. Separation of fissile components from these materials is difficult because, in most cases, they can not be easily dissolved in nitric acid — the first step in traditional fissile material separation processes. New processes could be developed for each specific feed material, but the ensuing small quantities of each feed material would make this option very expensive. However, the fissile content of these materials is sufficient such that they may be unacceptable for disposal as wastes because of safeguards and nuclear criticality concerns. An economical method to recover the fissile components of these materials is required so that (a) these wastes can be converted to an acceptable final waste form, (b) the uranium can be recovered for recycle in power reactors, and (c) the plutonium can be converted into an acceptable form for storage, use, or disposal.

2. GENERAL DESCRIPTION OF THE PROCESS

The flowsheet of the process is shown in Fig. 1. Conceptually, the process consists of the following major sets of process operations:

Boron-oxide (B$_2$O$_3$) Fusion Melt

Feed materials are converted into a B$_2$O$_3$ fusion melt which has characteristics designed to permit uranium and plutonium recovery using existing separation technologies. Oxides in the feed are converted to a B$_2$O$_3$ fusion melt. Organics are oxidized, and the residue is dissolved into the
BORON-OXIDE FUSION MELT

Offgas

Aqueous Scrubber

NaOH

PbX₂ + 2NaOH → Pb(OH)₂ + 2NaX

NaX (Halide)

B₂O₃

Pb(OH)₂

PbX₂

X=halide

Oxidation, Dehalogenation, and Oxide Dissolution

2Al + 3 PbO → Al₂O₃ + 3Pb
Pu + 2PbO → PuO₂ + 2Pb
2NaX + PbO → Na₂O + PbX₂

Lead Oxide Removal

Fusion Melt

C + 2PbO → CO₂ + 2Pb

B₂O₃

Silicate Glass Formulation

(Alternative End Point)

Frit (SiO₂)

Borosilicate Glass

Lead Oxidation

PbO

Pb

Oxygen

2Pb + O₂ → 2PbO

Noble Metal Recovery

(Optimal)

Noble Metal

Lead Oxidation

2Pb + O₂ → 2PbO

Oxidation, Dehalogenation, and Oxide Dissolution

2Al + 3 PbO → Al₂O₃ + 3Pb
Pu + 2PbO → PuO₂ + 2Pb
2NaX + PbO → Na₂O + PbX₂

Nitric Acid

Boron Oxide Recycle

(Optiona)

Aqueous Nitric Acid Dissolution

Separations Process

(Purex etc.)

Pu(NO₃)₄

UO₂(NO₃)₂

B₂O₃ = Input to Process

Lead Oxidation = Process

Borosilicate Glass = Process Output

Fig. 1 Flowsheet for recovery of fissile materials from waste
fusion melt. Metals (except noble metals) are oxidized, and the resultant metal oxides are
dissolved into the melt. Halogen-containing compounds are converted into a halogen-free B₂O₃
fusion melt and a secondary clean sodium-halide stream. Noble metals are separated from the
B₂O₃ fusion melt into a separate stream. The final fusion melt has all the remaining elements in
oxide form dissolved into the molten B₂O₃.

Most (but not all) of the fusion melt process steps are being developed as part of a new
process (Forsberg, 1995a) to convert wastes to borosilicate glass called the Glass Material
Oxidation and Dissolution System. Conversion of the dissolution glass to a B₂O₃ fusion melt is a
new process step unique to this process. The primary process inputs are oxygen (O₂), carbon, and
B₂O₃. The process outputs in addition to the B₂O₃ fusion melt (with all elements in oxide form)
may include (depending upon the feed) noble metals, carbon dioxide (CO₂), water (H₂O), and
sodium halide salts: sodium fluoride (NaF), sodium chloride (NaCl), and sodium iodide (NaI).

Uranium and Plutonium Separation

The B₂O₃ fusion melt is cooled, the solid fusion melt is dissolved into aqueous nitric acid; and
uranium, plutonium, and other desired elements are extracted from the aqueous solution. The
waste from the separation process is a boric acid — nitric acid waste steam. This set of operations
uses current industrial technology. The traditional processes for recovering plutonium and
uranium are the PUREX process (Benedict and Pigford, 1957) and several ion-exchange
processes. The primary input to the process is nitric acid. The outputs, in addition to the boric-
acid — nitric-acid waste stream, may include (depending upon the feeds) streams of uranium
nitrate and plutonium nitrate.

