ADVANCED VOLUME REDUCTION SYSTEM FOR PWR PLANT

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ABSTRACT

This advanced volume reduction system provides high volume reduction and long term stability for final waste package, through the following techniques:

- drying and pelletizing concentrated liquid waste, and incinerating combustible waste for volume reduction; and
- solidifying with an inorganic agent (cement-glass) into an inorganic high integrity for long term stability.

The system was installed in the Ohi 3 and 4 PWR units of Kansai Electric Power Co.. Good performance has been obtained.

INTRODUCTION

The fundamental goals in developing radioactive treatment systems are:

1. reduction of radioactivity release into the environment;
2. reduction of waste generation;
3. reduction of generated waste volume;
4. stable packaging for final disposal;
5. radiation exposure reduction.

In the case of volume reduction, we developed a technique with regard to achieving a method of final disposal. That is, the developed technique can provide not only efficient, high volume reduction, but also long term stability for the final package of land disposal as outlined in Fig. 1.

- High volume reduction
  - Volume reduction by drying and pelletizing waste.
  - Decomposition of organic waste such as sludge and resins by incineration into inorganic waste (ash).
- Long term stability of final package
  - Decomposition of organic waste by incineration
  - Solidification by an inorganic agent (cement-glass)
  - Packaging waste into an inorganic, high integrity container

The drying and pelletizing system was adopted in the first commercial plant in June, 1984. Since then, our experience includes 3 plants in operation and 1 plant under construction. This paper describes the operating results when the advanced volume reduction system was applied to a PWR plant.

OUTLINE OF ADVANCED VOLUME REDUCTION SYSTEM

The typical flow of the advanced volume reduction system is shown in Fig. 2. It consists primarily of three processes: a drying and pelletizing process (1,2), an incineration process, and a cement-glass solidification process (3,4).

Figure 3 illustrates the drying and pelletizing process. The concentrated liquid waste, whose major component is $Na_2B_4O_7$, is fed into the upper part of the thin film dryer. The liquid waste forms a thin film on the inner cylindrical surface which is heated by steam from the outside. The liquid film is concentrated as it falls and it is powdered by the rotating blades. The produced dry powder (particle diameter about 10 μm) falls through the lower outlet and is stored in the hopper of a tabletting machine. The steam produced is led from the top of the dryer to the condenser and the condensed water is transferred to the concentrator.

This system has capability of inorganic ash generated from an incinerator. In this case, the ash is transferred to the hopper by a conveyer. There the dried powder and ash are mixed by a screw feeder and pushed into a cylindrical die. The dry waste is compressed by a piston, and cylindrical pellets (30ϕ x 30h mm) are produced. These pellets are poured into a 200L high integrity container. The container is made of polymer impregnated concrete whose mechanical strength has been reinforced by steel fiber. (5)

Figure 4 illustrates the cement glass solidification system for the pellets. After the measured amount of cement-glass powder and water (water/cement-glass ratio $\fallingdotseq$ 0.3) are combined in a mixer, the paste is simply poured into the drum containing the pellets. The viscosity of cement-glass paste is 1500 Cp and that of regular cement is about 6000 Cp. Because of its low viscosity, cement-glass can fill the gaps between the pellets, and a voidless package is produced without a vibrating device. The mixer is treated as noncontaminated equipment, because mixing of radioactive waste pellets and cement-glass paste is unnecessary.

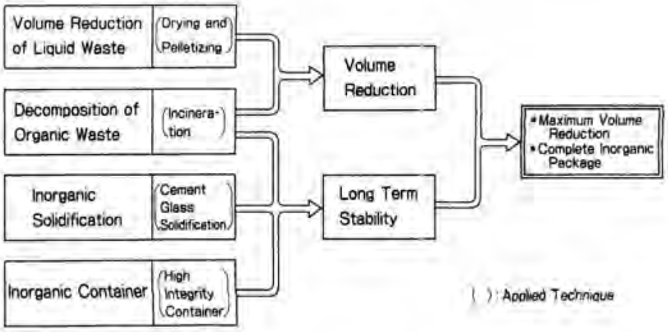

Fig. 1. Feature of advanced volume reduction system.

