Commissioning and Cold Test Operation of the German HLLW Vitrification Plant VEK

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ABSTRACT

In 2007 the German High Level Liquid Waste (HLLW) vitrification plant VEK (Verglasungseinrichtung Karlsruhe) located at the site of Forschungszentrum Karlsruhe (FZK) will be put into radioactive operation. The purpose of VEK is to immobilize in borosilicate glass approximately $8 \cdot 10^{17}$ Bq of radioactivity contained in about 60 m^3 of HLLW. The process technique used is based on the liquid fed ceramic-lined electric waste glass melter (LFCM) designed for processing of highly noble metals (Ru, Rh, Pd) containing HLLW.

By mid of 2006 the melter has been heated up to idling temperature of about 950°C. All major systems of the plant have been tested in 2005/2006. The next steps in the commissioning of the facility before hot operation include the cold test operation of the entire plant while vitrifying about 15 m^3 of HLLW simulant. The paper presents a short description of the VEK vitrification technology, steps of functional testing of process equipment, preparation and performance the cold test operation and an outlook for the forthcoming hot operation of the facility.

INTRODUCTION

Since the year 2000 the German HLLW vitrification VEK plant has been constructed on the site of Forschungszentrum Karlsruhe (FZK) with the objective to immobilize about 60 m^3 of HLLW. The waste solution with a total activity of $7.7 \cdot 10^{17}$ Bq is the remnant of a 20 years reprocessing operation performed by the former pilot reprocessing plant WAK (Wiederaufarbeitungsanlage Karlsruhe) which is currently in an advanced stage of dismantling. Final goal of the dismantling activities is its complete conversion to green field. Vitrification of the HLLW constitutes a precondition to continue the dismantling of the waste storage area. VEK is scheduled to start hot operation in 2007 [1].

The HLLW will be vitrified to about $5 \cdot 10^4$ kg of borosilicate glass and filled into 125 stainless steel canisters (~400 kg in each). The vitrification technology used by VEK is based on a liquid-fed ceramic melter (LFCM) which converts the waste liquor into glass by a single-stage process. The technology has been developed during the last three decades by the Institut fuer Nukleare Entsorgung (INE) of FZK [2, 3]. It was first time applied by the hot PAMELA plant in Mol/Belgium at the former EUROCHEMIC site [4]. One of the major design features of the waste glass melter is its suitability to process highly noble metals-containing waste solutions as generated by WAK reprocessing operation.

After a five years construction phase VEK has been completed in 2005 by final installation of the process equipment. Functional testing of single components and of single process systems (e. g. HLLW receipt system) as well as successful demonstration of all remote handling operations including cask loading were completed in 2006. Since the end of 2006 the VEK plant is ready for the integral test of the overall plant operation. This integral test using an HLLW simulant is considered as final check of all systems and their interaction prior to processing of radioactive material. Preceding to the hot production operation a short pre-test with a radioactively doped waste simulant will be carried out to ensure the safe function of the radiation measurement devices.

VITRIFICATION TECHNOLOGY

The core technology used in VEK comprehends the following systems: HLLW receipt, glass melting, wet off-gas treatment, dry off-gas treatment, secondary liquid waste (effluents from wet off-gas cleaning) and canister handling. Figure 1 shows a simplified flow diagram of the vitrification process. The receipt area comprises two HLLW receipt tanks (3 m^3) each equipped with a double-stage, vacuum-supported airlift systems to transfer the waste solution to the melting area. The melting area consists of the LFCM, a small HLLW feeding vessel (300 l) along with a feeding airlift connected to the melter, and a glass frit feeding system. Control of the glass composition is accomplished by HLLW flow rate measurement based on level variation in the feeding vessel and by adjusting glass batches according the HLLW flow rate. The wet off-gas treatment system includes a dust removal wet scrubber used for precleaning, a subsequent condenser which is followed by a jet scrubber and a NO_x absorption column (valve plate type). Final dry cleaning uses four filters, consisting of a high-efficiency mist eliminator (HEME), two HEPA-filters, and in between an Iodine filter. The scrub solutions arising from wet cleaning are recycled to avoid intermediate-level liquid waste to be transferred from the plant. Whereas the scrub solution of the dust scrubber is periodically directly fed back to the feeding vessel, the other liquids are collected and treated in a two-stage evaporator system. The resulting concentrate is recycled to one of the receipt tanks and the distillate leaves the plant as low-level waste for cementation.