Vitrification

The acid waste stream (after removal of fissile materials) is converted to high-quality
borosilicate waste glass using current waste vitrification processes. The primary input is glass frit
[primarily silicon dioxide (SiO₂)], which is used to make high-quality glass. In some cases, excess
boric acid may be in the aqueous waste stream. The boric acid may be separated from the acid
waste stream and recycled back to the borate-fusion-melt steps before the waste is converted to
glass.

3. BORON OXIDE FUSION MELT

The first set of steps, which converts feeds into a B₂O₃ fusion melt inside a glass melter, can be
operated as a batch, semibatch, or continuous process. The initial condition for the process is a
melter filled with a special molten oxidation—dissolution (lead borate) glass, which has a
composition of two or more moles of lead oxide (PbO) per mole of B₂O₃. The B₂O₃ fusion-melt
operations have three steps: (1) feed oxidation, dehalogenation, and oxide dissolution; (2) PbO
removal; and (3) lead oxidation. These operations can be carried out sequentially in either a single
vessel or in separate process vessels. The process consists of the following steps:
Oxidation, Dehalogenation, and Oxide Dissolution of Feed Material

The feeds are added directly to the melter. The ceramic and amorphous components in the feed that are exposed to the molten glass rapidly dissolve into the glass. Molten glasses will generally dissolve most oxides, but the glasses do not dissolve metals or organics. To dissolve these latter components into the glass, metals and organics must first be oxidized. Oxidation occurs in situ within the glass melter; and the PbO in the glass is a strong oxidizing agent. If the feed contains organics, the organics are oxidized to CO₂ and steam (H₂O), and the by-product lead metal sinks to the bottom of the melter. The CO₂ and steam exit the melter via the off-gas system. Metals (excluding the noble metals) are oxidized by the PbO in the glass to metal oxides and, subsequently, dissolve into the glass. The lead by-product then sinks to the bottom of the melter. Typical chemical reactions are:

\[2\text{Al} + 3\text{PbO} \rightarrow \text{Al}_2\text{O}_3 + 3\text{Pb}\downarrow\]
\[\text{Pu} + 2\text{PbO} \rightarrow \text{PuO}_2 + 2\text{Pb}\downarrow\]
\[\text{C} + 2\text{PbO} \rightarrow \text{CO}_2 \uparrow + 2\text{Pb}\downarrow\]
\[\text{Zr} + 2\text{PbO} \rightarrow \text{ZrO}_2 + 2\text{Pb}\downarrow\]

Rapid oxidation and dissolution are the results of the special characteristics of the \(\text{PbO}:\text{B}_2\text{O}_3\) dissolution glass. At operating temperatures (700 – 900 °C), the PbO is a powerful oxidizer. However, some metals and other materials form protective oxide coatings. The \(\text{B}_2\text{O}_3\) is an effective dissolution agent for oxides. It is used in many welding fluxes and analytical procedures for rapid dissolution of oxides. The combination of the PbO and \(\text{B}_2\text{O}_3\) creates the unique oxidation-dissolution capabilities of this molten glass. The \(2\text{PbO}:\text{B}_2\text{O}_3\) glass composition is chosen to maximize chemical reaction rates and maximize solubility of oxides in the melt.

The dissolution process simultaneously separates halogens from the melt. For example, let us consider a feed containing chlorides. In the dissolution glass, chlorides in the feed form lead chloride (PbCl₂), which is volatile at glass melter temperatures and exits to the aqueous sodium hydroxide (NaOH) scrubber. In the scrubber, the PbCl₂ reacts with the NaOH to yield insoluble lead hydroxide [\(\text{Pb(OH)}_2\)] and soluble NaCl. The insoluble Pb(OH)₂ is recycled back to the melter, in which it decomposes to PbO and steam. The aqueous NaCl stream is cleaned and discharged as a chemical waste. Other halogen-containing feeds behave similarly. Lead halides are thermodynamically more stable than uranium and plutonium halides (Forsberg, 1996); thus, volatile fissile halides do not form and can not escape the melter.

