

# RETRIEVABLE INTERIM SOLIDIFICATION OF HIGH LEVEL LIQUID WASTE

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## ABSTRACT

A process consisting of steps such as packing the powder of high level waste oxide into a stainless steel container, degassing and capping, compacting to obtain a high density monolithic solid in a sealed metal container by means of a high impact energy hot forming machine was studied to show a state of art feasibility of the Retrievable Interim Solidification concept in order to provide the management policy of the high level liquid waste with a flexible and easily accepted alternative route to be achieved. A stainless steel capsule was filled with a mixture of oxides powder simulating the high level waste oxide and compacted under a high impact energy (6.86 kJ) at 873 K to form a solid of 5,800 kg/m<sup>3</sup> in density and 4 W/m.K in thermal conductivity. Compared with a typical borosilicate glass characterized as the final disposal form, the compacted waste oxide characterized as the retrievable interim solid form will have had a unique feature in terms of transportation ease, engineered storage and heat or radiation to be utilized owing to its high waste oxide density, high thermodynamic stability and low ( $\alpha, n$ ) neutron yield.

## INTRODUCTION

Extensive developmental work has been done to establish the management technology of the high level liquid waste originating from the PUREX reprocessing of spent commercial nuclear fuels in Japan, in accordance with a definite policy to take the route of immobilization, engineering storage and eventual geological disposal. Despite such efforts, seeking extensive public acceptance toward the waste management policy, attention has been paid to technologies to utilize heat or radiation of the high level waste as well as partitioning and transmutation of long lived nuclides in Japan. The present study was intended to show a state of the art feasibility of the retrievable interim solidification concept in which the principal feature was to provide an efficient heat or radiation source material, and a most suitable retrievable interim product to be vitrified so as to be geologically disposed after the reliable storage for some indefinite period.

The retrievable interim solidification of high level liquid waste is going to be achieved by a simultaneous process which will form the compacted solid of calcined waste oxide without additives and the sealed metal containment in a uniform shape. It is referred to as the compacted waste oxide material and compared to the vitrified material in the present study. The hot isostatic pressing process had been highly popular in such an application as powder compacting into a container. However, the present study acknowledged the "Dynapak" (trade name) process which used to be applied to produce high density ceramic compacts as source material for the vibratory compacting of UO<sub>2</sub>-PuO<sub>2</sub> mixed oxide fuel at the Hanford Laboratory, U.S.A. (1),

mainly because of its dimensional control capability. Transformation of high level liquid waste into waste oxide material was an indispensable part of the concept. However, it was not included in the present study because it has been judged that a suitable denitration and calcining process could have been selected without difficulties among well established processes (2).

## EXPERIMENTAL

The waste oxide simulant was prepared as a mixture of 28 chemical compounds; mainly oxides to simulate a calcined product of the commercial high level liquid waste as shown in Table I. The chemical composition was fundamentally based on the ORIGEN calculation against the spent UO<sub>2</sub> fuel originally enriched with 4.5% <sup>235</sup>U, irradiated up to 45,000 MWD/t in a PWR and cooled for four years, and on typical PUREX process flow sheet conditions. Zirconium not only as a fission product but also as chips of cladding tubes, corrosion products from a stainless steel dissolver and degradation products from an organic solvent were also taken into account. Sodium, which used to be deliberately contained in the high level liquid waste, to aid borosilicate glass formation, was not taken into account, because there was no inevitability for acceptance of sodium in the compacted waste oxide material at all. Certain chemical compounds of radioactive elements such as Tc, Pm and actinides were substituted by the same weight of non-radioactive substitutional chemical compounds such as Re<sub>2</sub>O<sub>7</sub> and CeO<sub>2</sub>. The presence of Gd<sub>2</sub>O<sub>3</sub> suggested the possible application of burnable poison. Consequently, 81.2 kg of waste oxide should have resulted from the processing of one ton of designated spent fuel.

