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REGULATORY ASPECTS OF BOROSILICATE GLASS HIGH-LEVEL WASTE FORMS THE PROCESS, THE PRODUCT, AND THE DISPOSAL

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ABSTRACT

Immobilization of high-level radioactive waste (HLW) in borosilicate glass is acknowledged world-wide as an acceptable method for preparing HLW for geologic disposal. A waste acceptance process is under way in the United States that will provide specifications and procedures for waste producers well in advance of the availability of a federal repository. Extensive experimental data and rigorous quality assurance and control for plant operation are expected to provide convincing evidence that borosilicate glass waste forms produced in the vitrification plants meet the specifications and can be disposed of safely in a geologic repository.

INTRODUCTION

The disposal of high-level waste (HLW) is a subject of increasing discussion and occupation of time and effort both here and abroad. Ever since the first major vitrification of HLW began at Marcoule, France in 1978, questions surrounding final disposal have been raised. For example, Circular 779 published by the USGS, also in 1978, raised concerns about the integrity of geologic disposal. Prior to that, the major concerns had been focused on shipping HLW to a "safe" repository. However, USGS focused attention on uncertainties they believed would result from the adverse effects of the high temperature generated by HLW forms on long-term performance in a geologic repository. Meanwhile in Europe and Japan, the storage of heat-producing HLW for several decades of radionuclide decay prior to disposal was selected as an alternative means to reduce or eliminate the repository temperature effects. Also, in the same time frame in the United States, spent fuel was designated as HLW when commercial fuel reprocessing was banned. And finally, the U.S. government policy to dispose of defense HLW now in storage at Savannah River, Hanford, and Idaho, along with the "commercial" HLW stored at West Valley, brought about a determined large-scale effort by DOE to process, immobilize, and then to dispose of most of the HLW in a federal repository as borosilicate glass.

In October 1984, the Office of Civilian Radioactive Waste Management (OCRWM), created by the Nuclear Waste Policy Act of 1982 (NWPA), initiated a waste acceptance process to meet the needs of the borosilicate glass producers because vitrification plant startups are scheduled for West Valley in FY 1989 and Savannah River in FY 1990, about a decade before a federal repository could begin accepting HLW. The President's decision in April of 1985 that defense HLW should go to a "commercial" repository was the trigger that set the current accelerated waste acceptance process in motion.

In August 1986, two sets of waste acceptance preliminary specifications (WAPS) were issued by OCRWM to apply to the borosilicate glass products to be made at the Defense Waste Processing Facility (DWPF) at the Savannah River Plant, South Carolina, and at the West Valley Demonstration Project (WVDP) at West Valley, New York, respectively. These documents contain preliminary specifications that the two producers of canisters of borosilicate glass must meet prior to acceptance of canistered waste forms at a federal repository. The requirements are based upon federal regulations, such as 10 CFR 60 and 40 CFR 191, and on the need for assurance that a quality product will continue to be made during the operating life of the plants, which are expected to extend over a quarter century in the case of the DWPF. The preliminary specifications will be updated as part of the waste acceptance process and will become final after site selection and before repository licensing. The key to making the acceptance process work is the recognition that a quality product can be assured by careful quality assurance and control of the processes of waste handling, feed preparation, vitrification, and canister filling, storage, and shipping. Similar approaches to assure acceptable, high-quality products have been developed for other vitrification plants according to an international survey of operators and future operators of vitrification plants.[1]

REGULATORY ASPECTS OF THE PROCESS

Vitrifying HLW in borosilicate glass involves many typical chemical processes. HLW feed is prepared from waste solutions resulting from reprocessing spent fuel by concentrating the highly radioactive material by removing the nonradioactive residues of chemicals and liquids used in fuel reprocessing. The concentrated feed is then adjusted chemically and in some cases calcined before adding to the melter. Glass frit or equivalent glass-forming chemicals are also added simultaneously. The borosilicate glass is melted at temperatures near 1100°C either by induction or joule heating. The melted glass is poured into stainless steel canisters for storage and eventual shipment to a geologic repository for permanent disposal. This brief simplified description of waste vitrification and associated processes belies the complexity and technical challenges of an actual HLW vitrification plant. The high radiation and contamination requires massive shielding, remote operation, remote maintenance, and complex and expensive equipment and facilities to prevent the inadvertent escape of radioactivity from the plant. To assure that these remotely operated processes lead to an acceptable glass product requires a complex instrumented system of monitors, automatic controllers, recorders of information, and long-term storage of data. Thus the processes are controlled to make the acceptable product, and the product quality is maintained by the process controls which maintain processes within previously prescribed limits. Product analyses may also contribute to assurances of product quality.

