THE VEK PROCESS CONTROL SYSTEM – A TOOL TO SUPPORT HLW-GLASS QUALITY

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ABSTRACT

The VEK plant is expected to be the next vitrification plant achieving hot operation. The plant will be used for converting 70 m^3 of high-level liquid waste into approximately 50 tons of nuclear waste glass poured into 130 stainless steel canisters. Prior to the release from the plant these vitrified waste packages will have to undergo a final check performed to assure their suitability for interim storage and final disposal. The properties to be checked include a set of specified parameters, which had been evaluated as relevant for final disposal. The most important parameters concern the radioactive inventory in the package, which in turn are governed by the composition of the waste glass. The process control and monitoring system applied by VEK has been designed to control the production of the waste glass in line with the specified requirements. The control strategy had been tested and verified during a long-term test operation of a prototype non-radioactive vitrification test facility.

INTRODUCTION

Vitrification of 70 m^3 of high-level liquid waste (HLLW) with a total β/γ-activity of about 8 E17 Bq will be carried out in a new vitrification plant using a liquid fed Joule-heated ceramic waste glass melter [1]. In this plant designated VEK (Verglasungseinrichtung Karlsruhe) a computer-aided process control and monitoring system will be applied to maintain safe process conditions and to produce nuclear waste glass within a specified range of characteristic parameters. The parameters must cover radioactivity data, chemical and physical properties of the waste glass, and also mechanical properties. They are required by the licensing procedure for final disposal which is controlled by the federal government of Germany with the Federal Bureau of Radiation Protection (BfS) as the responsible licensing authority.

The Quality Assurance System applied for planning, construction and commissioning of the VEK facility – based on the German Nuclear Regulation KTA 1401 – has been supplemented by a QA procedure for electric and control components including the process control and monitoring system needed for plant operation. This QA procedure includes (1) details of measures of the plant operator to assure the quality of the waste glass package, (2) measures for surveillance of the quality assurance program, and (3) the cooperation of the plant operator with external laboratories and sites e.g., with the manufacturer of the glass frit. The measures for assuring the quality of the waste glass package include control of:

- Fabrication and acceptance of the glass frit (chemical composition)
- Fabrication and acceptance of the stainless steel glass containers (dimensions, stackability)
- Sampling of waste solution and analysis
- Feed streams to the waste glass melter including control of associated measuring equipment
- Operation of the waste glass melter
- Glass pouring including control of associated equipment
- Lid welding of the glass canister including control of equipment involved
- Decontamination of the glass canister
- Control of the surface contamination of the glass canister before release

This paper describes the acceptance criteria for the vitrified waste package along with the key features of the process control and monitoring system by which the required characteristics of the waste glass package are controlled.

ACCEPTANCE CRITERIA FOR THE VITRIFIED WASTE PACKAGE

The acceptance of vitrified waste packages for final disposal is based on the observance of a set of specified parameters characterizing relevant properties of the package. Besides mechanical properties like outside dimensions, stackability and total mass, the main parameters of the package are related to the chemical composition of the waste glass. Depending on the concentration of the chemical elements in the waste solution and on their specific radioactivity, parameters like the dose rate, the neutron flux or the Pu-content are governed by the mass portion of waste elements in the waste glass. This portion in turn depends on the waste glass loading and is given in terms of oxides, as the waste elements are usually present in this chemical form in the borosilicate glass.

Table I contains the compilation of the defined parameters/guaranteed values of the waste glass package with a comparison between nominal and guaranteed values. The nominal values refer to the production of a glass with a waste glass loading of 16 wt.%. This parameter resulted from a comprehensive laboratory-scale work aimed to develop a tailor-made glass matrix for the homogenous incorporation of the waste constituents. This work has been based on a spectrum of waste constituents according to the reference waste solution established from analysis data of samples taken from the genuine waste. The nominal data in Table I, related to a canisterized glass mass of 400 kg, represent the target values that are to be sustained through the means of the process control and monitoring system. The guaranteed values are based on calculations, which consider deviations (1) from the reference composition of the waste solution, (2) from the waste glass loading and (3) from the target of glass mass in the canister. The guaranteed values represent the limit tolerable for each parameter. In case that only one of these exceeds the limit, BfS will not accept the vitrified package as a qualified product.

