

<Technical Note>

Low & Intermediate Level Radioactive Waste Vitrification Using Plasma Arc Melting Technology

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Abstract

The purpose of this paper is to provide the results of a series of TB(Trial Burn) tests conducted in the PAM-200 system. The combined series of tests have demonstrated the effectiveness of the PAM graphite-electrode technology for the treatment of many types of low-level radioactive waste including : combustible material, solidified resins in cement, inorganic materials, steel, glass, and solidified boric acid cement. The objectives of PAM-200 evaluation were to verify that 1) the facility meets air emission regulations, 2) the facility can be safely operated when processing hazardous and radioactive materials and 3) satisfactory final waste forms can be produced. Results, derived from KAERI' s(Korea Atomic Energy Research Institute) analyses for samples of vitrified product, scrubbing solution and offgas collected during test period, show that PAM-200 can treat radioactive wastes as well as hazardous wastes with toxic constituents and radionuclides contained in the offgas exiting from the stack to the environment controlled to be far lower than the limit regulated by air conservation law and atomic law.

Key Words : plasma arc melting technology, trial burn test, radionuclide, offgas emission, leaching characteristics

1. Introduction

Vitrification is an emerging technology within the DOE complex that uses a heat source(usually resistance heating) to create a molten bath of glass-forming materials into which waste materials can be dissolved to become an integral part of the glass. In the process, organic compounds are destroyed(by the high temperatures), and when the

glass product cools and solidifies, any contaminations that were not destroyed or volatilized are immobilized. The method heating is the principle that distinguishes the various vitrification technologies. Graphite arc furnaces generate heat by a spark passing from a graphite electrode to either the materials to be melted or another electrode.[1] Five basic test conditions were used to satisfy the objectives of the PAM-200

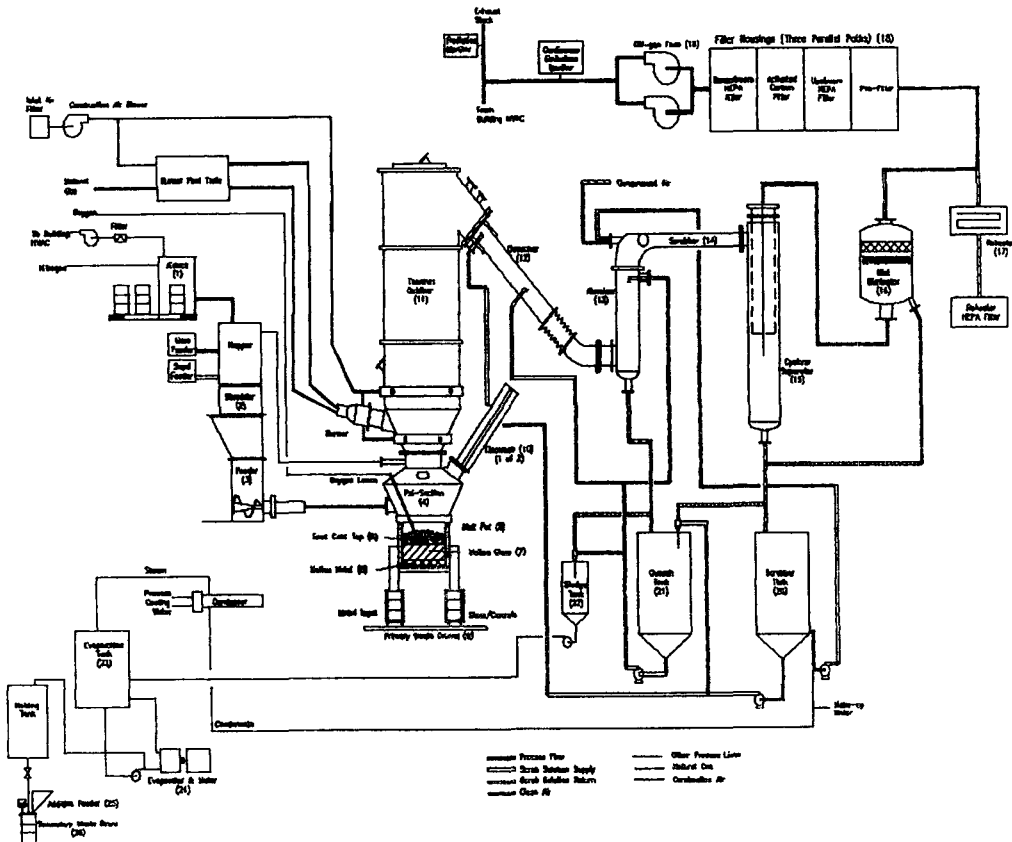


Fig. 1. PAM-200 Process Flow Diagram

trial burn (Figure 1). The five test conditions are: (1) the site acceptance test, (2) the high temperature metals test condition, (3) the low temperature organics test condition, (4) the low temperature non-combustible test condition, and (5) the final waste form test condition. The test conditions are briefly explained below. The high-temperature metals (HTM) test condition is the worst case condition for metals emission. The purpose of the HTM tests was to demonstrate that metal emissions are within regulatory limits when operating conditions have the highest potential to volatilized or entrain metals or compounds. Generally, metal emissions are highest when (1) operating at high temperatures (typical of processing highly combustible waste), (2) high