TABLE I

Composition of Waste Oxide Stimulant

No	Compound	Sp. Gravity	Weight %	Note
1	Cr <sub>2</sub> O <sub>3</sub>	5.21	1.980	
2	Fe <sub>2</sub> O <sub>3</sub>	5.24	10.166	
3	FePO <sub>4</sub>	2.87	0.755	* 1
4	NiO	6.67	1.724	
5	BaSeO <sub>3</sub>	no data	0.319	
6	Rb <sub>2</sub> O	3.72	0.652	
7	Sr <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub>	no data	2.467	* 1
8	Y <sub>2</sub> O <sub>3</sub>	4.84	0.998	
9	ZrO <sub>2</sub>	5.49	11.129	* 2
10	MoO <sub>3</sub>	4.69	8.421	
11	Re <sub>2</sub> O <sub>7</sub>	6.10	2.058	* 3
12	RuO <sub>2</sub>	4.67	4.825	
13	Rh <sub>2</sub> O <sub>3</sub>	8.20	0.862	
14	PdO	8.31	2.580	
15	Ag <sub>2</sub> O	7.22	0.122	
16	CdO	8.15	0.206	
17	SnO <sub>2</sub>	6.95	0.228	
18	Sb <sub>2</sub> O <sub>3</sub>	5.67	0.043	
19	TeO <sub>2</sub>	5.67	0.987	
20	Cs <sub>2</sub> O	4.36	4.571	
21	BaO	5.72	2.831	
22	La <sub>2</sub> O <sub>3</sub>	6.51	2.402	
23	CeO <sub>2</sub>	7.13	13.269	* 4
24	Pr <sub>6</sub> O <sub>11</sub>	6.61	2.266	
25	Nd <sub>2</sub> O <sub>3</sub>	7.24	8.002	* 5
26	Sm <sub>2</sub> O <sub>3</sub>	7.43	1.426	
27	Eu <sub>2</sub> O <sub>3</sub>	7.42	0.291	
28	Gd <sub>2</sub> O <sub>3</sub>	7.41	14.422	* 6

Weighted Av.

Sp. Gr. 6.15 100.002 Total

(Note)

\* 1: Phosphate form degraded solvent.

\* 2: Includes chips from shared calding.

\* 3: Substitute of Tc<sub>2</sub>O<sub>7</sub>.

\* 4: Includes substitute of actinides.

\* 5: Includes substitute of Pm<sub>2</sub>O<sub>3</sub>.

\* 6: Burnable poison.

Each weighed component of chemical compounds was mixed together and ground using an agate mortar and pestle, within a grove box kept under dry atmosphere in order to avoid possible deliquescence of certain compounds such as Rb<sub>2</sub>O, Re<sub>2</sub>O<sub>7</sub> and Cs<sub>2</sub>O.

The waste oxide simulant powder was characterized as the tapping density of 2,000 kg/m<sup>3</sup>, the cold compacted density of 4,000 kg/m<sup>3</sup> under 29.4 MPa in cylindrical disc form of 13 mm diameter and 4 mm thick, and no shrinkage

during sintering at 1,273 K with 4% weight loss and no eutectic reaction at the contact with a 304L stainless steel up to 1,273 K was observed. According to a thermo-gravimetric measurement in an air stream of 55 ml/s at a constant temperature rise of 5 K/min, the weight of the waste oxide simulant powder sample was kept constant between 873 K and 1,073 K. After about 4% of loss by 873 K, presumably due to dehydration, weight loss started again from 1,073 and became aggressive from 1,273 K to give about 19% gross weight loss from room temperature to 1,473 K. The differential thermal analysis did not show noteworthy endothermic or exothermic peaks in all temperature ranges tested. An X-ray diffraction measurement did not detect any new crystalline species after heating at 1,273 K.

The above preliminary tests revealed that the waste oxide simulant powder should have been degassed after loading into a metal capsule at the temperature not lower than 873 K to eliminate water vapor but lower than 1,073 to avoid possible volatilization of components, and the final hot compaction should have been done under a similar temperature limit to avoid possible pressure buildup due to excessive volatilization of components.

Small cylindrical experimental metal capsules of 304L stainless steel were fabricated by machine to form a vessel and a cap attached to an access pipe, and TIG welded together according to the drawing shown in Fig. 1. The waste oxide simulant powder was filled through an access pipe up to the bottom end of the access pipe then a ball of silica wool was placed at the top of the filled powder in order to hold the powder in place.

Each capsule filled with the waste oxide simulant powder was connected to a vacuum system to be evacuated for

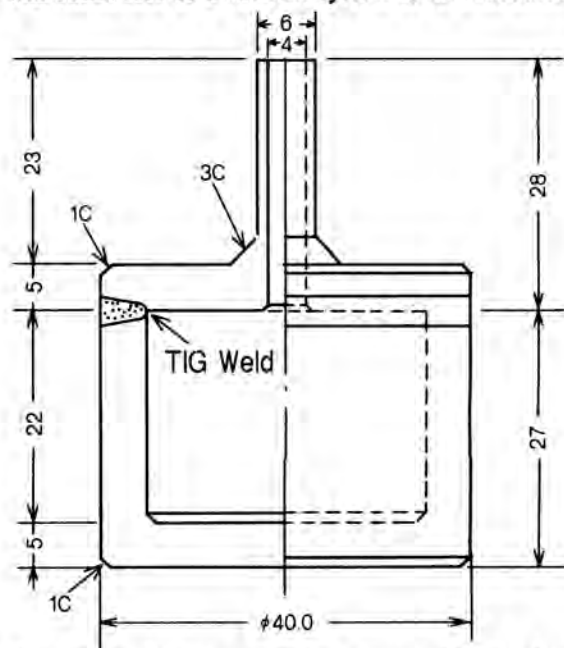


Fig. 1. Capsule for compacting waste oxide simulant.

three hours while heated at 873 K in order to eliminate water vapor prior to being sealed by pinching and clipping at the lower end of the access pipe. The sealed capsules were ready to be compacted by means of a high impact energy compacting machine, "Dynapak."

