RESEARCH AND DEVELOPMENT PROGRAMS ON WASTE MANAGEMENT IN JAPAN

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INTRODUCTION

The high-level liquid wastes (HLLW) generated from a reprocessing plant contain radioactive materials such as fission products, actinides, residual uranium and plutonium, mixed with nitric acid, alkaline salts, and corrosion products. Their contents and quantities vary with type, burn up, and cooling-time of spent fuels. They are highly radioactive and have long half-lives although their volumes are rather small. Thus, each HLLW must be isolated from the biosphere until its radioactivity decays out and its impact on the environment is reduced sufficiently, in order to eliminate contamination of environment and avoid exposure of the public to radiation over a long period of time.

The HLLW should be solidified into a stable form, stored temporarily, and then disposed, namely: (1) HLLW should be stored in tanks for a certain period of time until its radioactivity decays out and the decay-heat is reduced to the degree suitable for solidification. (2) HLLW should be solidified. Borosilicate glass is considered to be the most promising waste form. Vitrification is a process where HLLW is either denitrated and concentrated or calcined, then mixed with the glass frit, melted, and sealed in a canister. (3) The solidified waste (HLW) should be stored for a certain period of time to be cooled until it becomes suitable for disposal. (4) For final management, geologic isolation is considered most promising. The safety assessment should be fully evaluated before solidification and disposal.

Based upon the above policies, the Power Reactor and Nuclear Fuel Development Corporation (PNC) and the Japan Atomic Energy Research Institute (JAERI) are conducting active research and development programs, in accordance with "The Research and Development Program for Radioactive Waste Management," issued by the Radioactive Waste Management Committee in 1976. The PNC's Tokai Reprocessing Plant has been operated and HLLW has been stored in tanks since its hot test operation, and preparations for a commercial reprocessing plant are in progress since establishment of the Japan Nuclear Fuel Service Co., Ltd. in March, 1980. In view of the importance of waste management, it is important to organize a system to carry out the R&D programs as a national project. As the radioactive waste problem is common to all the countries having nuclear reactors, it is necessary to participate in international projects or to promote bilateral cooperations with other countries.

DEVELOPMENT OF VITRIFICATION TECHNOLOGIES

R & D programs of various vitrification technologies are under way and solidification into borosilicate glass is expected to be practical in the near future. A solidification and storage pilot plant based on these R & D programs is to be demonstrated. Also, tests on the vitrified waste are to be needed, for safety evaluation of liquid waste solidification processes and of storage and transportation of solidified wastes. Vitrification technology consists of waste pretreatment, off-gass treatment, glass melting and canister handling.

Since radioactivity to be handled in vitrification processes is extremely high, R & D programs should be carried out step by step through hot and cold tests and laboratory-scale and engineering-scale experiments. R & D programs on vitrification technologies are under way in Japan with the scope of operation of a pilot plant to demonstrate feasibility of solidification and storage in FY 1987. To achieve the target, engineering-scale cold tests are being conducted for pretreatment, glass melting, off-gas treatment, integrity and handling of canisters, and storage. Mock-up tests started in FY 1981 based on the results of engineering-scale cold tests, and solidification tests using actual HLLW from the reprocessing plant began in FY 1981 at the Chemical Processing Facility (CPF) at Tokai site of PNC. These test results will be reflected in design, construction and demonstration operation of the solidification and storage pilot plant which is planned to start operation in FY 1987.

Several types of simulated and vitrified wastes have been investigated by cold experiments for the purpose of safety evaluation. Furthermore, hot experiments by using synthesized radioactive wastes will start in the Waste Safety Testing Facility (WASTEF) at JAERI in 1982. Hot experiments with vitrified wastes will begin after 1986. Results of these experiments should be reflected to establish regulation criteria for design, construction, and operation of vitrification and storage plants.

There are two different methods of pretreatment. The first is the method in which liquid wastes are denitrated, concentrated and then fed to the melter together with glass frits. The other is the method in which liquid waste is first "calcined," then mixed with glass frits and fed to the melter. Research and development works on denitration, concentration, fluidized bed calcination, and spray calcination of liquid wastes have been being conducted. From FY 1981, R & D programs will be focused on the denitration and concentration method which is considered the most favorable pretreatment method to be studied before a solidification process is selected through mock-up solidification tests.

Development of glass melters in wich pretreated liquid wastes are melted together with glass frits, and development concerning operation, maintenance, decontamination, and disassembly of melters are also needed. For this purpose, engineering-scale melting tests have been made on two types of melters, a Joule heated ceramic melter and a high frequency direct induction melter. From FY 1981, R & D programs will be focused on the Joule heated ceramic melter, which is considered to be more favorable, by conducting cold mock-up tests.