This issue emphasizes the role of the process control and monitoring system as an important tool to assure the production of an acceptable waste glass. Especially the control of the melter feeding is decisive for the chemical and radiological properties of the glass product. The acceptability check performed by experts of BfS for each waste package is mainly based on data recorded by the process control and monitoring system. These data, compiled in a complete data sheet, are part of the documentation of each waste glass package and contain all information necessary to identify the chemical and radiological features. The radiological data are finally counterchecked by direct measurement of the dose rate of the package before release from the plant.

Table I. Parameters of the vitrified waste package considered to be relevant for final disposal. Comparison between nominal and guaranteed values

Parameter		Nominal Value	Guaranteed Value
Waste glass loading (oxides)		16 wt.%	≤ 19 wt.%
Mass of vitrified waste package		495 kg	≤ 550 kg
Activity Sr-90/Y-90		2.7 E15 Bq	≤ 4.5 E15 Bq
Activity Cs-137/Ba-137		3.2 E15 Bq	≤ 5.1 E15 Bq
Total α-activity		5.6 E13 Bq	≤ 8.6 E13 Bq
Total β/γ-activity		6.0 E15 Bq	≤ 9.6 E15 Bq
Total mass of U		3977 g	≤ 7200 g
Total mass of Pu		132 g	≤ 190 g
Total mass of Cm		10.6 g	≤ 25 g
Dose rate	β/γ on surface	-	≤ 440 Gy/h
	β/γ at 1 m distance	-	≤ 35 Gy/h
	Neutrons on surface	-	≤ 2 E-3 Gy/h
	Neutrons at 1 m distance	-	≤ 3 E-4 Gy/h
Decay heat		520 W	≤ 734 W

PROCESS CONTROL SYSTEM

A simplified scheme of the process control and monitoring system of the vitrification plant is given in Fig. 1. Its architecture ensures a safe and reliable control of the vitrification process backed up by a highly reliable protection system. The process control and monitoring systems consist of the following four main parts: (1) the protection system; (2) the conventional system; (3) the operation, monitoring and auxiliary panels: (4) the emergency panel. The protection system is not involved in the control of the vitrification process, but monitors security-relevant measurements and lockings. In case of an emergency the protection system drives the installation, or parts of it, automatically into a safe condition. The conventional part is built-up under the valid rules and regulations for engineering of electrical facilities without high security standard as required for nuclear power plants and can be complex and error-tolerable. Installations of the plant, which are managed by the conventional part of the process control and monitoring system, are for example the waste solution and glass frit feeding system, the melter power supply, the mean frequency heating system for the glass pouring equipment and others. For operation control and monitoring of the plant, several terminals are available in the control room and operated in parallel mode. The parallel mode ensures a high availability of the conventional system. The auxiliary panel provides additionally selected actual and historic analogue and digital process data to the operators. If the control room is not accessible for any reason, a redundant designed emergency panel is available in a separate and shielded room.

BASIC CONTROL OF WASTE GLASS PRODUCTION

One of the key issues that the waste glass packages meet the set of guaranteed values is the control of the chemical composition of the waste glass. The waste solution to be vitrified has passed a comprehensive sampling and lab-scale characterization program. Simultaneously, work for an optimized glass matrix has been completed and the waste