The machine applied in the present study was "Dynapak 620C" (made by General Dynamics, U.S.A.), as shown in the outline of the machine in Fig. 2. "Dynapak" is originally a single action mass-production type of hot forging machine used to produce complicated-shaped mechanical parts with a high dimension of accuracy using a die and punches, taking advantage of metal flow accompanied by a high speed of deformation under high impact energy in a very short time. The characteristic feature of "Dynapak" is that the high impact energy is applied to the work piece in a die by means of a massive ram/piston projected by high pressure firing gas. Thus, the impact energy at a certain stroke of the ram/piston is simply controlled by the pressure of the firing gas. Figure 3 shows the dependency of impact energy upon the pressure of the firing gas for "Dynapak 620C" at various amplitudes of the stroke of the ram/piston.

A die assembly was designed attempting to provide a ram/piston stroke of 22.3 cm, thus the highest impact energy

of 43.1 kJ could have been obtained at a firing gas pressure of 13.7 MPa. A die and punches were manufactured from die steel and punches were heat treated to give the hardness of RC 55 in order to free them from buckling during the hot high energy impact compactions.

Ten trial compactions were carried out with different preheated temperatures and impact energies applied as experimental parameters. Each compaction was made at a predetermined firing pressure immediately after a heated capsule was placed in the die cavity manually, then a right circular cylindrical compact was knocked out mechanically during the ejection mode of machine cycle.

Each compacted density attained by a impaction was calculated using dimensional data and previous weight data of a relevant powder and capsule. Capsules were removed metal clad partially or entirely by machine cut to make available monolithic solid of waste oxide simulant material. A combination of a diamond cutting wheel, ultrasonic cutting and abrasive papers was applied to prepare various samples for a visual demonstration of the cross section of compact and for measurement or testing as follows.

**Pycnometric density measurement:** A glass pycnometer loaded with several chips of irregular fragments of the

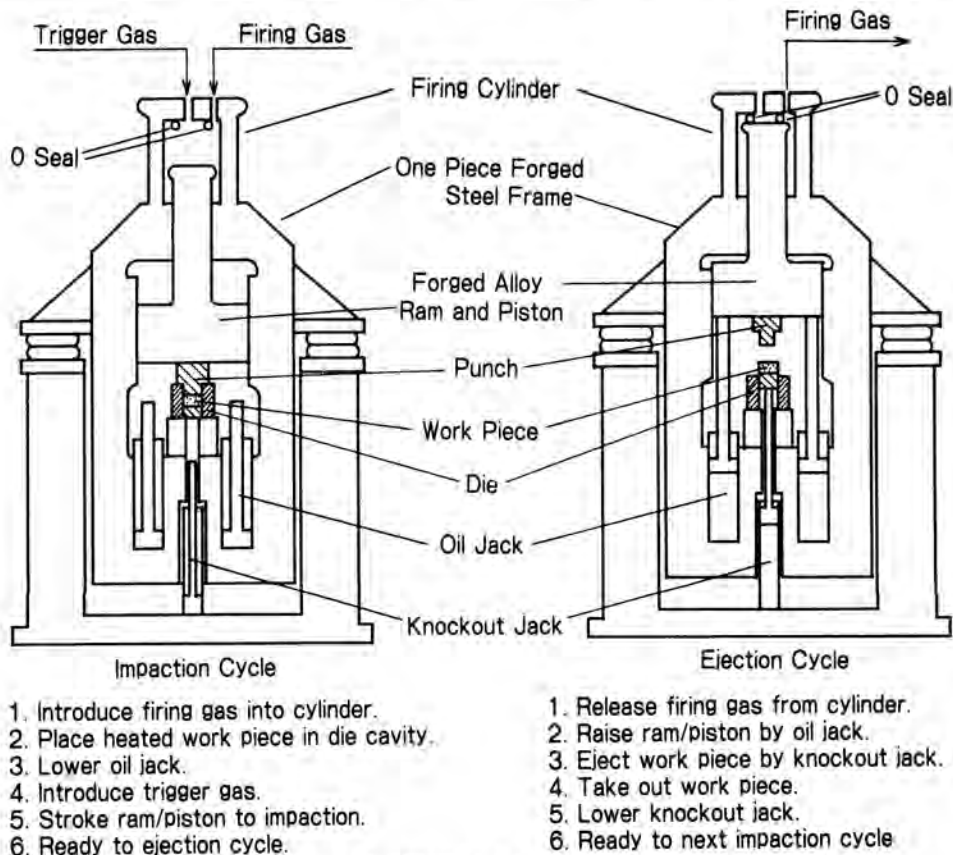


Fig. 2. Outline of "Dynapak 620C" high impact energy forming machine.