chlorine feed rate, and (3) high-regulated metal feed rate. The low temperature organics (LTO) test condition is the worst case condition for hazardous organic Destruction Removal Efficiency (DRE). These conditions include low temperature in the SCC (Secondary Combustion Chamber) and hazardous organic materials that are more difficult to destroy. The low-temperature non-combustible (LTNC) test condition tested the facility with highest waste feed rates and lowest temperatures. The purpose of the LTNC was to establish permit limiting operating conditions on the maximum soil/ash/residue/concrete/inorganic feed rate at the lowest operating temperature, which provides an acceptable DRE of POHC. The conditions for this are low temperature resulting from very low or

no combustible content and organic materials that are more difficult to destroy. This test condition was used to show that there is no limit on maximum inorganic content in the solid waste and to set non-combustible feed rate limits. The primary objective of the final waste form with simulated waste test condition was to demonstrate that final waste forms meet performance standards and establish operating conditions and additives associated with the acceptable FWF's(Final Waste Form). The facility was operated at normal conditions while feeding simulated waste plus any additives using the planned campaign sequence. Four different IWS' s(Input Waste Stream) were included in the campaign sequence. This test condition was used to show that the FWF' s meet

the minimum criteria for mechanical and chemical properties. The tests also established the partitioning or separation of the radionuclides and toxic metals into the PWF(Primary Waste Form) or SWF(Secondary Waste Form).

2. Experiment

2.1. Trial Burn Test

The trial burn test plan was developed from a DOE funded project written for testing of plasma torch melters in the USA.[2] The first objective of the trial burn was to demonstrate that the facility meets air emission regulations so that an operating permit can be obtained. The emission

Table 1. Test Informations for Phase 1

Test Phase	Waste Composition	Amount of Waste ⁽¹⁾	Spiking Material(g) ⁽²⁾	Test Time(hrs) ⁽³⁾
P1-1 (Comb.)	PE : 40.6% PVC : 15.6% Paper,Cloth : 43.8%	192kg	CoO: 2,420 CsCl: 1,735 PbO: 500 HgCl ₂ : 500 CdO: 500	17.5
P1-2 (Non-Comb.)	Steel : 2.6% Concrete : 7.7% Air filter : 20.5% Glass : 33.3% Sand, Soil : 35.9%	360kg ⁽⁴⁾	CoO: 968 CsCl: 694 PbO: 1,000 HgCl ₂ : 1,000 CdO: 200g	16
P1-3 (Resin)	Cement : 65.5% Water : 15.0% Resin : 19.4%	600kg ⁽⁵⁾	CoO: 968 CsCl: 694 PbO: 200 HgCl ₂ : 200 CdO: 200g	12
P1-4 (Campaigning)	Comb. : 160kg Non-Comb : 200kg Resin/Boric : 320kg	680kg	-	15

Notes) (1) Exclude Pre-charge Marerial, (2) Total amount of each test
(3) From waste feeding to final tapping (4) Include additives 200kg,
(5) Include additives 240kg

Table 2. Test Informations for Phase 2

Test Phase	Waste Composition	Amount of Waste	Spiking Material(g) ⁽²⁾	Test Time(hrs) ⁽³⁾
P2-1 (Comb.)	PE : 40.6% PVC : 15.6% Paper,Cloth : 43.8%	112kg ⁽¹⁾	Co-60 : 13.04 Cs-137 : 9.71	5
P2-2 (Non-Comb.)	Steel : 2.6% Concrete : 7.7% Air filter : 20.5% Glass : 33.3% Sand, Soil : 35.9%	240kg ⁽⁴⁾	Co-60 : 13.13 Cs-137 : 9.56	6

Notes) (1) Includes 100kg of additive(Soil 40kg, Limestone 60kg)

(2) Total amount in each test (3) From waste feeding to final tapping

(4) Includes 120kg of additives

fall into four classes:

- regulated metal emissions,
- destruction and removal efficiency(DRE) of Principal Organic Hazardous Constituent (POHC) in the waste,
- formation of hazardous products of incomplete combustion(PICs),
- emission of HCl, SO_x, CO, CO₂, NO_x, THC and emission of radioactive materials.

The second objective of the trial burn was to demonstrate that the facility can be safely operated when processing radioactive materials and measure radioactive emissions to the atmosphere. The first tests were performed with simulated waste spiked with both non-radioactive CoO and CsCl to determine the partitioning of these elements. On satisfactory completion of tests with simulated/spiked waste, processing tests were performed with radioactive ⁶⁰Co(NO₃)₂ and ¹³⁷CsCl as the spiking material. The third objective of the trial burn was to demonstrate the final waste form(FWF) meets performance standards while minimizing the use of non-waste additives. Two to five different input wastes were processed in a prescribed sequence. The sequence was designed

to produce an acceptable final waste form with a minimum quantity of additives to the process. Tests were performed with both simulated waste (spiked with non-radioactive CoO and CsCl) and with radioactive ⁶⁰Co(NO₃)₂ and ¹³⁷CsCl. Table 1&2 show test information for Phase 1&2 in detail.

2.2. Feed Materials

The waste stored at the Kori Unit #1 and #2 was used as the basis for the feed materials in the Trial Burn. The waste to be processed during the trial burn series of tests ranged from non-hazardous, non-radioactive surrogate feed in the phase 1 tests to radioactive surrogate feed in the phase 2 tests. Some of the test focused on segregated waste streams, such as combustible or non-combustible. Certain tests have been designated 'campaign' tests, in which PE bags of each waste type was processed, in a pre-determined sequence designed to represent the overall composition of the Kori waste. The composition of the surrogate waste streams are described in table 3.