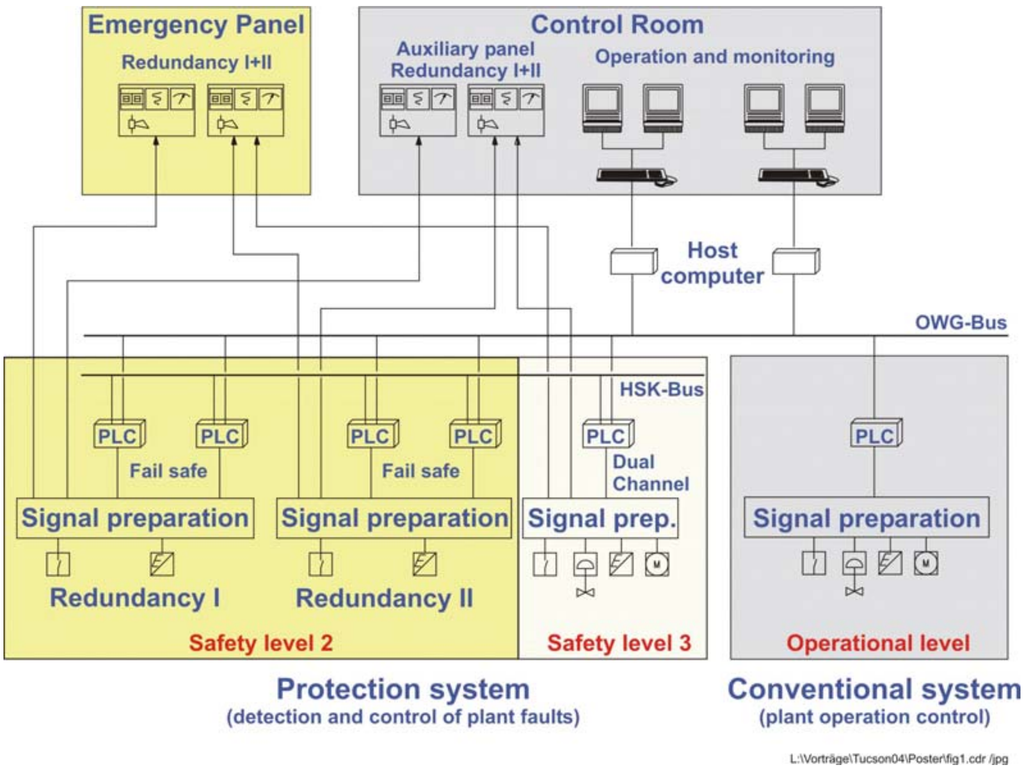

Fig. 1 Scheme of process control system

glass loading specified within a distinct range. The resulting chemical composition of the waste glass can be predicted by (1) knowledge of the actual chemical composition of the waste solution batch overtaken from the storage plant, (2) the chemical composition of the glass frit and (3) appropriate control of the ratio of these two feed streams to be fed to the melter. One of the major tasks of the conventional part of the process control system is to keep the process parameters effecting the glass composition under reliable control. As the strongest requirement, the conventional part of the process control system must avoid the melting of unacceptable waste glass. The control of the melter feed stream along with the chemical analysis data of each batch of waste solution transferred from the HLLW storage facility allows immediate prediction of the waste glass composition. Thus, melter feeding, along with glass pouring, is most important referred glass quality control.

Control of melter feeding

The melter feeding method applied is illustrated in Fig. 2. The HLLW and glass frit beads are fed into the melter via separate lines. The waste solution, – transferred from a storage tank into the receipt tank and sampled and analyzed prior to processing – is batchwise (25 dm^3) transferred by a two-stage airlift (1500 dm^3/h) into a small feeding tank. The batch transfer is initiated when the signal 1 is released at a given minimum level in the feeding tank. From the feeding tank, a continuous flow of the waste solution to the melter is sustained by an one-stage airlift. Batch feeding of glass frit is automatically initiated by the process control system during the time the 25 dm^3 HLLW batch is fed to the melter. The frit feeding program starts as soon as signal 2 is release, i.e. when the maximum level in the feeding tank is achieved and the batch transfer switched off. The mass of frit (m)