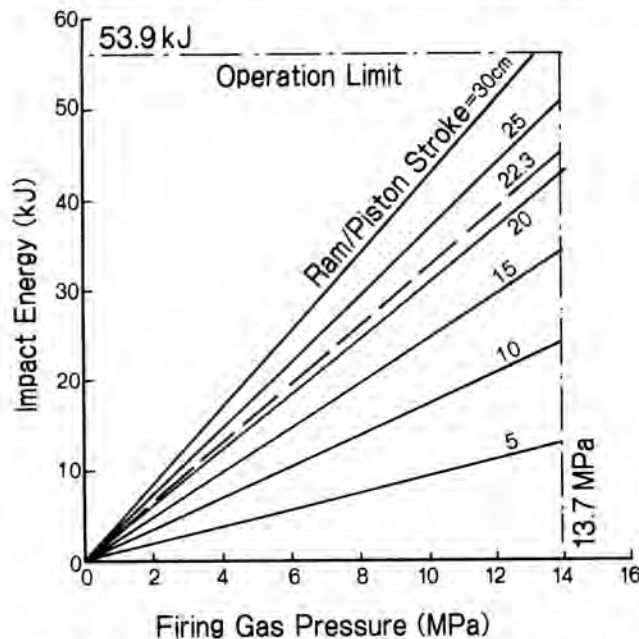


Fig. 3. Operation control scheme of "Dynapak 620C".

compact was hot dried until reaching a constant weight, filled with water and weighed at room temperature. This practice did not intend to penetrate water into pores but to wet the surface by water. Density was calculated with density of water at the room temperature as a reference.

Uniaxial compressive strength test: Each of two parallel-pipe shaped samples of 25 mm<sup>2</sup> in cross section and 6 mm high respectively, were set in a universal material testing machine, and measured a compressive fracture stress at room temperature.

Micro-vickers hardness test: Two discs with polished parallel surfaces were used for the measurement by applying 5 kg load. Metallographs were taken at x 60 magnification.

Thermal conductivity measurement: Two cylindrical discs with polished parallel surfaces of 10 mm in diameter and 4 mm thick were used to measure the specific heat and thermal diffusivity using a laser flash technique at 302 K. A thermal conductivity was calculated based on measured data and a geometrical density of a sample disc respectively.

Leaching rate measurement: A nearly cubic sample of 5-6 mm in size was placed in a TFPE capped vessel with deionized water (100 ml of water per unit square centimeter of the surface area of a sample) and maintained at the constant temperature of 363 K. Water in a capped vessel was replaced and analyzed the amount of leached elements using the ICP every 24 hours up to 30 cycles.

Solubility measurement: A nearly cubic sample of 5-6 mm in size was treated by 500 ml of boiling 3 M nitric acid in a glass flask attached with a condenser for 24 hours. An aliquot of dissolving solution was automatically pipetted every one hour for analysis of dissolved elemental component of the sample, while 3 M nitric acid was supplied periodically so as to keep the volume of acid constant.

RESULTS

The relevant experimental data including process conditions for trial compactions, and densities, mechanical and thermal properties for the designated samples are listed in Table II.

TABLE II

Results of Property Measurements on Waste Oxide Compacts  
Impact Condition Density

No of Compact	Temp. (K)	Energy (kJ)	Geometric (kg/m <sup>3</sup> )	Pycnometric (kg/m <sup>3</sup> )	Thermal Conductivity (W/m.K)	Unilateral Compressive Strength (MPa)	Micro Vickers Hardness (GPa)	Note
1	873	4.32	4,660	---	---	---	---	d
2	873	6.86	5,530	5,770	4.58	---	2.7	
3	873	6.86	5,380	5,880	---	268 and 300	---	
4	873	6.86	5,040	5,920	---	---	---	a, b
5	873	6.86	5,070	---	---	---	---	c
6	873	6.86	5,260	---	---	---	---	d
7	873	6.86	4,930	5,670	---	---	---	b
8	873	13.7	5,340	5,760	---	---	---	a
9	1,073	13.7	5,530	6,160	---	---	---	a, b
10	873	20.3	5,050	6,080	3.55	---	2.9	

(Note) a: Leach Rate in Water, b: Solubility in Nitric Acid, c: Cross Section Demonstration, d: Appearance Demonstration, ---: No Data

The effect of impact energy and preheat temperature upon the density of compacted waste oxide simulant is schematically shown in Fig. 4. There was obvious systematic discrepancy between the geometric density and the pycnometric density, and the former always about 10% lower than the latter, despite the former showed more scattering. Since the theoretical specific gravity of waste oxide simulant was hypothetically given by a weighted average specific gravity of the mixture of compounds as 6.15 as shown in Table I, it is assumed that the pycnometric density of a compact would have been closely reached to the saturated level unless the impact energy was not lower than 6.86 kJ. Impaction at 1,073 K gave slightly higher density than at 873 K, however, it was perceived that the application of higher temperature than 873 K was not worth the risk of possible pressure build up. Thus, it was concluded that the compact ring condition of 6.86 kJ in impact energy and of 873 K in preheat temperature was appropriate at least for the specific capsule configuration in the present study.