Development of off-gas treatment technology will be focused on treatment of ruthenium and cesium which are dominant radioactive elements in off-gas streams from pretreatment and melting processes and on removal of NOx which is the main component of off-gas. Adsorption test using adsorbers, such as ferric oxide, silica gel, will be conducted for the removal of ruthenium, and for NOx removal, decomposition by catalysts and scrubbing by water will be tested. Based upon these tests, a favorable off-gas treatment method for the solidification and storage pilot plant will be selected. R & D programs by using cold mock-up solidification tests started from FY 1981.

Canister which can meet the requirements for long-term integrity in storage will be developed, and methods of handling, such as charging of molten glass in canisters, welding for subsequent sealing, decontamination before storage, and inspection, are also to be studied. Considering probable failures by falling in handling, damage of canisters in case of falling should be evaluated. After vitrification, wastes must be stored and cooled at storage facilities until final management. Requirements for these storage facilities should be studied, and technologies necessary for their construction, operation, and maintenance should be developed, and the results of these studies will be reflected in design, construction, and demonstration operation of the solidification and storage pilot plant. The most significant problem in storage is heat removal, for which water cooling and air cooling methods are available. However, R & D programs will mainly be for air cooling method for the time being, because the existing experiences of spent fuel storage can be utilized for water cooling method.

Studies of characteristics of vitrified wastes by using actual HLLW will be made. For this purpose, construction of CPF was completed in 1981 and now is in operation. The CPF will conduct a series of tests on the vitrification processes, such as pretreatment of HLLW, melting, charging of molten glass into canister, welding of canister, and treatment of off-gas. Non-destructive inspection on glass homogeneity, helium leak tests of packages, measurement of time changes of properties of solidified wastes, tests on mechanical strength, leaching rate, thermal conductivity of vitrified wastes, are also to be conducted at CPF.

A solidification and storage pilot plant with a capacity equivalent to the PNC's Reprocessing Plant will be constructed and demonstration operation will be started in FY 1987. For this purpose, the conceptual design of the plant is now under way taking various factors into consideration, prior to the basic design and the detailed design.

In the cold tests for safety evaluation, vitrified waste products will be prepared with several types of simulated wastes and the effects of glass components and preparation conditions on their densities, thermal conductivities, thermal expansion coefficients, softening temperatures and leachabilities will be evaluated and the measurement methods will be developed for evaluation of chemical stability, thermal stability, and mechanical strength. The vitrified simulated wastes have already been prepared, and their properties have been evaluated on the items above mentioned by means of several methods, such as the powder-boiling method, Soxhlet type method, and high pressure method, for leachability measurements. The results will be analyzed and evaluated by 1982 for safety evaluation of hot tests.

WASTEF is under construction as a facility for safety evaluation of hot tests. The results of cold tests above mentioned will be confirmed by the simulated synthetic wastes with radioactive isotopes after 1982 in WASTEF. Safety evaluations similar to the cold tests will be carried out by using the actual high level liquid wastes after 1986 also in WASTEF.

RESEARCH AND DEVELOPMENT OF GEOLOGIC DISPOSAL

The objective of geologic disposal of HLW is to isolate radioactive wastes from biosphere by means of "barriers" and "distance from human environment," until the impacts of radioactivity of these radioactive wastes buried into geological formation of the biosphere are reduced sufficiently through the decay of their radioactivity. The most probable or likely release pathway between geologic repository and biosphere is dissolution and transport of nuclides by flowing groundwater. Therefore, appropriately stable geologic formations with as few underground water as possible should be selected for waste disposal, and the concept of multiple barriers, such as natural barriers of geologic formations combined with engineered barriers, should be adopted. Since the research and development of geologic disposal require a very long period of time, it is advisable that the R & D programs should be conducted step by step with a long-range prospect. R & D programs for HLW geologic disposal can be conducted in five steps of "Research on potential geological formations", "Research on candidate geological formations", "In-situ test with simulated wastes", "In-situ test with actual wastes" and "Trial disposal". In parallel with these R & D programs safety evaluation methods should be developed to be used in the assessment of disposal technologies at each step.

For this purpose, PNC is conducting the survey and research on geologic formations, the research works on engineered barriers and the studies on geologic disposal systems. An overall evaluation of potential geological formations is expected to be done in FY 1983. Furthermore, JAERI will conduct literature surveys, geological explorations, and surveys of hydrogeological structures to make clear the current status of available geological formations. Also, rock characteristics tests, water permeability tests, and nuclide sorption tests, will be made to clarify the function of geological formation as natural barriers and to study their barrier effects. In respect to the engineered barriers to be combined with natural barriers of geological formations, the development of grouting and buffer mass technology, the integrity evaluation test for estimation of the effectiveness of engineered barriers and the compatibility tests between engineered barriers and geological formations are to be made. The concept of the geologic disposal system suitable for our country should be established, and the performances of solidified wastes, engineered barriers, natural barriers and the disposal system are to be estimated. To make an overall safety evaluation, analyses of events generated after the disposal, development of simulation models for safety evaluation, and accumulation of data for safety evaluation are needed. Concerning the geological formations in our country and those under investigation abroad, their natural and social factors such as earthquakes, active faults, floods, population density, environmental conditions, etc., are to be surveyed by records and literatures. The movement of underground water is the main factor for transport of radionuclides contained in HLW to the human environment. It is necessary to clarify the hydrological mechanisms of underground water, such as flow velocity and direction. For this purpose, the data obtained in development of underground resources will be collected to be used to develop a hydrological model. The barrier effects of geological formations such as water permeability and nuclide sorption effects, thermal and stress effects on rocks, will be investigated to evaluate the effectiveness of natural barriers for geologic disposal.