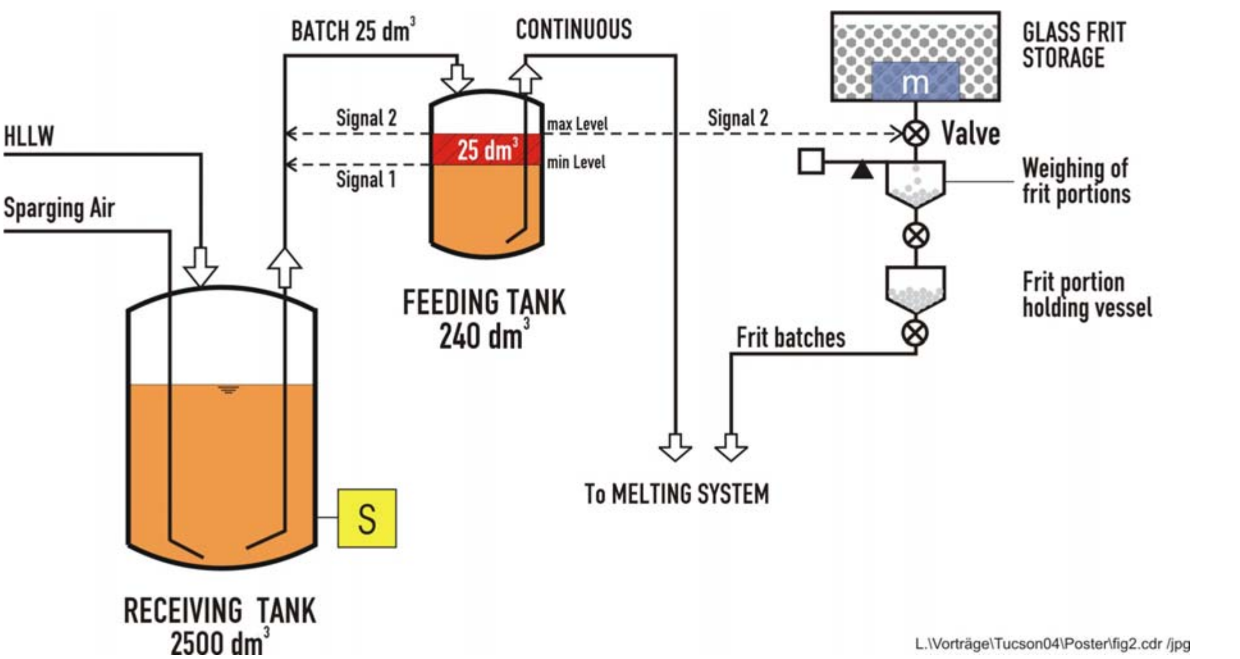

Fig. 2 Control of melter feeding by the VEK plant

needed to vitrify the overtaken batch of 25 dm^3 of waste solution is fed by about 5 sub-batches into the melter within preselected intervals. The intervals are set so that the last sub-batch is fed before the minimum level in the feeding vessel is reached again and a new cycle starts. The HLLW feed rate is calculated by the process control system using the volume and time needed to process each HLLW batch overtaken from the receipt tank into the feeding tank. The mass of glass frit to be fed is controlled by twofold weighing the individual sub-batches prior to feeding it to the melter.

Control of glass pouring

Batches of waste glass are periodically discharged from melter by means of a bottom drain. This pouring device consists of a mean frequency-heated thick-walled pipe made of INCONEL 690^R with its upper part firmly integrated into the melter bottom structure [2]. By induction heating of the pipe to about 1050°C the glass flow into the stainless steel canister is initiated. During pouring the values of the following parameters are recorded and limits controlled by the conventional part of the process control and monitoring system:

- Weight increase of the stainless steel glass canister due to glass pouring
- Glass flow rate into the canister (using weight increase data and time)
- Pre-selected weight limit for a pouring operation
- Power limit for induction heating of the pipe
- Temperature of the INCONEL 690^R pouring pipe

The protection of the canister against overfilling is also assured by the process control system. If a quantity of glass of more than the target (400 kg) has been detected in the canister, an automatic switch-off of the pouring system is performed by terminating the heating of the pouring pipe.

NONRADIOACTIVE TESTING OF PROCESS CONTROL STRATEGY

Prior to its radioactive application in VEK the process control strategy to produce an acceptable waste glass has been demonstrated in the course of a long-term nonradioactive test operation. It took place with a full-scale prototype vitrification facility at the Institut für Nukleare Entsorgung (INE) of Forschungszentrum Karlsruhe [3]. During this test operation a process control and monitoring system was applied for development of the strategy to assure the correct composition of the waste glass by means of adequate control steps and monitoring functions. This control system formed the basis for the design of the conventional part of the control and monitoring system to be used by VEK including the complete tools and features of the user-interface.

The results from the test operation have been applied to support and experimentally confirm the process qualification, which is the essential part of the vitrified waste package licensing procedure. During the testing it was proven that the control strategy is suitable to assure the melting of the glass product with a composition within the specified ranges. During the production of approximately 18 tons of simulated waste glass, poured into 43 canisters, a waste glass loading within a range of 16.0-16.4 wt.% was achieved. The tolerable range has been 13-19 wt.% with a target of 16.0 wt.% as it will be for the active production. The composition of the glass determined by analysis of glass samples – taken from the glass pouring stream for control purposes– was found to remain constant over the whole test run and to meet well the target values.

Figure 3 shows, as a typical example, the results of a completed test run. The graph contains the concentration of selected glass constituents as oxides as function of the sequence of samples taken throughout the test campaign. Silicon dioxide is the main glass structure element originating from the glass frit material. Sodium oxide is also an important structure element, as it has a strong effect on the physico-chemical properties of the glass. It is contained in the waste solution as well as in the glass frit. Values of cesium oxide and strontium oxide in the waste glass are representative for the bulk of radioactivity immobilized in the glass.