Deformation of a capsule during compacting is schematically shown in Fig. 5 and illustrated in Fig. 6 as a comparison between a cross section and an intact compact. It is clear that the waste oxide simulant powder was compressed not only longitudinally but also radially by the deformation of a capsule clad wall. The diameter of a compact was controlled as 41.6 mm according to the inside diameter of die while that of a capsule was 40 mm. The compacted waste oxide simulant had macroscopically monolithic structure but the existence of a horizontal gross fissure suggested more or less stratified morphology due to excessive irregular residual stresses. This has been recognized occasionally by laminal chipping during machining of compacts to shape

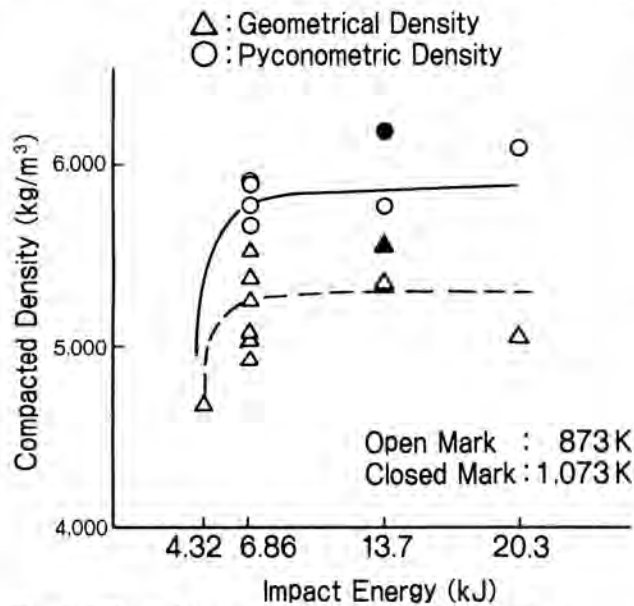


Fig. 4. Effect of impact energy and temperature on compacted density of waste oxide simulant.

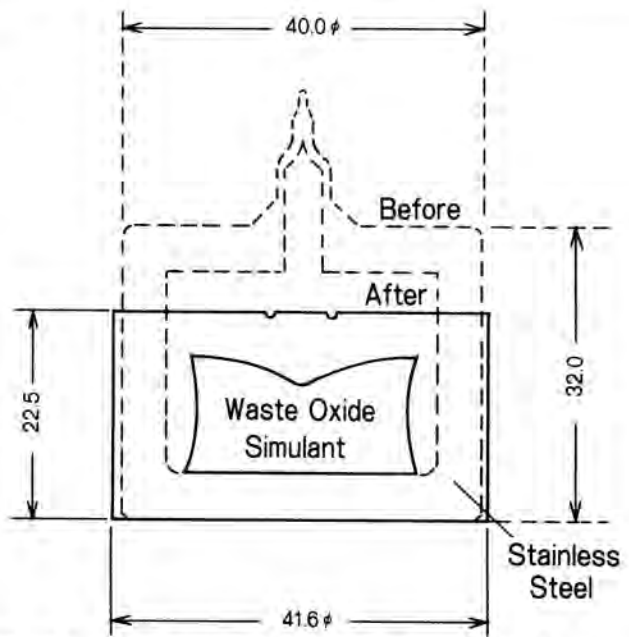


Fig. 5. Deformation of capsule includes waste oxide simulant during high energy impaction forming.



Fig. 6. Compacted waste oxide simulant and the longitudinal cross section.

samples. It should be noted that a circumferentially continuous crack initiated from the upper inside corner was propagated outward. This fact suggested that very strict quality control at the upper circumferential weld joint should have been applied to ensure full penetration.

Thermal conductivities of samples taken from compact No. 2 and No. 10 respectively were fairly the same (but not exactly) despite reversely related each other to the density variation. It is suggested, according to metallographs taken from the samples from the same compacts shown in Fig. 7, that the higher fraction of void on the polished surface of compact No. 10 might be attributed to the lower thermal conductivity. The voids apparently were related to higher selective leach rate by water at the surface during wet sample preparation.