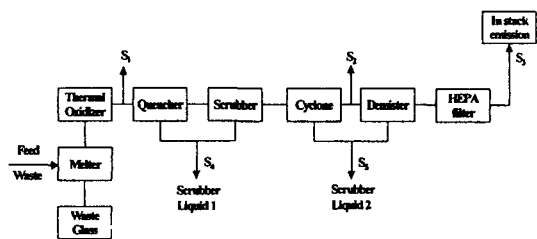
Table 3. Composition of Trial Burn Surrogate Waste Stream on a Per Drum Basis

Waste type	Composition(wt%)	Total Mass(kg)
Combustible	PE:46%, PVC:15.6, Paper:43.8	32.1
Non-combustible	Concret:5.3, Filter:20.5, Glass:33.3 Sand, etc:35.9, Other : 5	195.0
Cemented Boric acid	Boric acid:5.4, Water:29.5, Cement:58.9 Limestone:6.2	355.0
Cemented Resin	Cation resin:9.7, Anion resin:9.7	315.0

2.3. Sampling and Analysis

The sampling and analysis activities focused in the measurements needed to verify that the regulatory requirements would be met during the processing of the KHNP Kori 1&2 nuclear power plant LLW streams. Each test in the trial burn includes sampling of the stack effluent. These samples are then analyzed for the pollutants summarized in table 4. Offgas sampling and device installation based on the method for measuring

gaseous heavy metals described in domestic process test method for pollution and multiple metals sampling method in U.S. EPA.[3] The sampling points described in Figure 2. The

**Fig. 2. Sampling Locations in the Plant****Table 4. Summary of Stack Sampling Plans for PAM-200 Trial Burn Tests**

Gas Sample	Test Condition	Reference Sample Method(s)
Regulated Metals	HTM, LTO, LT, FWF(Simulated)	EPA Multi-Metal Train ^(a)
Particulate Matter	HTM, LTO, LT, FWF(Simulated)	Method 0010 ^(b)
HCl	All	CEM(Photo-acoustic)
NO _x	All	CEM(Chemiluminescence)
CO	All	CEM(NDIR)
THC	All	CEM(FID)
O ₂	All	CEM(Paramagnetic)
SO ₂	All	CEM(Photo-acoustic)
CO ₂	All	CEM(NDIR)
Radioisotope	HTM, LT	Method 0010 ^(b) , RMS

(a) 40 CFR 266, Appendix ix, "Methodology for the Determination of Metals Emissions in Exhaust Gases from Hazardous Waste Incineration and Similar Combustion Sources."

(b) "Test Method for Evaluating Solid Waste-Physical/Chemical Method," SW-846 third Edition, September 1986

KAERI's analyses for samples of vitrified product, scrubbing solution and offgas collected during test period. The KAERI's were analyzed for the off-gas samples and waste glass samples obtained from a series of trial burns to review the decontamination characteristics of radionuclide and heavy metals during PAM operation and the integrity of glassified final waste form. The specifications of analyser are as followed : (a)Inductively coupled Plasma/ mass Spectrometer (Model: Varian, Ultramass 700), (b)Atomic Absorption Spectrometer (Model :Perkin-Elmer, 5100 PC).

3. Trial Burn Test Results

3.1. Continuous Emission Monitoring Measurements

The stack CEM(Continuous Emission Monitoring) oxygen concentration(Figure 3) range mostly from 15% to 18% for the duration of the test except for two very sharp peaks at the beginning and the end of the test. These peaks are most likely erroneous data from the analyzer because the CO₂ has the same two peaks. The CEM sampling tube heater was not available for Phase 1-1 test. The value are as expected from the mixing of the 10% excess combustion air, the scrubber air and the reheater air. The stack CEM CO₂ concentration (Figure 4) ranged from 2.0% to 4.6%. The two spikes that are also on the O₂ plot are most likely an analyzer error. The values are as expected. The stack CEM CO concentration(Figure 5) remained in the 60~80 ppm range for the majority of the test. The US EPA emission limit is also plotted at 150 ppmdv (If THC<20 ppm) over the time of the test. The MOE(Ministry of Environment)/KINS(Korea Institute of Nuclear Safety) limit is 600 ppm. Both the unrestricted US EPA and the US proposed MACT(Most