COMMISSIONING OF THE PLANT

After termination of installation in 2005, the functional testing of the process equipment was mainly carried out in 2006. At the end of 2006, all single components as well as process systems like glass melting or off-gas treatment were commissioned. Table 1 gives an overview about the complete systems of VEK. The systems directly related to the vitrification core process are indicated on the right column of this table. They cover the HLLW receipt system, the vitrification system (including HLLW and glass frit feeding), the melter off-gas and secondary liquid waste treatment systems as well as the can handling system. Other process systems comprise the plant ventilation, the tank ventilation, electric equipment, water supplies, as well as the system for pressurized air, steam and supply of chemicals.

Commissioning of the process systems

The commissioning of the process systems as indicated in Table 1 comprises the following main steps for each system:

- Function tests of its single items (mechanical valves, control valves, air pressure reducer etc.)
- Function tests of its components (e.g. for the vitrification system the function tests of the feeding vessel, the glass frit feeding device, the melter, and the mean frequency generator used for induction-heating of the bottom drain)
- Start up programs for selected systems (e. g. HLLW receipt system, vitrification system, off-gas system wet/dry)
- Final test during cold test operation (while VEK is vitrifying HLLW simulant)

<u>Function tests of single items of a system</u>

In 2005 function tests of the single items of each of the process systems were performed. As for example for the vitrification system the tests of single items included hand- and pneumatically operated valves,