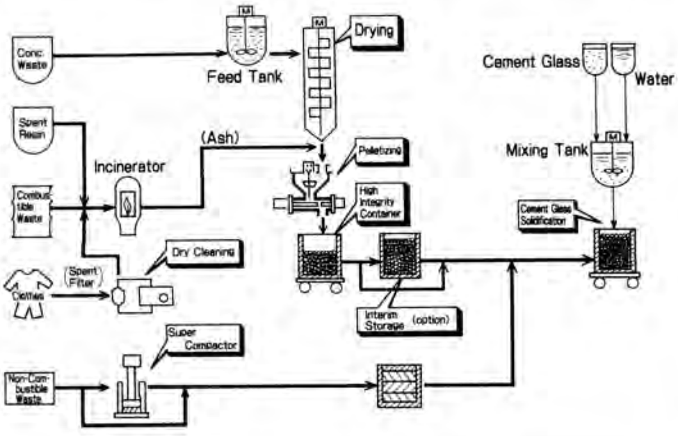

Fig. 2. Advanced radwaste volume reduction system.

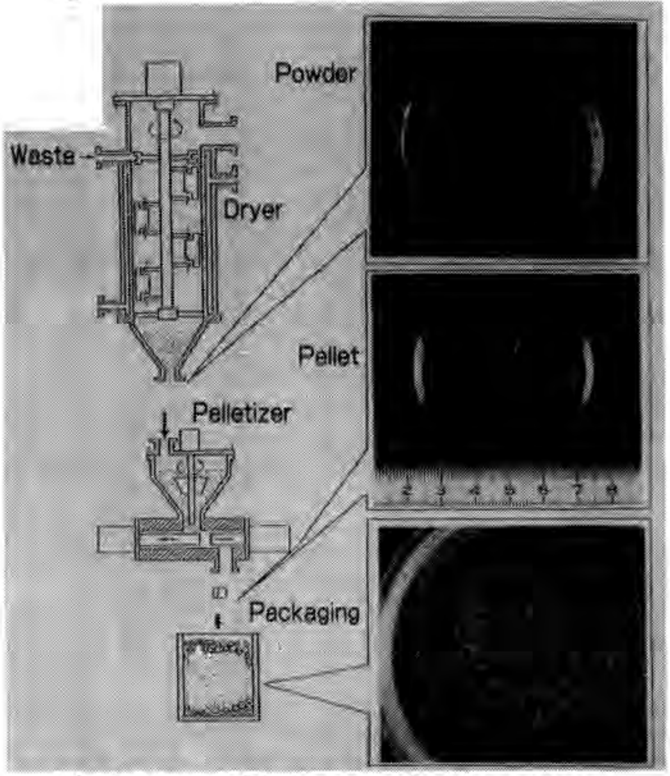

Fig. 3. Scheme of drying and pelletizing processes.

PERFORMANCE RESULTS

Powdering Process

The main component of BWR concentrated liquid waste is sodium sulfate, which exists only as Na_2SO_4. By contrast six *chemical* compounds are present in the complex sodium borate chemical reaction Na_3BO_3, $NaBO_2$, $Na_2B_4O_7$, NaB_3O_5, $Na_2B_8O_{13}$, and NaB_5O_8. Experimental results using a pilot plant made clear that a vertical thin film dryer could produce only $Na_2B_4O_7$ powder. If the ratio of Na/B differed from 0.5, the viscosity of sodium borate liquid film on the heated surface increased too much. As a result, highly viscous liquid film stuck to the rotating blades and did not fall on the heated surface, hindering the powdering mechanism.

Powdering experiments with different Na/B ratios were conducted by a pilot plant whose capacity equaled to an actual plant. For a 0.5 Na/B ratio, the water content of the produced powder were nearly constant throughout the experiment. When the Na/B ratio was changed to 0.47 or 0.56, the water content gradually increased, but remained below 5 wt%. Then, the amount of concentrated liquid waste was set to adjust the Na/B ratio between 0.47 to 0.56 entering before the thin film dryer.

The water content of sodium borate powder produced by the thin film dryer was between 2 and 5 wt%, which was considerably more than the 0 and 1 wt% of water in sodium sulfate powder. This difference was caused by water of crystallization in sodium borate. While sodium sulfate can exist only a Na_2SO_4 under the dryer operating conditions, $Na_2B_4O_7$ can exist as $Na_2B_4O_7 \cdot 5H_2O$, $Na_2B_4O_7 \cdot 5H_2O$, $Na_2B_4O_7 \cdot 2H_2O$, or $Na_2B_4O_7 \cdot H_2O$. Though sodium borate powder contained about 3 wt% water, it seemed to be dry.

Pelletizing Process

While powders are compressed, they are gradually deformed plastically and the contact area between them is increased. This plastic deformation is known to a key process for producing high density and strength of pellets. (6) If two contacting powders are the same chemical compound, they easily combined with each other. Since several chemical compounds are present in sodium borate powder, the mechanical strength of their pellets is poor.