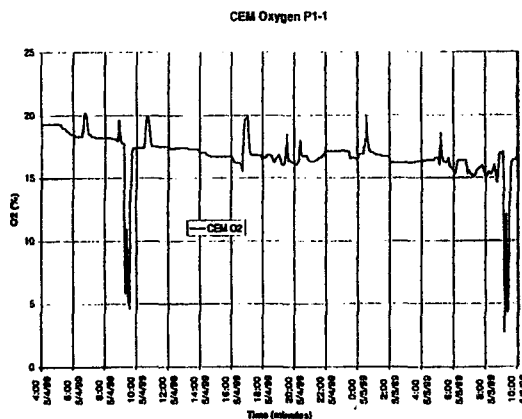


Fig. 3. Plot of the CEM O₂ Concentration

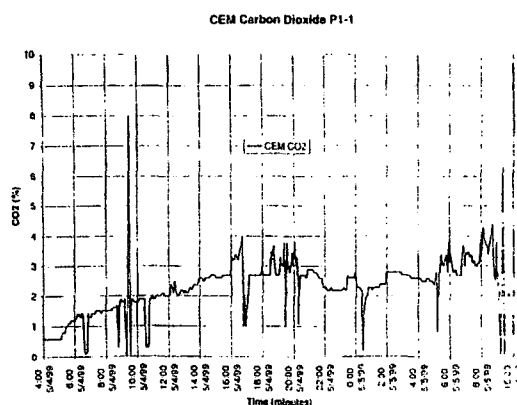


Fig. 4. Plot of the CEM CO₂ Concentration

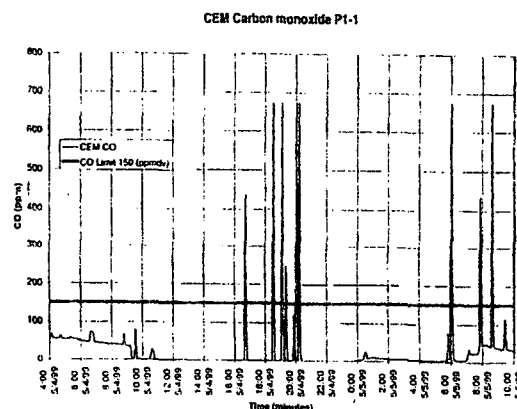


Fig. 5. Plot of the CEM CO₂ Concentration

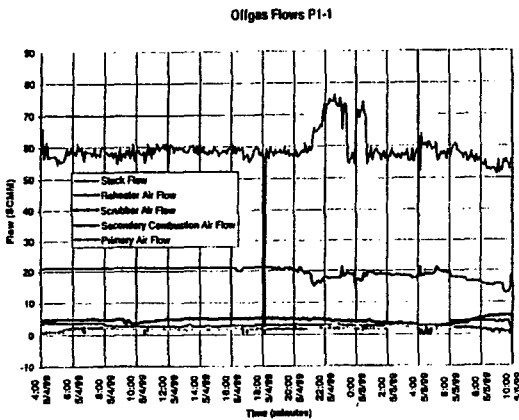


Fig. 6. Plot of the Offgas Flows

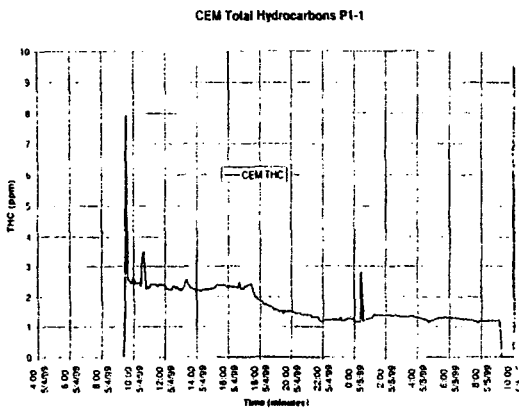


Fig. 7. Plot of the CEM THC Concentration

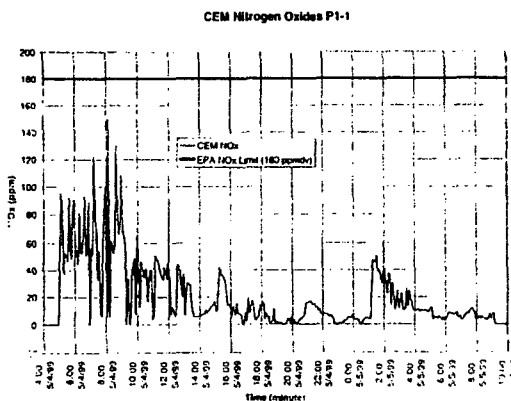


Fig. 8. Plot of the CEM NOx Concentration

Achievable Control Technology) limit is 100 ppm. Several CO spikes in excess of 650 ppm were recorded. These correspond to the time periods for feeding for combustible materials and are considered to be related to the sensitivity and response time for the melter pressure control system and to operator initiation. On the offgas plot(Figure 6), shows that the secondary air flow rate was not increased to allow more oxygen into the SCC during the processing of combustible materials. This could be done in anticipation of feeding combustibles to decrease the CO peaks. Nevertheless, the 24 hours CEMS emission is well below the present US and MACT standard. The stack CEM total hydrocarbon concentration (Figure 7)range from approximately 3.4 ppm at the start of the test approximately 1 ppm at the end of the test. The US EPA standard is 20 ppm and the proposed MACT standard is 10 ppm. The data indicates a gradual downward trend throughout the duration of the test. The spike at the beginning of the test was probably when the CEM was turned on. The CEM sampling tube heater was not available for this test for which some heavier hydrocabons may have condensed out in the tube. In later tests, the sampling tube heater was operational and the THC results were similar and well below emission limits. The stack CEM NOx values(Figure 8) are in the 40~140 ppm during the arc starting mode for the initial melting. These values drop to the 0~40 ppm range in normal operation during processing of the various wastes. The first year US EPA limit was plotted across the time of the test at 180 ppmdv. For subsequent years the limit is 150 ppm, based on 24-hour CEMS measurements. At the starting of the test during the drawing of intermediate to long arcs the NOx level increased to approximately 165 ppm. As a general rule, the long arc and non-transferred arc operating mode increases NOx generation and the normal

Table 5. Comparison of Emission and Regulatory Standards

Pollutant gas	Measured concentration for each gaseous pollutant (ppmdv)				Air Act	US clean Proposed	US MACT
	P1-1	P1-2	P1-3	MOE/KINS P1-4			
CO ₂ (%)	~6	~2	~2	~3	NA	NA	NA
CO (ppm)	~50	4~30	~50	~22	600	50~150	100
THC (ppm)	~2	~0.8	~1	~0.2			10
NO _x (ppm)	~110(starting) ~30(running)	~40(starting) ~6(running)	~35(starting) ~10(running)	~40(starting) ~5(running)	200	150 (180 1 st yr)	
SO ₂	0	Failed	Failed	0	300 at 12% O ₂	30	
HCl	0	Failed	Failed	Failed	50	25	10

submerged arc mode minimizes NO_x generation. These results show that graphite-electrode arc melters meet NO_x emissions without additional treatment, not only during normal operation, but also during starting. The occurrence and concentration of HCl and SO₂ was measured at 10 minute intervals during the sampling period using Drager tubes. All the drager tube measurements read zero(undetectable) concentrations of HCl and SO₂ in the exhaust gas. A summary of the gas emission is given in table 5.