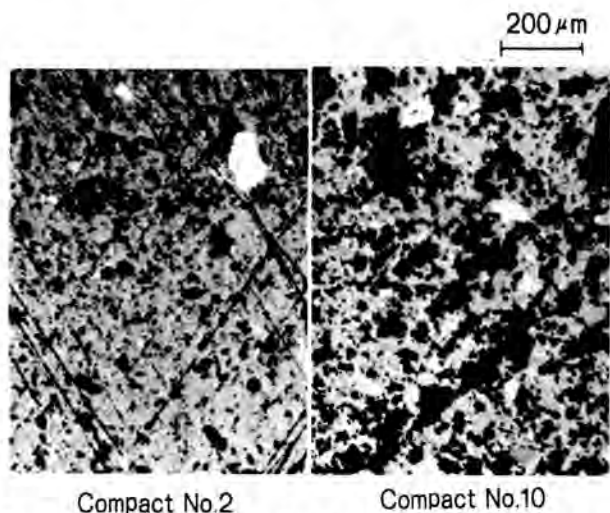


Fig. 7. Metallographic surface structure of compacted waste oxide simulant.

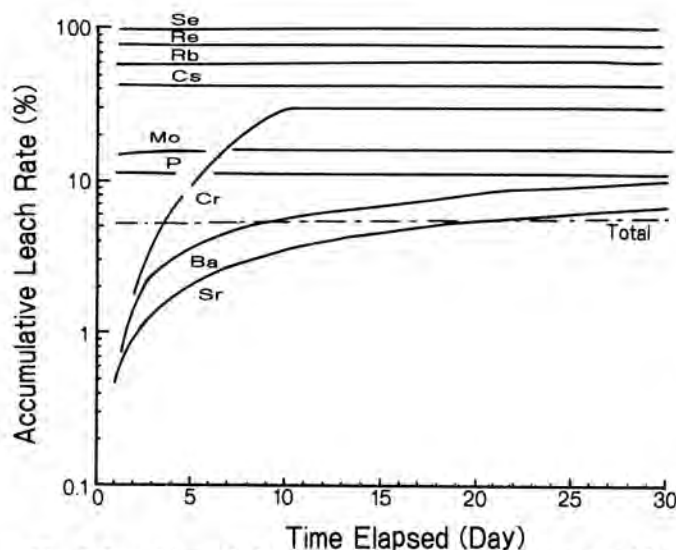


Fig. 8. Leaching of elements from compacted waste oxide in hot water.

The elemental leach rate of the compacted waste oxide simulant in hot water (363 K) along the time elapsed is typically shown for compact No. 4 in Fig. 8. Some elements such as Se, Re, Rb, Cs, Mo and Cr were leached to a certain extent during the first 24 hours, but no more leaching was detected after that until 30 cycles of experiment. On the contrary, P, Ba and Sr were continually leached along the time elapsed. The accumulative gross leached fraction reached 5% in the first 24 hours, but kept fairly constant up to 30 cycles. It was likely that some elements in soluble compounds had been washed away to a certain extent during wet preparation of a sample and 24 hours was long enough to leach a remaining portion from a sample. Nevertheless, the yellow color of dichromate ion was revealed

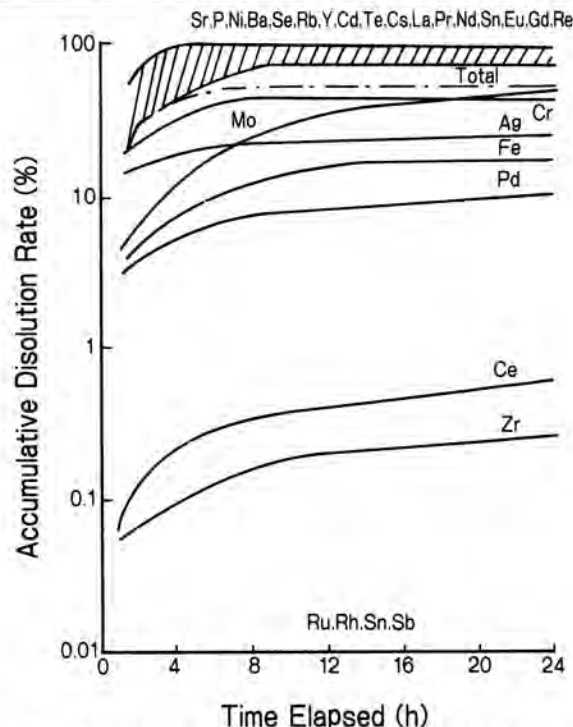


Fig. 9. Dissolution of elements from compacted waste oxide in boiling 3 M HNO<sub>3</sub>.

occasionally when the wet abraded samples were wiped by a piece of filter paper.