The dissolution glass also oxidizes sulfur-containing components to sulfur oxides that exit via the off-gas. Lead smelters convert lead ores (primarily sulfides) and recycle materials into lead metal and lead oxide (Queneau and Siegmund, 1996). The same chemical processes are used in the melter to remove sulfides and other sulfur compounds from the feed materials. Typical reactions include:
The noble metals are not oxidized by the PbO. During feed dissolution, they separate from the glass and dissolve into the lead metal. Noble metals are not soluble in glass, but they are highly soluble in molten lead (Jensen 1984). The noble metals sink to the bottom of the melter with the molten lead. In this system all metals more noble than copper (gold, platinum, etc.) dissolve into the lead, while copper and less noble metals are oxidized. The noble metals can be separated from the lead by vacuum distillation of the lead or by several other demonstrated processes. Significant quantities of noble metals are found in some lead ores. The noble metals remain with the lead metal during smelting operations. Consequently, multiple processes for noble metal separation from lead have been developed and deployed (King 1995).

**Lead-Oxide Removal for Conversion of Molten Dissolution Glass to a B₂O₃ Fusion Melt**

After the dissolution step is completed, carbon is added to the dissolution glass. Carbon reduces the PbO to lead metal, and gaseous CO₂ is produced. Reduction of PbO to lead metal in glassy slags using carbon is part of many lead-smelter processes (Queneau and Siegmund, 1996). All of the PbO is removed from the dissolution glass to produce a B₂O₃ fusion melt (oxides dissolved in B₂O₃). During this step, it may be necessary to supply additional B₂O₃ (depending upon the feed material) to keep all materials in solution. The solubility limits of certain elements in a PbO:B₂O₃ dissolution glass may be higher than in just the B₂O₃ without the PbO.

The resultant B₂O₃ fusion melt is poured from the furnace and allowed to solidify before the glassy B₂O₃ solid is fed to the separations step. Formation of crystalline compounds during solidification is to be avoided because of their slower dissolution rates in nitric acid. The solubility of various oxides in B₂O₃-fusion melts is strongly dependent upon the temperature of the melt. With rapid cooling of the melt, higher loadings of oxides can remain dissolved in the B₂O₃ while forming a solid glassy B₂O₃ structure. This approach minimizes the B₂O₃ in the solid and reduces feed volume to the separations step. With current technology used in research reactor fuel fabrication, the option exists for rapid cooling (up to 10⁶ K/sec) and atomization of melts with uniform particles with sizes as small as 50 to 100 microns (ANL, 1993).

**Lead Oxidation**

Lead is an oxygen carrier in the dissolution process. Oxygen is injected into the molten lead recovered from (1) the lead-borate dissolution step and (2) the conversion of the dissolution glass to a B₂O₃-fusion melt. Lead is oxidized to PbO. The oxidation reaction is:

\[
2 \text{Pb} + \text{O}_2 \rightarrow 2\text{PbO}
\]
The PbO is recycled and used to make the next batch of lead-borate dissolution glass. The option exists to oxidize the lead in the melter by adding $O_2$ to the melter after removing the $B_2O_3$ fusion melt. This process is used to make PbO for lead-acid batteries and other purposes (King, 1995).

4. URANIUM AND PLUTONIUM SEPARATIONS

The processing of the feed material into a $B_2O_3$ fusion melt creates a solid, oxide feed that is optimized for recovering uranium, plutonium, and other elements by using current acid-based separations processes such as PUREX (Benedict and Pigford, 1957) and ion exchange. In all of these separations processes, the solidified $B_2O_3$ fusion melt is dissolved into aqueous nitric acid, and the desired elements are then separated from the nitric acid solution by solvent extraction, ion exchange, or similar processes. The differences in the processes is the choice of extraction agent and its efficiency in removing of one element vs another element.