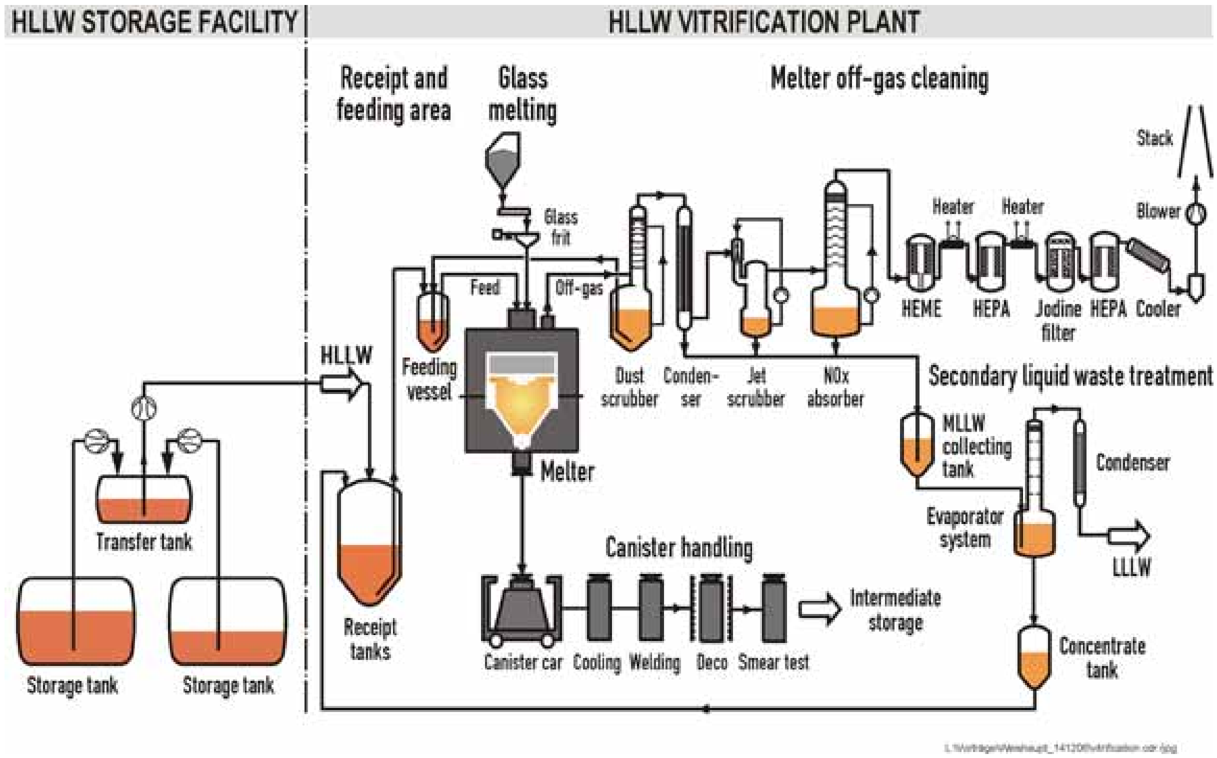

Fig. 1: Simplified diagram of the VEK vitrification process including the HLLW storage facility

Table 1: Systems of the VEK facility. Core process systems are marked.

System	Core process	System	Core process
Vitrification plant		Fresh water supply	
Outdoor facilities		Cooling-/Cold water supply	
Process building		Pressurized air system	
Process systems		Steam/Condensate system	
HAWC receipt system	•	Supply of chemicals	
Vitrification system	•	Sampling system	
Can handling system	•	Mobile radiation protection	
Can buffer store		Fixed radiation protection	
MLLW evaporation	•	Fire protection	
Tank ventilation system		Process control system	
Melter off-gas treatment wet	•	Plant security equipment	
Melter off-gas treatment dry	•	Collection of secondary	•
Auxiliary systems		liquid waste	
Plant ventilation		Solid waste management	
Electric equipment		Glass can lock and transport	

magnetic valves, hand- and pneumatically operated control valves, and reducers for pressurized air. All systems of the VEK vitrification plant together amount to nearly 2000 of such single items. Most of them are installed in the valve galleries.

Function tests of system components

For the function test of each system an approved functional test instruction program has been used. Within these programs the steps of the tests to be carried out are described in detail for each component. It describes the aims of the tests, the preconditions, the test basis, the test means and finally the detailed instructions for performing the test.

Function tests of components of the systems belonged to the major activities in 2005. They included components of the core systems of the VEK plant (e.g. receipt tanks, feeding vessel, dust scrubber, condenser, jet scrubber, NO_X-column), but not yet the melter.

The HLLW feeding vessel of the vitrification system is representative of these types of components which had been tested in 2005. Its function test can be taken as typical for others. The functional test instruction of the feeding vessel covered the following in detail:

- Establishing the volume vs. level curve of the feeding vessel
- Testing of the homogenisation equipment of the vessel
- Testing of devices for level/density measurements including tests of the limits (e.g. warnings high/low)
- Checking of the procedure to empty the vessel
- Measurement of feed rate curve of feeding air lift
- Testing of temperature measurement devices
- Testing of deco-equipment of the vessel (circular tube with holes placed in the upper part of the vessel through which pressurized deco liquid can be sprayed)
- Testing of the sampling device

The tests were carried out using water as the liquid and the results were documented in check protocols. The function tests of the HLLW receipt tanks included additionally the test of the two-stage airlift systems (performing batch transfers of HLLW into the feeding vessel), and the test of the water cooling system of each receipt tank. The function tests of components of the off-gas line additionally included the tests of pump-driven circulation of the scrub solutions.

One of the most extensive functional tests refers to the waste glass melter carried out in 2006. It requires a special program starting with the heat up of the internal melter structure by external heat sources. The melter, which is schematically shown in Figure 2, needs a special function test program because most key functions require the presence of molten glass in the glass tank. As glass does not provide electrical conductivity at ambient temperature, the empty melt tank must be first heated to temperatures of approximately 1000°C. A typical heating up vs. time curve of the melter is shown in Fig. 3. Then a suitable start glass must be filled into the melter. At increasing temperatures above 800°C the start glass becomes gradually electrically conductive and thus suitable for Joule-heating. Heating up is done by 5 SiC-heating elements encased in INCONEL 690 protecting tubes. They are placed inside the melter as illustrated in Fig. 2. Heating up is performed slowly in order to avoid thermally induced stresses inside the thick-walled ceramic refractories of the glass tank. When the temperatures of the melter interior have reached about 1000°C, the heating devices are removed from the melter and start glass is batchwise put into the glass tank via the glass frit feeding system, about 10-30 kg every hour. When the Joule heating can be applied the temperature in the melter is adjusted to about 900°C by power control.