3.2. Evaluation of Glass Samples[4]

Samples of the vitrified material were selected from each test. Some samples were taken by capturing a small quantity of liquid glass during a tapping operation and pouring it into a cylindrical mold created from refractory brick. Other samples were taken from the 200 liter drums where the

liquid glass was cast into after the drum had cooled for one to two days. A summary of the waste form properties is shown in table 6. The quality of the sample depends not only on the composition of the glass, but on how the sample was obtained. A sample from the tap will cool quickly, be very glassy, have large thermal stresses within it, and may crack up even before being tested. In the actual application of tapping into a PWF disposal drum, the glass will cool slowly because of the presence of other hot glass beneath it or poured on top of it. At the edges of the drum, the PWF will be glassy because of more rapid cooling. At the center of the drum, the glass will often be cooled slowly in continuous operation and crystallize into a ceramic with very small mineral crystals. The appearance will be cloudy, not shiny like a glass, indicating it contains crystals. The PWF is usually multi-phased, with mineral crystals immersed in a glass matrix. It is therefore

Table 6. Primary Waste form(PWF) Properties

Test No.	Input Waste Stream	Sample ID	Density (kg/L)	Compressive strength(MPa)	Microhardness (Gpa)
P1-1	Combustibles	1S-C09	2.952	110.4	5.83
P1-2	Resin	1S-R01	2.690	33.8	5.60
P1-3	Non-Comb.	1S-NO1	2.590	87.3	5.53

very important to gather samples of the PWF as generated and not create a sample that does not represent the actual conditions of formation of the PWF. The following discusses samples taken while tapping and were cooled rapidly. The properties of the tapped samples are given in Table 6 for the P1-1 through the P1-3 tests. The densities vary from 2.95 for the P1-1 test in which there was much glass from the pre-charge to 2.42 from the P1-3 noncombustible test. The densities are in the range of 2.5 to 2.9 as expected. The compressive strength of the glassy samples is also given in the table 6. The compressive strengths vary from 33.8 to 110.4 MPa. These values are much lower than expected. Prior measurements on similar compositions at the Idaho National Engineering and Environmental Laboratory(INEEL) on a similar composition that obtained a range of 110~430MPa,[5] but these samples were not cooled rapidly. The 33.8MPa value is extremely low, no better than good concrete which ranges from 21~55MPa. The reason for the lower values with the resins and non-combustibles could be the higher calcium content, or the lack of heat treating the glass samples to relieve thermal stresses generated during cooling. Microhardness values are also given in table 6 and are typical for a glass-ceramic calcium-alumina silicates and appear related to the given densities.

3.2.1. Microhardness Data

Microhardness tests were conducted as another determination of the durability of the glass final waste form by following relation. The microhardness of glass samples from phase 1 as shown in Fig 9. Vicker's Microhardness instrument (Clark Co., Model MHT 1 Knoop Indentor) was used.

$$H_v = \text{applied load/contact area of indenter} \quad (1)$$

$$= 1854.37 P / d^2$$

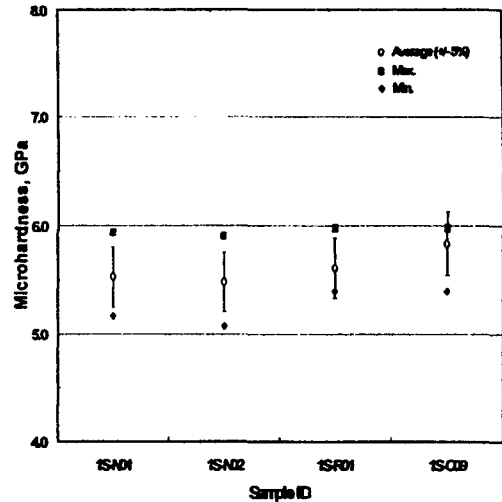


Fig. 9. Micro-hardness Result of Glass Sample From Phase 1

- where H_v : Vickers hardness number [kgf/mm²]
- P : Applied load [g]
- d : Diagonal of indentation [m]

3.2.2. Glass Density Data

The density of the glass samples are calculated by the following equation ;

$$d_s = \frac{(W_s - W)}{V - \frac{(W_m - W_s)}{d_w}} \quad (2)$$

where, $V = (W_w - W)/d_w$

- W_s : mass of the bottle with sample
- W : mass of the empty bottle
- W_m : mass of the bottle with the sample and full if distilled water
- W_w : mass of the bottle with full of distilled water
- d_w : density of water at temperature
- d_s : density of the sample
- V : volume of the bottle