Then, about 4 wt% cellulose binder was added to the sodium borate powder and the mixture was compressed into cylindrical pellets at a pressure of 0.15 GPa. The compressive strength of the pellets was 1.6 MPa which was enough to allow them to be thrown into the drum. The pellet density was 1.48 to 1.51 g/cm^3 which was about 63% of the $Na_2B_4O_7$ density.

Solidification Process

The cement-glass solidification process is assumed as

$$n\,\{2Si\,(OH)_4 + 2NaOH + P_2O_5 \cdot 2SiO_2\} \rightarrow 4\,(SiO_2)n + 2nNaH_2PO_4 + 3nH_2O. \quad \text{(Eq. 1)}$$

Since produced $(SiO_2)n$ forms a three-dimensional structure through the polmerization reaction, the compressive strength of solidified cement-glass exceeds 25 MPa. (6) Since X-ray diffraction analysis of the $(SiO_2)n$ did not show any crystal pattern, the structure was amorphous. (7)

Ordinary Portland cement is solidified according to the following reaction:

$$3CaO \cdot 2SiO_2 + 3H_2O \rightarrow 3CaO \cdot 2SiO_2 \cdot 3H_2O \cdot \quad \text{(Eq. 2)}$$

This hydration reaction generates much heat and the temperature at the center of the cement package exceeds 100°C. Since sodium silicate of cement-glass was fully hydrated initially, the heat generated was small and the maximum temperature was below 50°C.

Due to the mild solidification reaction, no shrinkage occurred during the solidification process. Therefore, no gaps formed between the container and solidified agent, and no cracks were observed in the package (Fig. 4).

Waste Form Characteristics

Table I summarizes the test results which show that the cement-glass package has better characteristics than previous waste packages using ordinary Portland cement.

The compressive strength of 200 L drum packages, which were produced by the pilot plant using simulated waste,

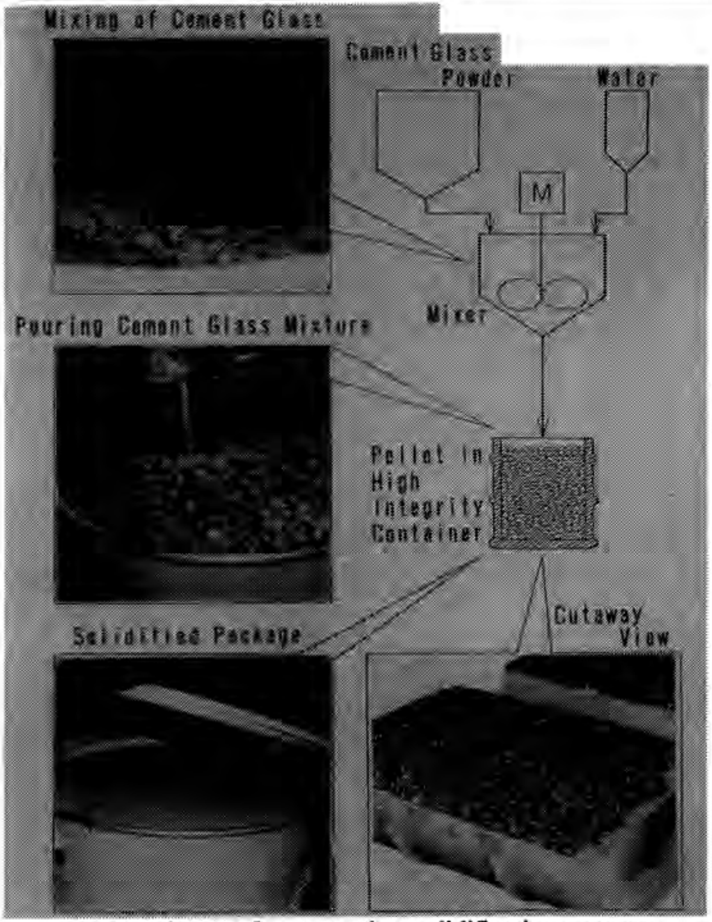

Fig. 4. Scheme of cement-glass solidification process.

exceeds 17 MPa. Densities of the sodium borate and ash packages are 1.6 and 1.8 respectively. Also drop and fire resistance tests were conducted using 200 L drum packages as shown in Fig. 5. The package of sodium borate was dropped horizontally on the steel plank from a 1.2 m height. No cracks of the drum occurred and no solidified material leaked from the package. Maximum change of the drum shape was 7 mm. A 200 L drum was placed in the center of a flame for 30 minutes. Weight loss was less than 1.5 wt%, because all of the radioactive material, the solidification agent, and the container were inorganic material.