The elemental solubility of the compacted waste oxide simulant in boiling 3 M nitric acid along the time elapsed is typically shown for compact No. 7 in Fig. 9. Large numbers of element were dissolved completely in eight hours within experimental errors, but some elements such as Mo, Fe, Ag and Pd were less soluble; Zr and Ce were much less soluble; Ru, Rh, Sn and Sb were not soluble. Accumulative solubility was reached 50% after eight hours of boiling. Principal elemental components of the undissolved material were to be Ce, Zr, Fe, Ru, Mo, Pd and Rh in the order of abundance.

### DISCUSSION

One of the main targets of the retrievable interim solidification was to transform the high level liquid waste into an immobilized waste oxide form as compact as possible. It has been achieved obviously by compacting waste oxide simulant without additives into an almost saturated density, though the fractional volume of metal clad should have been taken into account as far as the loading efficiency of waste oxide was concerned. It is obvious that the larger the scale of compact, the higher the loading efficiency provided the thickness of clad is assumed as identical, and what is most economical.

Assuming that the impact energy during "Dynapak" operation had been consumed only by the deformation of a peripheral vertical wall of metallic clad, provided that the impact energy of 6.86 kJ could have deformed 12.6 cm<sup>3</sup> of



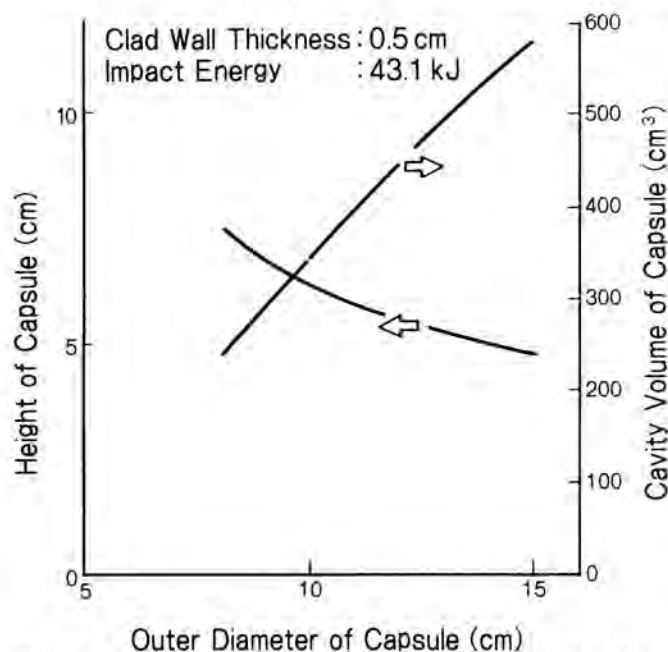


Fig. 10. Allowable dimensions of cylindrical capsule to be impacted by "Dynamak 620C".

304L stainless steel at 873 K under 22.3 c, of a ram/piston stroke in the experiments, the full capacity of "Dynamak 620C" of 43.1 kJ under 22.3 cm of a ram/piston stroke will have deformed 80 cm<sup>3</sup> of 304L stainless steel at 873 K. According to the above assumption with the original clad thickness of 0.5 cm, a relationship between dimensions of a capsule and the related net volume of a capsule to be impacted at the maximum firing pressure of "Dynamak 620C" is shown in Fig. 10, taking the deviations of ram/piston stroke depending upon height of capsule into account. It is obvious that the net volume of a capsule depends only on the diameter but not on the height.

Loaded packing density of the waste oxide powder is a factor to be concerned with to produce a larger compact under the identical process conditions. Loading a pre-compacted waste oxide of 4,000 kg/m<sup>3</sup> in cold-pressed density instead of waste oxide powder itself of 2,000 kg/m<sup>3</sup> in tapping density, as in the present study, will have made twice the net volume of a compact under the same process conditions. Thus, a process to obtain a full-scale compacted waste oxide will be tentatively proposed as follows:

- The precompact waste oxide powder is to be a disc of 11.9 cm in diameter and 4.2 cm high at the density of 4,000 kg/m<sup>3</sup>.
- Place a piece of the compact in a stainless steel capsule of 12.0 cm in inner diameter and 4.3 cm depth with 0.5 cm in clad wall thickness.
- Seal weld a cap to the loaded capsule while heated at 873 K in vacuum. The finished capsule is 13.0 cm in diameter and 5.3 cm high.

- Place the capsule, preheated at 873 K, into the die cavity of 13.2 cm in diameter. A 0.2 cm of cold diametral clearance assumes the thermal expansion of a capsule between room temperature and 873 K.
- Apply 43.1 kJ of impact energy and form a compact of 13.2 cm in diameter and 4.0 cm high. A piece of compact is 3.596 kg in gross weight and contains 1.880 kg of dry waste oxide.
- The 32 compacts are sealed into a stainless steel overpack container tube of 13.3 cm in inner diameter and 123 cm in depth with a 0.5 cm wall thickness. A 0.1 cm of diametral clearance assumes a handling margin. A container contains a total of 60.16 kg of the waste oxide.