The feed requirements for such separations processes are (1) conversion of the desired elements into dissolved ions in acid solutions and (2) removal of troublesome components that interfere with separations. The conversion process to make the $B_2O_3$ fusion melt produces a desirable feed to the aqueous separations process for the following reasons:

- **Dissolution kinetics.** The $B_2O_3$ fusion melt is soluble in acid and has rapid dissolution kinetics. Many oxides [aluminum oxide ($Al_2O_3$), plutonium oxide ($PuO_2$), etc.] are soluble in nitric acid but have very-slow dissolution kinetics. When oxides are dissolved into a solid $B_2O_3$ matrix, they dissolve into nitric acid more rapidly as the $B_2O_3$ matrix around them dissolves into the nitric acid. In conventional processing slow dissolution kinetics necessitates the addition of fluoride ions, mercury ions, and other reagents to accelerate feed dissolution. These reagents then cause major problems in downstream waste processing operations. Furthermore, different reagents are needed for different feeds and each has a different set of process requirements.

- **Preoxidation of feed.** The PbO oxidation step destroys troubling organics and converts metals to oxides. This avoids the need for added nitric acid to oxidize feed materials.

- **Halogen removal.** The dehalogenation process eliminates troublesome halogens that can interfere with separations and simplifies engineering. Halogens mixed with nitric acid are highly corrosive and create major problems in terms of equipment corrosion.

The dissolution of $B_2O_3$ in nitric acid and its behavior in the PUREX separation process have been investigated (Schulz, 1984; Korovin, 1966; and Vinogradov and Azarova, 1967). The data show low extraction coefficients for boric acid by tributyl phosphate in the PUREX process; it is relatively easy to separate uranium and plutonium from the boric acid in nitric acid systems.
5. VITRIFICATION

The acid waste stream from the separation process is converted to borosilicate waste glass using current industrial waste vitrification processes (Courtois 1996). The wastes are concentrated by evaporation of excess water and then are fed to a separate glass melter simultaneously with glass frit (primarily SiO₂). The nitrates are decomposed to oxides and the resultant oxides are then converted to glass. The earlier borate-fusion steps eliminate several potential problems in waste vitrification by removing the halides and noble metals from the feed. Halides form poor-quality glass. Noble metals cause operational problems.

6. BORON-OXIDE RECYCLE

The dissolution of the solid B₂O₃ fusion melt in acid produces an aqueous stream with significant concentrations of boric acid. There are economic incentives to minimize the boric acid in this stream and recycle the B₂O₃. There are several techniques to accomplish these goals. The preferred option or options have not been identified.

Minimization of B₂O₃ in Boron Fusion Melt

The solubility of various oxides in B₂O₃-fusion melts is strongly dependent upon the temperature of the melt. With rapid cooling of the melt, higher loadings of oxides can remain dissolved in the solid glassy B₂O₃ structure which ensures easy dissolution in nitric acid. This is feasible because of the unusual characteristic of B₂O₃ which preferentially forms glassy (not crystalline) structures upon cooling (Sokolov, 1996).

Separation and Recycle of B₂O₃ before Nitric Acid Dissolution

Boric acid is highly soluble in hot water. After the B₂O₃ fusion melt is cooled, much of the B₂O₃ can be dissolved in water as boric acid, the water can be evaporated, and the B₂O₃ can be recycled to make added dissolution glass. The undissolved material following the hot-water wash is then fed to the nitric acid dissolution step for uranium and plutonium recovery. The viability of this option is dependent upon what other materials are in the B₂O₃ fusion melt.

Direct Conversion to Glass

The waste can be converted to glass using additional glass frit to dilute the excess B₂O₃ in the waste stream to acceptable waste glass compositions.

Mixing with Other Wastes

In the United States and several other countries, large facilities exist to convert nitrate wastes [primarily high-level waste (HLW)] in waste tanks to borosilicate glass for disposal. These wastes do not contain significant quantities of boron; hence, borates are added to the glass melters to make borosilicate glass. At such sites, the boric-acid, nitric-acid waste stream from the process
herein can be mixed with other waste streams and simultaneously converted to glass. At such sites, coprocessing of waste streams provides a method to beneficially use the excess boric acid in the waste stream from this process.

Separation of B₂O₃ from Acid Waste Stream

The B₂O₃ can be separated from the acid waste stream and recycled back to the front of the process. There are several options for separation of B₂O₃ depending upon the purity desired for the B₂O₃. These include such techniques as adding methanol and forming volatile boron compounds such as trimethyl borate. The volatile gas is then oxidized to B₂O₃ for recycle.