Borosilicate glass containing HLW has properties that make it acceptable for HLW disposal in a geologic repository.[2] These properties exist when the chemical compositions of the glass are restricted to a well-defined range of chemical constituents and quantities. Figure 1 shows this region for typical waste-containing glasses.[3] It has been demonstrated that releases of radioactivity from glasses falling within this range are very similar; thus, it is necessary only for a vitrification plant to assure that its product meets repository specifications by guaranteeing compositions within the prescribed acceptable range. One method by which this can be accomplished is by using actual plant operating data obtained during extended nonradioactive run-in operations. These data can be used to prescribe measurable, verifiable operating conditions that will guarantee the glass product to have the expected and hence acceptable properties for disposal. In order to achieve these objectives by using in-plant measurement, an extensive distributed control system can be designed and installed.[4] A system using manual controls can also be designed. The control system can be made of several field operating stations and central control rooms that contain facilities for monitoring processes, and collecting, recording and retaining data on the performance of the process and each product canister.

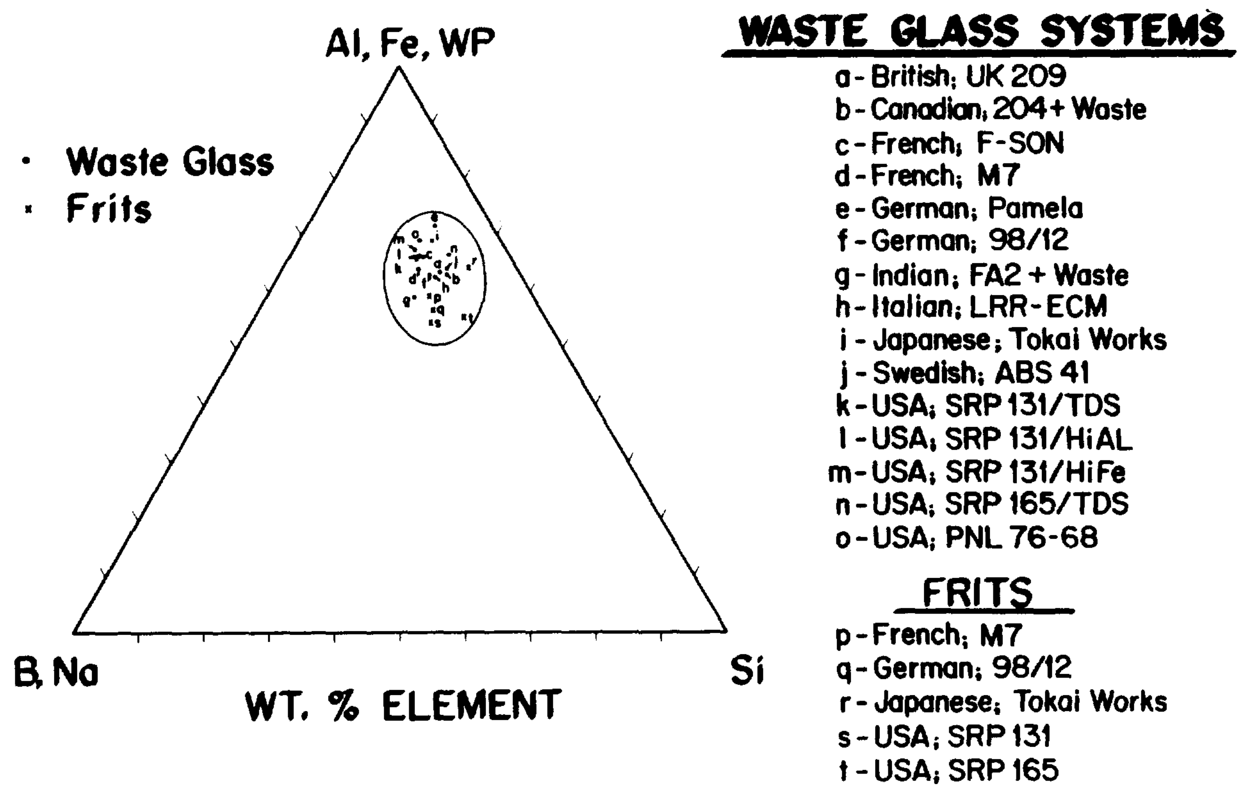

Figure 1. Compositional ternary diagram for waste glass and frit systems

REGULATORY ASPECTS OF THE PRODUCT

The canistered waste forms containing vitrified high-level waste must meet many regulatory requirements. The first step in the waste acceptance process for disposal initiated by OCRWM are the Waste Acceptance Preliminary Specifications.[5] They are based primarily on specific requirements in NRC regulations and EPA standards. The primary focus of the specifications are as follows:

- Canisters must meet on-site storage requirements
- Canisters must meet transportation-related requirements
- Data on canister composition and content must be adequate so that repository licensers can properly evaluate canister performance in the disposal environment.