Key functions of the melter include, besides glass heating by releasing Joule-heat between the power electrodes, also glass pouring, glass level detection, multiple temperature control and underpressure control in the melter at a limited air-inleakage rate of about 10-20 Nm^3/h (referring to standardized conditions). These last three functions are tested during the starting up program of VEK for selected systems.

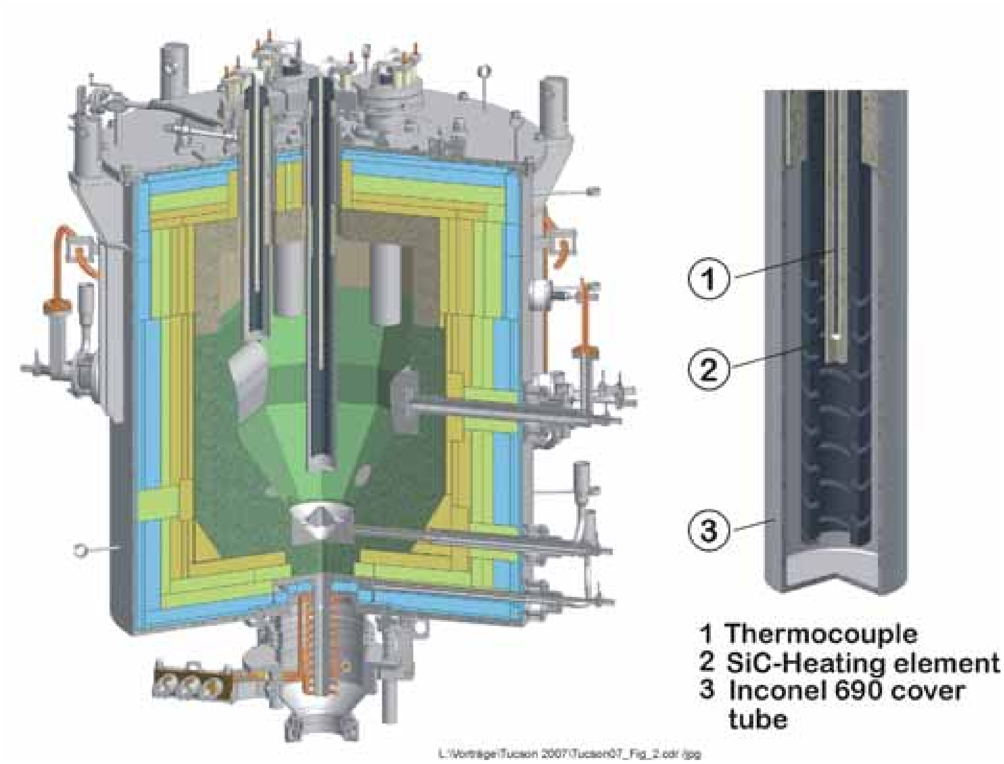

Fig. 2: Heating up of the internal melter structure by an external heat source (five SiC-heating elements encased in INCONEL 690 protection tubes including a thermocouple)