3.2.3. Compressive Strength Test

In general, the compressive strength is

Table 7. Compressive Strength of the Phase 1 Test Glass Samples

Sample I.D	Dia.(cm)	Hight(cm)	CX area(cm ²)	Max Load(kgf)	Compressive Strength (kgf/cm ²)
1S-C09	2.2	4.60	3.7994	4,280	1126.5
1S-R01	2.2	4.05	3.7994	1,310	344.8
1S-N01	2.2	3.80	3.7994	3,405	896.5

* Compression strength of the glass samples(Surrogates) : 156~358 MPa

* Compression strength of the commercial glass(Pyrex No. 7740) : 264 MPa

calculated by making max. load recorded on measuring device divided by cross-sectional area of sample.

$$\sigma_c = P_f / A \tag{3}$$

where, C Compressive strength (kgf /cm²)
 P_f Structural load (kgf)
 A Cross-sectional area (cm²)

Compressive strength which is very important in quantifying structural stability of vitrified product is highly dependent on the method of specimen making and testing. In compressive strength test, loading velocity, size(height/diameter), surface condition, relative humidity and temperature, etc. affect structural modification of specimen. Compressive strength tests were conducted on solidified glass samples taken during the tapping

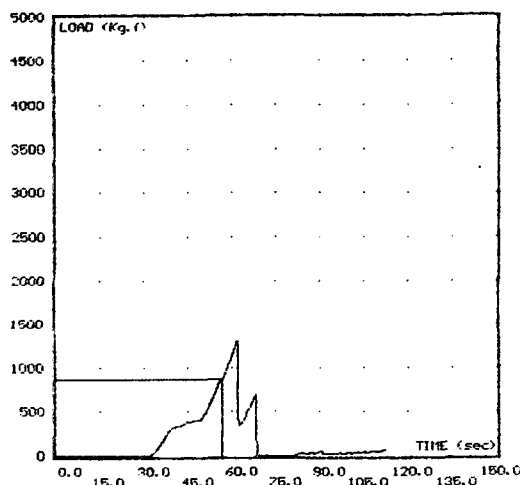


Fig. 11. Stress-strain Curve of 1S-R01

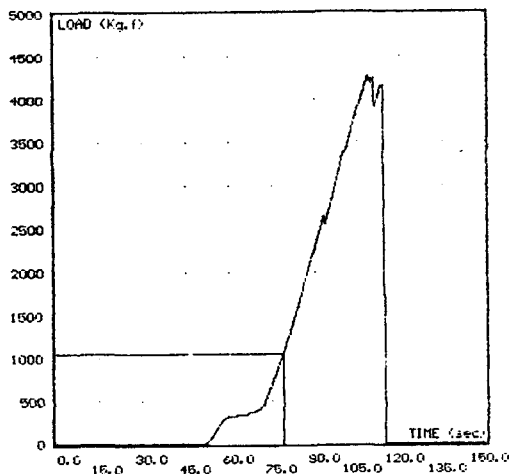


Fig. 10. Stress-strain Curve of 1S-C09

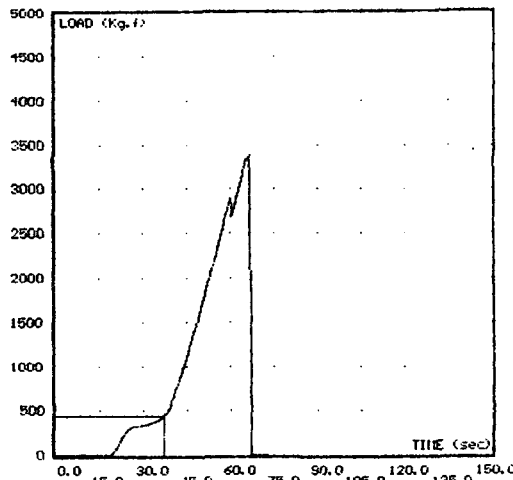


Fig. 12. Stress-strain Curve of 1S-N01

operation. As previously described, the liquid glass was poured into small molds approximately 2.2cm diameter by 4cm long which were contained in a oven at 800 °C to provide a slow cool down environment. These samples were not representative of the bulk glass cast into the 200 liter drums. These samples appeared to have either reacted with the refractory brick or developed an unusual microstructure on cooling. Values for compressive strength of each sample are shown in table 7, and strain-stress curve as shown in Fig 10~Fig 12.

3.2.4. Leaching Characteristics

Leaching test was difficult for a comparison of evaluation vitrified sample with leaching data due to adapt a different leaching method at each country. To analyze leaching characteristics like leached fraction, leaching velocity, etc., PCT test was performed for the particles broken into 75~150 μm. The following contents is for leaching test;

- Period : 7days
- Temperature : 90 °C
- Leaching solution : demineralized water
- solution volume/sample weight : 10mL/g
- Particle size : 75~150 μm

Leaching characteristics was analyzed based on leaching test results by analyzing leached fraction and leached velocity. The calculation to be used is as follows;

- Leached fraction

$$FL_i(\text{Fraction Leached}) = \frac{C_{t,i}}{C_{0,i}} \quad (4)$$

where,

F_L leached fraction of constituent i

$C_{t,i}$ weight of constituent i in leaching solution at t, g

$C_{0,i}$ weight of constituent i in non-leached sample, g

- Leached velocity

$$LR(\text{Leach Rate}) = \frac{C_{t,i}}{SA \times t}, \text{ g/m}^2\text{day} \quad (5)$$

where,

LR leached rate, g/m² day

SA surface area, m²

t period for leaching solution recovery, day

We assumed that glass particles were spherical and surface area of particles was calculated by using Gaussian method. The surface area and volume of spherical particle is calculated by the following formula.