7. SYSTEM CONFIGURATION

The B₂O₃ fusion-melt process steps can be configured as batch, semibatch, or continuous operation. The preferred option will depend upon the scale of operation and other factors.

In a batch operation all of the major steps (except off-gas processing) are performed in a single vessel in a sequence of four steps over a period of time. The melter starts with the dissolution glass. As feed is added to the melter, feed oxidation, dehalogenation, and oxide dissolution simultaneously occur in the glass with buildup of lead metal at the bottom of the melter. After feed dissolution, carbon is added for conversion of the dissolution glass to a B₂O₃ fusion melt. The B₂O₃ fusion melt is poured from the melter and the molten lead metal is left in the bottom of the melter. The solidified B₂O₃ fusion melt is sent to the separations process. A new batch of dissolution glass is made in the melter by oxidizing the lead metal with O₂ and adding B₂O₃ to the melter. The cycle is then repeated. There is off-line recovery of any noble metals that build up in the lead over time.

In a semibatch or continuous operation, the lead metal is drained from the melter as it is produced and it is reoxidized off-line. There are also continuous process options (see the following) for large-scale operations.

8. EQUIPMENT

The equipment requirements for the process have been identified. The separations and vitrification steps use existing equipment designs. The B₂O₃ fusion melt step requires a cold-wall melter because of the corrosive characteristics of the initial dissolution glass. The dissolution glass will dissolve all materials except noble metals and the molten lead dissolves noble metals. Cold-wall melters have cooling jackets in the wall to produce a "skull" of solidified material that protects the wall from the melter contents. Cold-wall melters are used industrially to melt high-temperature materials (e.g., titanium and superalloys) and to produce ultrapure materials (e.g., glass for fiber optics). Russia, France, and the United States are modifying such equipment for processing various radioactive wastes (Courtois, 1996). Batch size may be as large as hundreds of kilograms for MFM with low fissile material concentrations. In Europe, cold-wall melters are currently being developed for throughputs of up to 800 kg/h. There are multiple heating methods.
Figure 2. shows a small, laboratory, cold-wall, induction-heated melter (Courtesy of Consarc, New Jersey).
9. STATUS OF DEVELOPMENT

The process described herein is a combination of several existing industrial technologies and several new technologies. Conversion of feeds to a lead-borate fusion melt using the lead-borate glass is a new technology. The technology is currently being developed for conversion of wastes to borosilicate glass (Forsberg, 1995a; Forsberg 1995b). Conversion of the dissolution glass to a \( \text{B}_2\text{O}_3 \) fusion melt is an extension of that technology. The use of \( \text{B}_2\text{O}_3 \) in welding fluxes for dissolution of oxides to avoid oxide inclusions in welds and \( \text{B}_2\text{O}_3 \) fusion melts in analytical chemistry laboratories to dissolve "insoluble" residues are established technologies. Separation of uranium and plutonium from nitric acid streams has been an industrial process used since 1954 (Benedict and Pigford, 1957), and the vitrification of nitric acid waste streams has been an industrial process since 1978 (Courtois, 1996).

A thermodynamic study of the borate dissolution process has been completed, and an experimental program has investigated the key steps (Forsberg, 1995a). Tests in lead-borate glass demonstrated the dissolution of \( \text{UO}_2, \text{ZrO}_2, \text{Al}_2\text{O}_3, \text{Ce}_2\text{O}_3, \text{MgO}, \) and other oxides. Oxidation-dissolution tests demonstrated the oxidation of the following metals and alloys (followed by the dissolution of their oxides into the melt): \( \text{U}, \text{Ce}, \text{Zircaloy-2}, \text{Al}, \text{stainless steel}, \) and other metals. Figure 3 shows a crucible test at the half way point to dissolve Zircaloy clad into the dissolution glass. Some of the Zircaloy has reacted and dissolved into the glass, and by-product lead has been produced. Oxidation-dissolution tests also demonstrated the oxidation of carbon and graphite and the resultant production of \( \text{CO}_2 \). Proof-of-principle tests showed the conversion of chlorides to \( \text{PbCl}_2 \) and its escape into the off-gas system.