A full scale compacted waste oxide container prepared using the above procedure is roughly equivalent to a typical vitrified waste canister of 43 cm in diameter, 130 cm tall, containing 400 kg of glass in terms of the weight of waste oxide contained provided its loading factor is 15%. Accordingly, the waste storage facility to store the vitrified waste canister will have seven times more storage capacity using the same storage practices by introducing the compacted waste oxide container which is three times smaller in diameter than the vitrified waste canister.

Borosilicate glass has been perceived not only in Japan but also internationally as one of the best forms to be geologically disposed of, particularly based on its long term chemical stability. Extensive engineering developments have been done to acquire the necessary practices to perform the so called engineered storage. However, a few daring attempts have been made to use a vitrified waste canister as a heat or radiation source (3).

One of the outstanding characteristics of the compacted waste oxide simulant was that it has almost four times the reported thermal conductivity of a borosilicate glass (2). Even if we could have assumed that the thermodynamic stability limit of the compacted waste oxide was 1,073 K, up to which temperature volatilization of chemical components was not discernible according to a preliminary thermogravimetric test, it would be possible to allow surface temperature of the compacted waste oxide as high as 973 K for the waste arisen from four years cooled 45,000 MWD/t burned spent fuel. Mechanical strength of the compacted waste oxide material is also favorable for various kinds of handling. These features would allow us to use the decay heat from fission products by means of conventional technologies.

The heat output of the accumulative high level waste to be utilized from a reprocessing plant with 800 MTU per year throughput of four years cooled 45,000 MWD/t of spent fuel for ten years is approximately 15 MW, kept at a constant along the plant operation when radioactive decay is taken

into account. This heat output is nearly comparable to 3/8 of the heat consumption used to produce  $5 \times 10^5$  t/year of steam in a reference industrial-scale (4 t/day) reprocessing plant as quoted in the INFCE report (4).

Another aspect of the compacted waste oxide is its high radioactive density mainly due to the pure waste oxide and the high density of the matrix. Fission products will have been typically concentrated in a piece of compacted waste oxide of 13.2 cm in diameter, 4.0 cm high and 1.88 kg in net weight as high as 13,000 Ci and when the gamma energy release rate is  $1.4 \times 10^{14}$  MeV/s is being produced. This is approximately equivalent to a  $^{60}\text{Co}$  gamma source of 1,500 Ci, but will decay significantly slower and last longer than  $^{60}\text{Co}$  source. There might be a potential possibility of using such a gamma source to irradiate the liquid effluent at a reprocessing plant to reduce organic impurities.

If there are no parasitic additives, particularly consisting of light elements such as Li, B, Na, Al or Si, etc., to the compacted waste oxide material, (alpha-n) neutron yield is kept minimized as pointed out occasionally (5). The spontaneous fission of Cm is practically the only neutron source to be concerned with when the compacted waste oxide is transported, stored and even considered as a gamma radiation or heat source.

The appreciably high leach rate, even in cold water, was perceived as a drawback for the utilization of the compact from a safety point of view, even though properties accounted for the direct disposal had not been necessarily regarded in the performance of retrievable interim solidification of high level liquid waste. This will emphasize the necessity to examine the chemistry of calcined waste oxide material instead of a mixture of oxides, as well as of high temperature solid state reaction involving the oxygen potential variation during the hot impactation in a closed container. Waste oxide and clad chemical interference is also a matter of concern in order to ensure the long-term robustness of the compact.

Affinity for the compacted waste oxide material to possible chemical treatments is the identity of the retrievable interim solidification process to represent its retrievability. Not only the solubility of the material in nitric acid but also a reactivity to form glass will be matters to be considered in order to establish the new waste management concept.

### CONCLUSION

The technical feasibility of the retrievable interim solidification of high level liquid waste, in which the "Dynapak"

high energy hot impactation process was applied to form a compacted waste oxide material sealed into a stainless steel clad, was fundamentally justified using a cold simulant in terms of process conditions and properties of the compact.

Practical implications of characteristic features of the retrievable interim solidification are summarized as follows:

1. Shorten the cooling time prior to immobilization of the high level liquid waste.
2. Expand the capacity of existing high level solid waste storage by a factor of up to seven using the same storage practice.
3. Reduce the cost of transportation.
4. Provide a heat source with surface temperature as high as 973 K.
5. Provide a highly rated gamma radiation source with less neutron contaminations.
6. Provide an immobilized source material to be vitrified after efficient engineering storage.

The authors hope that the social consensus is going to be granted to initiate the process feasibility demonstration covering the entire scope in full scale. Various attempts to improve chemical stability, to increase clad robustness, to rationalize process parameters, as well as development of practical methods of using the compacted waste oxide material as a heat or gamma radiation source are likely to be undertaken successively.

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