$$A = \pi d^2 \quad V = (1/6) d^3 \quad (6)$$

where, d is a diameter of average particle. The weight/g and the surface area/g of powder sample can be calculated by density & volume. These value are also given in table 8. In table 9, leaching characteristics measured by each method

Table 8. The Weight/g and the Surface Area/g of Powder Sample

Sample ID	1S-C09	1S-R01	1S-N01
Particle Diameter(m/ea)	0.000112	0.000112	0.000112
Particle surface area(m ² /ea)	3.94E-08	3.94E-08	3.94E-08
Particle volume(m ³ /ea)	7.35E-13	7.35E-13	7.35E-13
Density (g/mL)	2.95	2.69	2.59
Particle weight(g/ea)	2.17E-06	1.98E-06	1.90E-06
Particle Number in 1g	460673	505624	525070
Surface area(m ² /g)	0.018	0.020	0.021

Table 9. Comparison of Leaching Characteristics Measured by Each Method Several Countries

	Japan NGK	Japan PNC	Japan Kobe	Germany NUKEM	Russia RADON	PAM-200
Method	Induction	Microwave	-	Muffle fur	Induction	Graphite arc
Waste	DAW Ash	DAW Ash	DAW Ash	DAW Ash	Radioactive Liquid waste	Radioactive waste
Density ¹⁾	2.7~2.9	2.2~2.3	2.52~2.71	1.9~2.9	-	2.42~2.95
Compressive strength ¹⁾	80~120	-	-	68~160	-	30~229 ²⁾
Leaching Method	IAEA (100day)	MCC-1P	IAEA Standard	ISO-6961	IAEA Standard	PCT-7 (7day)
Leaching Characteristic	Leached Fraction. Co $10^4 \sim 10^3$ Cs $10^3 \sim 10^2$	Leached Velocity. ¹⁾ $\sim 10^{-1}$	Leached Velocity ¹⁾ Co, Mn $< 10^{-7}$	Leached Velocity ¹⁾ Cs 5×10^{-1}	Leached Velocity ¹⁾ Na 2.4×10^{-1} Cs 5.4×10^{-2}	Refer to below ³⁾

1) Unit : Density(g/cm³), Compressive Strength(MPa), Leached Rate(g/m² day)

2) Core samples from the drum containing PWF : 30.4 ~ 229.0MPa

3) PAM-200 : Leached Velocity Co($10^7 \sim 10^6$), Cs($10^5 \sim 10^4$)

Leached Fraction Co($1.27 \times 10^4 \sim 1.08 \times 10^3$), Cs($2.46 \times 10^3 \sim 3.23 \times 10^2$)

adopted by several countries are shown. Considering difficulty in sample selection and collection, it can be said that compressive strength of sample is almost equal to that of stabilized products in other countries even in the case that it is strangely low. Each leached fraction(Fig. 13) for Co and Cs is $1.27 \times 10^4 \sim 1.08 \times 10^3$, $2.46 \times 10^3 \sim 3.23 \times 10^2$, and leached rate(Fig. 14) $10^7 \sim 10^6$,

$10^{-5} \sim 10^{-4}$. These results shows that vitrified product in these tests has a similar or superior chemical stability compared with that of other countries. Leached fraction and Leached rate data are provided in table 10~11. The detail data of glass concentration and leachant concentration are also given in table 12.

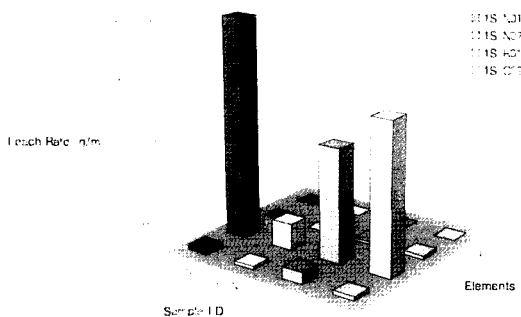


Fig. 13. Fraction Leached of Metals and Surrogates in Solidified Form

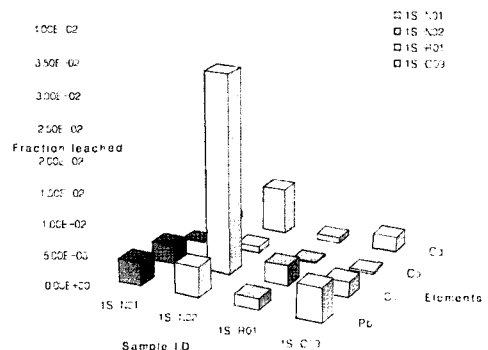


Fig. 14 Leach Rate of Major Glass Components in Solidified Form

Table 10. Each Leached Fraction of Vitrified Samples(PCT Leach Test, 7days)

Elements	(Leachate Volume) / (Specimen mass) = 10mL/g		
	1S-N01	1S-R01	1S-C09
B	5.29E-05	6.52E-04	6.80E-05
Cd	9.53E-04	8.68E-04	2.55E-03
Co	1.30E-04	1.27E-04	3.20E-04
Cs	2.96E-03	3.26E-03	2.46E-03
Fe	4.93E-04	4.77E-04	1.06E-03
Pb	3.79E-03	1.85E-03	5.45E-03
Ti	9.36E-05	1.11E-04	1.38E-04
Zn	2.64E-03	1.65E-03	2.95E-03
Mg	3.07E-04	1.57E-04	3.17E-04
Al	9.68E-04	8.95E-04	9.45E-04
Si	1.26E-03	1.30E-03	1.35E-03
K	2.86E-03	4.72E-03	3.03E-03
Ca	1.07E-03	1.41E-03	2.82E-03
Na	4.42E-04	6.76E-04	7.32E-04