In addition, an overriding consideration for all technical data is quality assurance. NRC Commissioner Asselstine indicated in a speech at the Waste Management '85 Conference[6] regarding geologic repositories that the "licensing process will be very similar to the present licensing process for nuclear power plants." "Quality assurance will inevitably be a component in the Commission's licensing decision and could well be at issue in the formal licensing hearings." The problem is that much of the data to be used for assuring safe disposal will be developed well before formal licensing begins and over a decade before the repository is ready to receive waste. This puts a significant burden on assuring quality of current activities and requires extensive and careful work to avoid unanticipated challenges during the extended licensing process. Thus the regulatory aspects of the canistered product focus on two main items: the technical data base and quality assurance of the data.

The technical data base for the borosilicate glass product involves historical as well as current data. The base includes measurements of the chemical and physical properties of the glass, glass leaching tests, the determination of mechanisms of glass dissolution and solubility in aqueous media based upon in-laboratory, in-situ, and simulated in-situ testing.[7,8] In addition, a quality-assured determination is required of the canister properties, of its integrity as welded, and its lack of surface contamination upon arrival at a repository. It is the intention that the technical data base along with the methods of measurement of the specified requirements and the verification of plant processes and the product quality combine to form extensive and verifiable resources of information that will satisfy the repository needs in the preparation of a repository license application for NRC. These quality-assured data will be available prior to the vitrification plant startups and well in advance of the repository license application. Thus, it is planned to combine verifications obtained from plant operations on product quality with technical verifications from an extensive data base to provide ongoing assurance that canistered waste forms produced over a quarter century or more will be acceptable at a federal repository beginning a couple of decades from now. It has been proposed that canistered borosilicate glass be accepted no sooner than 2004[9] even in the event that a repository facility is available for receipt of commercial spent fuel in 1998 as called for in the Nuclear Waste Policy Act of 1982 (NWPA).

REGULATORY ASPECTS OF DISPOSAL

From the producer's viewpoint, HLW disposal is the province of the repository operators. Spent fuel, the major commercial HLW, is by definition an acceptable waste form, and the expectation is that by adhering to the OCRWM waste acceptance process and providing quality-assured input to the technical data, that borosilicate glass containing HLW will also be acceptable.

The primary concerns of the repository are whether the waste packages and the engineered barrier systems designed to contain the canistered waste forms will meet the release limitations imposed by NRC regulations[10] and whether the repository will meet the 10,000 year release limitations in the EPA standards.[11] The role of the waste form in the limitation of release of radioactive nuclides has not been thoroughly defined, but experiments on glass-aqueous solution interactions predict very low release under expected repository conditions for canistered waste forms. This expectation provides considerable confidence to the producers and was a major consideration when the decision to build the DWPF was made in 1982.[12] The positive response of NRC staff indicated, however, that more information in realistic disposal conditions should be obtained. The major focus of experimental programs since then has resolved many of the perceived deficiencies in the data base.[13,14]

In the final analysis, some mention of the hazard of disposal is needed to put the consequences of isolating HLW from future generations in proper perspective with the accepted consequences of other radioactive environments. Figure 2 shows that the risks for HLW are reduced, by disposal, substantially lower than those for any other radioactive waste. This extraordinary restriction has been challenged as unreasonable, but has been justified by regulators in that they believe it "correctly" reflects public opinion and concerns.

We can hope that the risk reduction of the repository is convincing and leads to public support. We can also hope that the extensive conservatism does not become an upper limit in the decades ahead for needless additional restriction on HLW disposal.

One reason for these concerns is the thrust of and the responses to the Environmental Assessments for the five recommended sites for a federal geologic repository. In the recommendations, DOE estimates[15] that the highest release rate for any of the proposed sites, in 10,000 years, is three orders of magnitude lower than the EPA limits,[11] without apparently taking any credit for excellent retention properties of the waste form. If these expectations for the repository are challenged by litigation, the consequences could be that the conservatism shown in Figure 2 will become the upper limit on expected repository performance, an unfortunate and unnecessary consequence. The more optimistic consequence could be that the expected performance of the repository candidates would increase public support, a very beneficial consequence.

The technical community recognizes the importance of technical verification of conformance to existing regulations and standards, but it must continually balance technical facts with the reminder that public perception