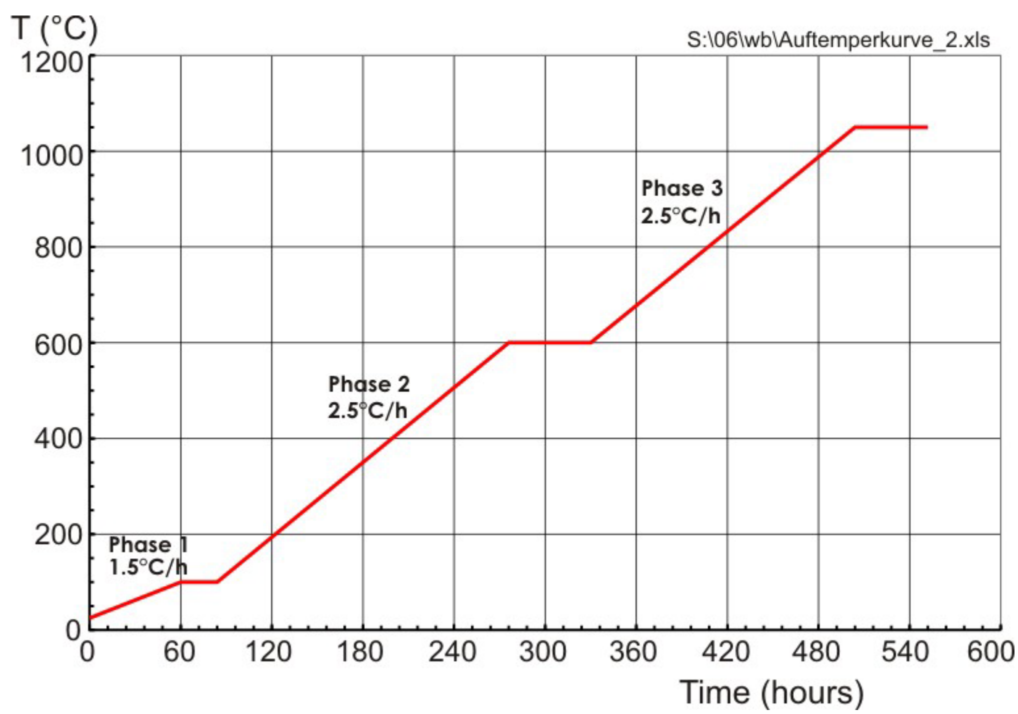

Fig. 3: Temperature vs. time curve for heating up of the inner melter structure

Starting up program of selected systems

Whereas the majority of the process systems require successful functional tests only to be ready for cold test operation, the core process systems need another additional step of commissioning, i.e. a starting up program. Within the starting up program all components of a system are operated simultaneously. Thus the correct operational interactions between components are checked. In particular the correct communication with the central VEK process control system must be demonstrated. The starting up programs have been carried out in 2006. The systems which are to pass a starting up program are the HLLW receipt system, the vitrification system, and the melter off-gas cleaning systems (wet/dry).

HLLW receipt system

The starting up program for the HLLW receipt system includes:

- Filling of the receipt tanks with demineralised water
- Start up of the water cooling circuit, the agitation air, and the level measurement devices
- Testing of overtaking evaporator concentrate from evaporator system (i.e. demineralized water from concentrate tank of the evaporator system)
- Sampling tests using sampling system
- Finally functional coupling of the receipt system (i.e. the two-stage airlift system) with the vitrification system (i.e. to the feeding vessel and to the glass frit feeding device)

Vitrification system

The starting up program for the vitrification system includes particularly demonstration of key functions of the melter as described before. Regarding glass heating, the electrical power data are monitored and compared with the design data. For testing the glass pouring the glass pool must be heated to approximately 1150°C under the condition of continuous water feeding and batchwise feeding of start glass into the melter via the water-cooled feed- and glass frit inlet tube. These pouring tests are carried out in connection with phase 3 of the start up program for the melter off-gas system (see below). By feeding of water and start glass into the melter and adjustment of the water flow rate a “cold cap” of evaporating water and melting start glass is formed across the major surface of the glass pool. It keeps the temperature of the melter plenum and thus the upper melter structure below the desired range of about 500°C. Feeding of start glass into the melter via the glass frit feeding system serves for replacing the glass mass poured for testing. Tests of the glass pouring system uses start glass melt because its viscosity vs. temperature curve has been tailored to be similar to that of the waste glass product and thus suitable for this purpose. The normal glass frit is not suitable because in absence of the waste oxides its viscosity level is too high.

Melter off-gas system

The starting up program to be carried out for the melter off-gas system wet/dry is divided into three phases. Before, all components of the off-gas system are first prepared to be ready for operation. This includes for the wet off-gas line filling of the components with demineralised water, set up the valves associated with the components to the right position, and filling of the circulation pumps of the jet scrubber and NO_X-Absorber with demineralised water. Additionally the dust scrubber entrance has been prepared with a variable shutter to simulate proper pressure conditions along the off-gas line. For the dry off-gas line the preparation includes selection of one of the parallel filter lines to be used, selection of the off-gas blower to be used (1 of 3), set up of valves to the right position and preparation of the electric circuits for the off-gas heaters. Afterwards the three phases of the start up program were carried out.