Tests for selecting suitable grout materials and for development of techniques of grout injection into ground will be conducted in order to make the grouting techniques appropriate to repair portions of rock mass affected by the stress during the excavation of shafts and tunnels and to reinforce the boundaries between rocks and buffer materials. Tests for selecting the appropriate buffer materials and the development of their construction method are needed for the purpose of developing the buffer materials which can serve to prevent the intrusion of underground water and to prevent the movement of the water dissolved radionuclides. There are various kinds of buffer materials, as overpack, filler for the gaps between the deposition hole and solidified waste, sealing material for tunnels and shafts, plugs for boreholes and monitoring holes, etc. The buffer materials and their work execution technique are to be developed for each application. Integrity evaluation tests on engineered barriers under the conditions simulating waste repository environment, and tests on compatibility between engineered barriers and rocks are also to be made. The concept of the disposal system should be clarified based upon information about the functions required for geologic disposal system, characteristics of disposed wastes, engineering measures to be taken under the present status, and the geological conditions. A nuclides release scenario will be prepared by considering nuclides migration pathways at each barrier constituting the geologic disposal system. On the basis of the scenario, the respective isolation or retardation effects of solidified wastes, engineered barriers, and geologic formations, will be formulated, and some analytical models will be prepared based on the conditions of the solidified wastes and its disposal environment.

Effects of disposal of high level wastes on human beings must be evaluated. Estimations of events generated after disposal and of the probability of their occurrence are needed, and models will be established for nuclide migration paths to the environment. The events, which may cause migration of nuclides from the repository to the environment, must be analyzed and the probabilities of these events also must be analyzed. For this purpose, fault tree analyses will be useful and probabilistic calculations can be done by assuming estimated probabilities for each event. Simulation model for nuclide migration paths must be developed based upon the most probable events and then the amounts of migrated radioactive nuclides to the hydrosphere, such as oceans, rivers, lakes and ponds, are to be estimated. On the basis of the amounts of released nuclides to the environment, by event analyses and simulation models, exposures and accumulated doses to the public are to be evaluated.

OTHER RESEARCH AND DEVELOPMENT PROGRAMS

To cope with radioactive waste management, including solidification, storage, transportation and disposal, it is necessary to make studies for establishing a reasonable management system of full-scale disposal with emphasis on safety necessary for public acceptance. For this purpose, scenarios for HLLW management should be examined and prepared from the viewpoint of a long-term and comprehensive radioactive waste management, which will incorporate all aspects of technology, institution, law, and regulation.

Regarding transportation of vitrified wastes, experience of transportation of spent fuels is expected to be fully utilized. It is necessary to study characteristics of containers such as impact, heat, and pressure resistances, in order to improve transportation modes, and to examine inspection methods for vitrified wastes before and after transportation, and to make safety evaluation of transportation.

In order to develop waste forms with better durability during storage and disposal in comparison with borosilicate glass, R & D programs for metal matrices, glass ceramics and sintered ceramics will be conducted. Concerning metal matrix solidification technology, solidification tests for metal matrices and glass beads should be conducted, and conceptual design studies on processes for making glass beads and incorporating glass beads into matrix are to be made. For glass ceramics, melting and solidification conditions and optimum compositions will be investigated. For sintered ceramics, sintering techniques and optimum shapes of solidified waste will be studied in respect to ceramics and metal complexes. Furthermore, synrock solidification methods which produce solids of compositions similar to natural minerals will also be investigated.

For technology of partitioning to separate strontium, cesium and transuranic elements from HLLW, and of transmutation to convert transuranic elements into nuclides with shorter half-lives, basic studies will be continued. In Japan, R & D programs are in progress on separation of transuranic elements aiming at transmutation, and on separation of strontium and cesium aiming at solidification. Separation tests with actual HLLW are now under way by using solvent extraction and ion exchange. These tests will be continued until 1983 for studying recovery rate, safety, and economical efficiency, etc. Feasibility of transmutation has been investigated by making theoretical calculation of reactor physics, and by collecting basic data from critical experiments. Solidified liquid wastes are planned to be temporarily stored and then disposed after cooling. However, for long-term storage, which will likely become necessary, durability of structural materials to be used for storage, such as corrosion resistance, mechanical strength, physical and chemical characteristics, and detection methods and repair systems will be examined from the standpoint of extention of technologies of temporary storage.