OPERATING EXPERIENCE

BWR Plant

Two advanced volume reduction systems which do not include a solidification process for pellets are used at Japanese BWR sites. The first system started commercial operation in June 1984 at the Centralized Radwaste Treatment Facility in the Fukushima Daiichi Nuclear Power Station of the Tokyo Electric Power Company. In this facility, concentrated liquid waste of the floor drain and regeneration waste from four reactor units are treated in one unit of the drying and pelletizing system. A second commercial plant began its operation in September 1986 at the Tokai-2 Station of the Japan Atomic Power Company.

The pellets were stored in a big cubic tank in Fukushima site or a container in Tokai site, because the final disposal method for low level radioactive waste had not been determined until the construction time.

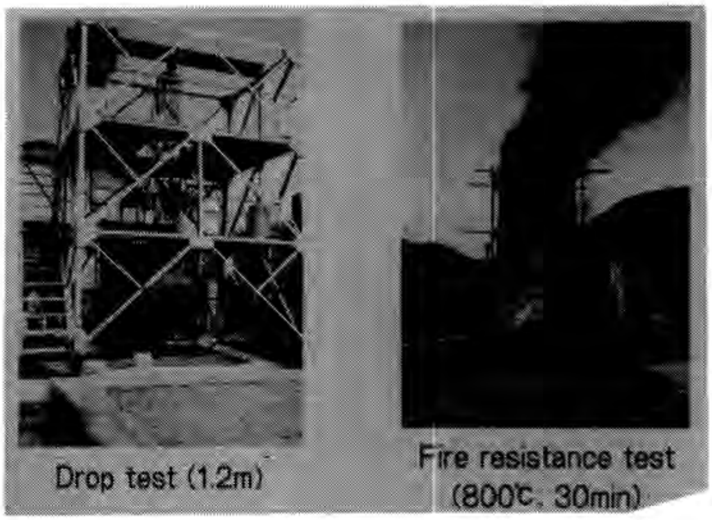

Fig. 5. Package performance tests.

PWR Plant

The final disposal program for low level radioactive waste will be implemented in 1992 at a site in Aomori Prefecture located in the northern part of Japan. The technical standards of the packages for final disposal were published in January 1988 by the Science and Technology Agency. The pellet cement-glass package meets these standards.

Then, the first advanced volume reduction system which included a cement-glass solidification process was installed for the Ohi 3 and 4 units of Kansai Electric Power Co. in 1991. The capacity of drying concentrated liquid waste is 45 L/h and cylindrical pellets are produced at a rate of about 8 kg/h.

Because of the small volume of the generated waste, the system occupies a small space. Produced pellets are poured into 200 L drums that have an inner polymer impregnated concrete layer. Due to the high volume reduction ratio of the powdering and pelletizing processes, only one pellet package of a 200L drum is solidified per week. Low viscous cement-glass paste is added for about 5 minutes, filling gaps between the pellets, and it is allowed to stand for one day while solidifying. No shrinkage or cracks were observed.

CONCLUSION

In order to achieve maximum volume reduction and long term stability, we have developed an inorganic packaging system. Its main features are drying and pelletizing processes for volume reduction, and cement-glass solidification for stability.

In order to apply it to a PWR plant, the following techniques were developed. First the chemical component of concentrated liquid waste was adjusted to improve drying ability of the thin film dryer. Secondly a tabletting machine was adopted instead of a briquetting machine because of the small volume of generated waste. The improved system was installed in the Ohi 3 and 4 units and good operating experience has been obtained for actual waste.

ACKNOWLEDGEMENTS

Part of the cement-glass solidification technique was developed in a joint study with 10 Japanese power utilities and the Central Research Institute of Electric Power Industry. We

TABLE I

Summary of Pellet Cement Glass Waste Form Characteristics

Item	Size*	Test Method	Results
Specific gravity	**	-	> 1.3
Compressive strength	**	Similar to JIS A1108	$\geqq 1.7 \times 10^4$ Pa
Heat cycle resistance	**	Similar to ASTM C666 - 75 -19°C-15°C 300 cycle	Weight changes $\leq 0.3\%$ Size changes $\leq 0.1\%$
Fire resistance	***	800°C 30 min	Weight loss ≤ 1.5 wt%
Leachability	**	Similar to IAEA	10 - 100 $\mu g/m^2 \cdot d$
Drop test	***	1.2m	No leakage
Radiation resistance	**	10^8 Rad	Strength change $\leqq 3\%$ Weight change 0

* ** 200ℓ size
*** small size such as 100 φ x 200ℓ

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