- Phase 1

  In phase 1 the off-gas blower is put into operation and the air flow rate through the off-gas system is adjusted to approximately 40 Nm^3/h. The further steps include to put the off-gas heaters in the dry off-gas line as well as the gas cooler before the blower into operation. The scrub solution circuits of the dust scrubber, jet scrubber and NO_X-columns are started up followed by adjustment to the parameters gained as preliminary values from former functional test program. Further tests in phase 1 include the switch from the dry filter line to the parallel one. Also switch of the circulation pumps in the wet off-gas system to the redundant ones are carried out.

- Phase 2
  In phase 2 the off-gas system is connected to the melter via the off-gas pipe melter-dust scrubber. In this phase the glass melter is kept at idling conditions, i.e. the glass pool is at about 900°C. Adjustment of the off-gas blower to an underpressure in the melter of 2±1 mbars is done followed by monitoring and documentation of the operational parameters of each component and the pressure drop across the entire off-gas line. Furthermore switching of the circulation pumps for the jet scrubber and NO_X-absorber scrub solution circuits and of the dry filter line to the parallel one are performed again under particular monitoring of the melter underpressure.

- Phase 3
  In phase 3 the off-gas system will be operated under conditions of melter feeding with demineralised water and start glass to allow the key function tests of the melter as outlined above. Under these conditions and heating up the glass pool to 1150°C all tests of phase 2 are repeated under particular observation of the underpressure in the melter. The complete data set will be documented and used as preliminary operation parameters for the later cold test operation.

Cold test operation

Objective of cold test operation starting early 2007 is to show the correct function of the entire plant and its systems under normal operation conditions. This includes the demonstration of the procedure to produce glass canisters according to the qualification program. The canister lid welding and the entire canister handling will also be demonstrated. Single function tests of the lid welding were already performed before as shown in Figure 4. During cold test operation, 15 m^3 of HLLW simulant will be vitrified and the resulting simulated waste glass poured into 27 stainless steel canisters each having a glass capacity of 400 kg. The chemical composition of the HLLW simulant is given in table 2 compared with the reference composition of the radioactive HLLW. During cold test operation sampling will be applied according to the analytical sampling plan worked out for the hot operation.

Figure 4: Demonstration of the canister lid welding in the canister handling cell of VEK

The chemical composition of the HLLW simulant will be as similar as possible to that of the radioactive HLLW. Radioactive samples have recently been taken from the HLLW storage tanks and analysed. Only

Table 2: Chemical composition of the HLLW-simulant in terms of oxide residue compared to the genuine HLLW solution