Many of the other process steps to generate a \( \text{B}_2\text{O}_3 \) fusion melt (removal of lead from the dissolution glass, oxidation of lead back to \( \text{PbO} \), and removal of noble metals) are steps in existing industrial processes in lead-smelting and lead-battery production and gold recovery industries. Specifically, it is recognized that the creation of a \( \text{B}_2\text{O}_3 \) fusion melt has similarities to several state-of-the-art lead-smelter processes such as the Queneau-Schuhmann-Lurgi (QSL) continuous lead-smelting process (Queneau and Siegmund, 1996), as shown in Fig. 4. The QSL furnace has an oxidizing zone (similar to the oxidation, dehalogenation, and oxide-dissolution step) and a reducing zone (similar to removal of excess \( \text{PbO} \) and conversion of the lead borate to a \( \text{B}_2\text{O}_3 \) fusion melt).

In the QSL oxidizing zone, \( \text{O}_2 \) and \( \text{PbO} \) convert molten slag feed materials (lead sulfide ores and recycled lead battery materials with some plastics) to (1) \( \text{PbO} \), which remains in the slag; (2) lead metal, which separates from the slag and sinks to the bottom of the system; and (3) an off-gas stream of sulfur oxides, carbon oxides, and steam. In the QSL reducing step, coal is added to the molten glassy slag containing feed impurities and \( \text{PbO} \). The \( \text{PbO} \) is reduced to lead metal, which separates from the slag and sinks to the bottom of the furnace. The glassy slag low in \( \text{PbO} \) is discharged as a waste. Much (but not all) of the chemistry in the two processes is identical. During these analogous operations, the process described herein is optimized to produce a \( \text{B}_2\text{O}_3 \) fusion melt, whereas QSL is optimized for economical lead recovery from ores.
Fig. 3. Oxidation-dissolution of Zircaloy-2 in lead borate glass at the half-way point.
QSL Process For Lead Smelting

Reduction Zone — Oxidation Zone

Air (if required)

Lead Concentrates + Fuel

Reduction Zone Oxidation Zone

Off-Gas

Lead Oxide/Silicate Slag

Weir

Carbon + Carrier Air + Oxygen

Oxygen

Lead Bullion

Slag

Conversion Of Fissile Wastes To Borate Fusion Melt

Reduction Zone — Oxidation Zone

Off-Gas

B$_2$O$_3$ + Fissile Wastes

Dissolution Glass 2PbO : B$_2$O$_3$

Weir

Borate Fusion Melt

To Lead Cleanup

Carbon

Oxygen

Fig. 4. QSL chemical reactor and analogous chemical reactor for continuous conversion of materials to a B$_2$O$_3$ fusion melt.
QSL lead smelters have capacities of from 60,000 to 75,000 t/year. While such large throughputs are not required for fissile material recovery, there is an experience base in these types of chemical systems with PbO. Furthermore, some of the small-scale work for development of the QSL and related processes is applicable to processing of MFM.

In recent years, the lead-borate dissolution glass has been used in various analytical tests and has become the preferred solvent used in high-temperature calorimetry tests for determination of the thermodynamic properties of complex minerals (Navrotsky 1997). It has been successfully used in calorimetry tests for dissolution of complex minerals containing MgO, Al2O3, SiO2, alkali oxides, alkaline earth oxides, MnO, Mo (M=Co, Ni, Zn, Cd), Mn2O3, MnO2, Fe2O3, Cr2O3, TiO2, ZrO2, rare earth oxides, GeO2, Ga2O3, hydrous phases, carbonates, fluorides, and other compounds. For these applications and for recovery of fissile materials, lead borate is used because of its extraordinary dissolution capabilities. For all of these applications, the preferred dissolution glass is the 2PbO:B2O3 mixture.

10. CONCLUSIONS

A new process has been invented for treatment of MFM. This new process includes both proven technologies and new process operations. Most of the chemistry of the process has been demonstrated, but significant development is required. The process, if successfully developed, would create a general-purpose method to treat almost all MFM and to recover fissile materials and convert the wastes to borosilicate glass, which is an acceptable form for disposal.

REFERENCES


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