SUMMARY

The acceptance of the vitrified waste packages produced by VEK for interim storage and final disposal will be linked to the observance of a set of parameters that will have to meet specified ranges. These parameters, which have been evaluated as relevant for final disposal include chemical and physical properties of the waste glass, radioactive properties as well as mechanical properties of the package. As laid down in the license regulations, the complete specification must be met for release from the plant. As the bulk of the parameters (radioactivity, waste loading, dose rate, etc.) is related to the composition of the waste glass, surveillance of the melter feeding plays a dominant role in the strategy of quality assurance.

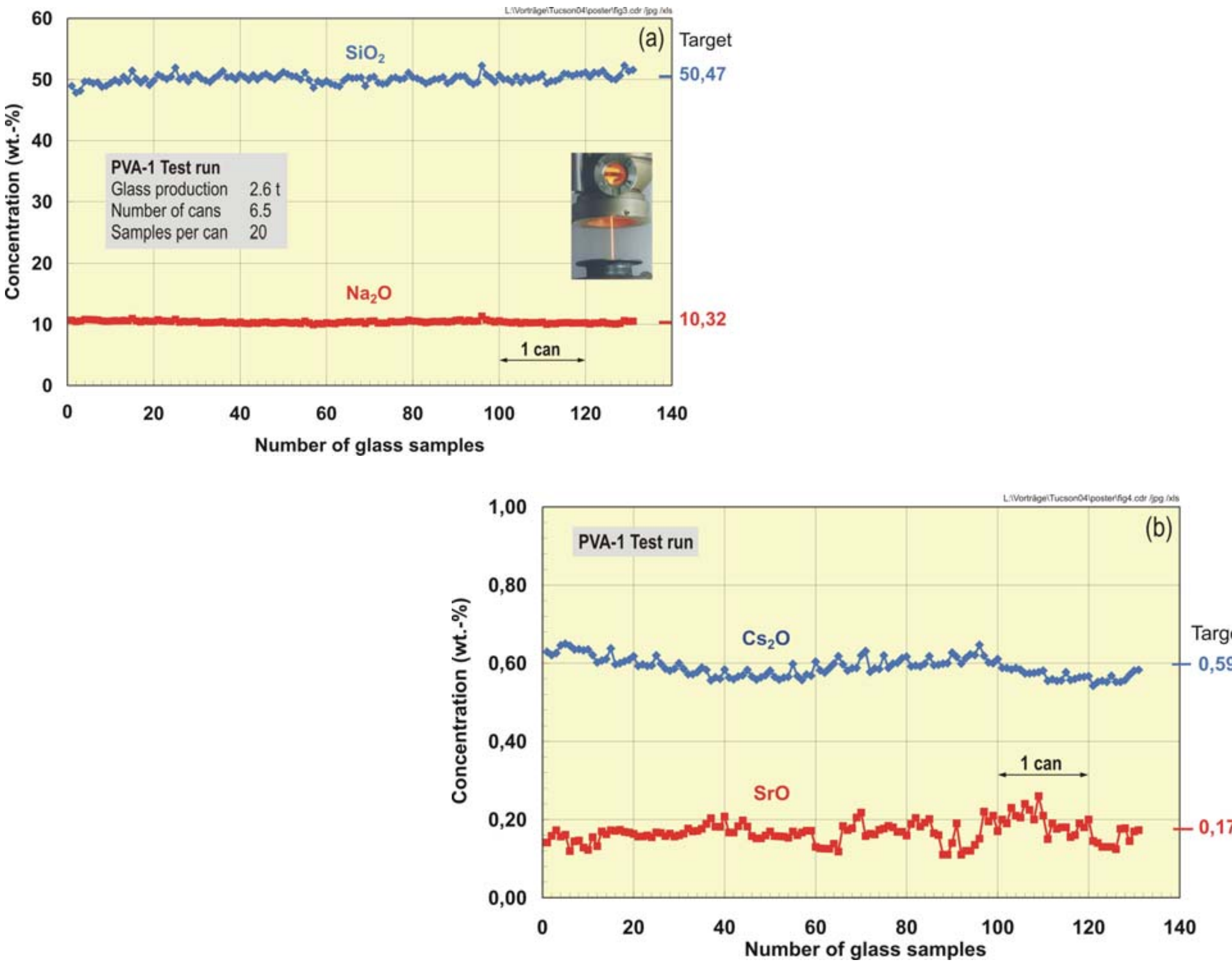

Fig. 3 Concentration of selected glass constituents based on glass samples from the pour stream during a test run with the Prototype Non-Radioactive Vitrification Facility.
(a) Concentration of silicon dioxide and sodium oxide. (b) Concentration of cesium oxide and strontium oxide

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