Charging material : Borosilicate glass(60kg), sand(40kg), limestone(40kg)

Table 11. Each Leached Velocity of Vitrified Samples (PCT Leach Test, 7days)

Elements	(Leachate Volume) / (Specimen mass) = 10mL/g		
	1S-N01	1S-R01	1S-C09
B	2.01E-04	1.10E-03	1.40E-04
Cd	8.86E-08	1.46E-07	5.51E-08
Co	6.25E-07	5.38E-06	5.53E-06
Cs	3.87E-04	1.99E-04	2.65E-04
Fe	3.32E-04	5.81E-04	5.12E-04
Pb	1.06E-05	2.12E-05	7.22E-06
Ti	1.59E-05	3.31E-05	4.36E-05
Zn	2.30E-05	2.95E-05	1.10E-05
Mg	3.18E-04	3.20E-04	2.82E-04
Al	7.65E-03	6.54E-03	1.03E-02
Si	3.86E-02	4.01E-02	4.39E-02
K	6.31E-03	7.15E-03	4.78E-03
Ca	2.92E-02	5.55E-02	5.11E-02
Na	1.82E-03	1.21E-03	1.16E-03

Charging material : Borosilicate glass(60kg), sand(40kg), limestone(40kg)

3.3. Radioactive Emission Testing

Emission of radioactive isotopes is indicated in Table 14 in the form of decontamination factors

the ^{60}Co decontamination factor is $>4.4 \times 10^5$ ($>99.9998\%$ collected) in both the Phase 2-1 and the Phase 2-2 test. For the ^{137}Cs the decontamination factor is $>3.2 \times 10^5$ ($>99.9997\%$

Table 12. Detail Data of Glass Concentration and Leachant Concentration

Elements	1S-N01		1S-R01		1S-C09	
	C _g (wt%)	C _l (ppm)	C _g (wt%)	C _l (ppm)	C _g (wt%)	C _l (ppm)
B	2.620393	83.145	1.11807	437.617	1.24103	50.6517
Cd	6.41E-05	0.036667	0.00011	0.05833	1.3E-05	0.02
Co	0.003311	0.258333	0.02808	2.14333	0.01045	2.00833
Cs	0.090293	160.145	0.04059	79.36	0.06516	96.215
Fe	0.464587	137.5283	0.808	231.293	0.29111	185.875
Pb	0.001926	4.383333	0.00763	8.45167	0.0008	2.62167
Ti	0.117283	6.586667	0.19712	13.1733	0.19098	15.82
Zn	0.006003	9.526667	0.01187	11.7667	0.00225	3.98
Mg	0.713651	131.3817	1.35077	127.267	0.53788	102.328
Al	5.448332	3164.795	4.85322	2605.16	6.56498	3722.87
Si	21.18752	15970.86	20.5157	15953.9	19.6747	15933.2
K	1.520334	2608.008	1.00656	2848.81	0.95424	1734.92
Ca	18.77953	12065.53	26.1356	22088.9	26.4634	18532
Na	2.840241	753.3333	1.19104	483.333	0.95977	421.667
Weight(g)	3	3	3	3	3	3
Volume(mL)	50	50	50	50	50	50
SA(m ²)	0.020682		0.019916		0.018145	
Time day	7		7		7	

Table 13. Decontamination Factor for the Spiked Radionuclides During Phase 2 Test

Spiked Radionuclide	Phase 2-1	Phase 2-2
⁶⁰ Co	>4.4 10 ⁵	>4.4 × 10 ⁵
¹³⁷ Cs	>3.2 × 10	>3.2 × 10 ⁵

collected) for both the phase 2-1 and the phase 2-2 tests. For the determination of decontamination factor, the sample taken only at a S₃ point during phase 2 test

4. Conclusion

Through demonstration tests for PAM-200, followings are verified ; It is possible to control concentration of hazardous constituents, heavy metals and radionuclides below the regulatory limit. Establishing the offgas quality was one of the major objectives of the test series. it was found that, for all tests, the emission were well within US and Korean emission limits for CO, NO_x, THC.

This graphite electrode plasma system has been shown to produce NO_x emissions of less than 40 ppmdv during startup and less than about 10 ppmdv during normal operations. Similar glass-ceramic compositions have indicated a leach resistance equivalent to or better than borosilicate glass used for stabilizing high-level radioactive waste. The compressive strength more than meets any disposal criteria designed to prevent subsidence in a disposal facility. Based on results from analyzing compressive strength & leaching characteristics, vitrified product in these tests is similar or excellent compared with others in foreign countries. Lastly, one of the other major objectives was to maintain control of radioactivity

such that radiation neither posed any danger to the operating staff nor to the public. During the two tests with radioactive cobalt and cesium, no radioactive gaseous emission were measured leaving the stack. All radioactivity was confined within the system and the primary waste form. Operator monitored with dosimeters received only minimal exposure during these tests. As confirmation, emission testing showed >99.999% surrogate Co, and Cs retention by the system. While these trial burn tests were unequivocally successful with respect to the primary objectives discussed above, there were a number of lessons learned that will be incorporated into subsequent systems.

5. References

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