1.8.2005 Oxide residue	Radioactive HLLW			HLLW-Simulant		
	Element	Oxide		Element	Oxide	
	g/l	g/l	Wt.%	g/l	g/l	Wt.%
SeO2	0,09	0,13	0,11	0,09	0,13	0,11
Rb2O	0,42	0,46	0,38	0,42	0,46	0,38
SrO	1,11	1,32	1,09	1,11	1,32	1,09
Y2O3	0,82	1,04	0,86	0,82	1,04	0,86
ZrO2	4,01	5,41	4,48	4,01	5,42	4,48
MoO3	4,38	6,57	5,44	4,38	6,57	5,44
TcO2	1,11	1,65	1,36	–	– 1)	– 1)
RuO2	3,82	5,03	4,16	–	– 2)	– 2)
Rh2O3	0,89	1,09	0,90	–	– 3)	– 3)
PdO	2,00	2,30	1,91	–	– 4)	– 4)
Ag2O	0,20	0,21	0,17	0,20	0,21	0,17
CdO	0,12	0,14	0,11	0,12	0,14	0,11
SnO2	0,09	0,12	0,10	0,09	0,12	0,10
Sb2O3	0,02	0,02	0,02	0,02	0,02	0,02
TeO2	0,80	1,00	0,82	0,80	1,00	0,82
Cs2O	3,57	3,79	3,13	3,57	3,79	3,13
BaO	3,41	3,80	3,15	3,41	3,81	3,15
La2O3	2,32	2,72	2,25	11,88	13,93	11,52
CeO2	4,38	5,38	4,45	4,38	5,38	4,45
Pr2O3	2,04	2,38	1,97	2,04	2,38	1,97
Nd2O3	7,23	8,44	6,98	7,24	8,44	6,98
Pm2O3	0,00	0,01	0,00	0,00	0,01	0,00
Sm2O3	1,58	1,83	1,52	1,58	1,83	1,52
Eu2O3	0,20	0,23	0,19	0,20	0,23	0,19
Gd2O3	0,61	0,70	0,58	0,61	0,70	0,58
UO2	8,21	9,68	8,01	–	– 5)	– 5)
Np2O3	0,54	0,60	0,49	–	– 6)	– 6)
PuO2	0,25	0,29	0,24	–	– 7)	– 7)
Am2O3	0,56	0,61	0,51	–	– 8)	– 8)
CmO2	0,02	0,03	0,02	–	– 9)	– 9)
Cr2O3	2,03	2,96	2,45	2,03	2,96	2,45
MnO2	0,32	0,50	0,42	4,54	7,18	5,94
Fe2O3	7,63	10,90	9,02	7,63	10,91	9,02
CoO	–	–	–	0,86	1,09	0,90
NiO	1,58	2,02	1,67	3,39	4,32	3,57
CuO	0,03	0,04	0,03	0,03	0,04	0,03
ZnO	0,02	0,03	0,02	0,02	0,03	0,02
PbO	0,01	0,01	0,01	0,01	0,01	0,01
Na2O	24,08	32,45	26,85	24,08	32,46	26,85
MgO	0,59	0,98	0,81	0,59	0,98	0,81
Al2O3	0,08	0,16	0,13	0,08	0,16	0,13
K2O	0,31	0,38	0,31	0,31	0,38	0,31
CaO	0,51	0,71	0,59	0,51	0,71	0,59
F	0,07	0,07	0,06	0,07	0,07	0,06
Cl	0,05	0,05	0,04	–	–	–
P2O5	1,15	2,63	2,17	1,15	2,63	2,17
Sum		120,85	100,0		120,89	100,0
Density g/cm^3				1.20-1.30	–	–
HNO_3 mol/l				2.5	–	–

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1) TcO_2 replaced by MnO_2
2) RuO_2 replaced by MnO_2
3) Rh2O3 replaced by CoO
4) PdO replaced by NiO
5) UO_2 replaced by La_2O_3
6) Np_2O_3 replaced by La_2O_3
7) PuO_2 replaced by La_2O_3
8) Am_2O_3 replaced by La_2O_3
9) CmO_2 replaced by La_2O_3

the noble metals ruthenium, rhodium and palladium as well as the actinides and technetium will be replaced by other elements. The HLLW simulant will be delivered in batches of several m^3 by tank truck.

A first batch of 4.5 m^3 has already been received and stored nearby VEK, waiting for vitrification by VEK in early 2007. By special tanks with a capacity of about 1 m^3 the HLLW-simulant will be transferred into the receipt tanks of the HLLW receipt system.

The continuous cold test operation will last about 70 days. Operation will take place in a manner similar to the later hot operation. It includes the establishment of a control area and operation of the plant according to the operation manual for each system. Major goals of the cold test operation are:

- Demonstration of the overall plant operability
- Final adjustment of operational database
- Test of sampling and analytical procedures
- Finalization of the process/product qualification
- Training of operational staff

OUTLOOK

Subsequently to demonstration of the process systems by cold test operation commissioning of the process systems will be continued within the final step, i.e. the hot test. During the hot test approximately 2 m^3 diluted HLLW will be vitrified consisting of a mix of HLLW simulant as used in the cold test operation, and about 1 Vol.% of genuine HLLW.

The hot test operation of the process systems will be of particular importance before the plant will be put into active operation. It serves for final check of the transfer systems from the HLLW storage and of all devices related to radiation measurement. During active operation the plant will vitrify the HLLW stored on site, producing approximately 130 glass canisters (430 mm in diameter, 1335 mm high, appr. 400 kg glass each) for intermediate storage and later final disposal. The operation time is anticipated to be about 1.5 years.

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