Thermal treatment for radioactive waste minimisation and hazard reduction

Initiative: EU Horizon 2020 - Euratom Research and training programme
Grant Agreement No: 755480
Start date: 01.06.2017 Duration: 36 Months
Project Coordinator: VTT Technical Research Centre of Finland Ltd

WP No: 3
Deliverable No: D3.2
Title: Summary of Demonstration Trials Carried Out Under WP3.
NNL document ref: EU10302/06/10/04
Lead author: NNL
Contributors: NNL, ORA, CEA, USFD, VTT, VUJ
Dissemination level: Public

Due date of deliverable: 30-November 2019
Actual submission date: 22-November 2019
<table>
<thead>
<tr>
<th>History Chart</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of revision</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Name</th>
<th>Signature</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Author</strong></td>
<td>J I Roe</td>
<td>22 November</td>
</tr>
<tr>
<td><strong>Checked By</strong></td>
<td>C R Scales</td>
<td>22 November</td>
</tr>
<tr>
<td><strong>Approved By</strong></td>
<td>S Clarke</td>
<td>22 November</td>
</tr>
</tbody>
</table>
Table of Content

Table of Content.......................................................................................................................... 3
THERAMIN Project Partners ......................................................................................................... 4
1. Introduction ................................................................................................................................. 6
2. Scope ........................................................................................................................................ 7
3. Definition of Work Programme .................................................................................................. 8
4. Summary of Demonstration Trials ............................................................................................ 10
5. Assessment of Attributes for Deployment .............................................................................. 24
6. Conclusions ............................................................................................................................... 26

Acknowledgement

This project has received funding from the European Union’s Horizon 2020 Euratom research and innovation programme under Grant Agreement No 755480.
# THERAMIN Project Partners

<table>
<thead>
<tr>
<th>Partner</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andra</td>
<td>Agence nationale pour la gestion des déchets radioactifs – France</td>
</tr>
<tr>
<td>CEA</td>
<td>Commissariat à l'énergie atomique et aux énergies alternatives – France</td>
</tr>
<tr>
<td>GSL</td>
<td>Galson Sciences Limited – UK</td>
</tr>
<tr>
<td>FZJ</td>
<td>Forschungszentrum Juelich GmbH – Germany</td>
</tr>
<tr>
<td>LEI</td>
<td>Lithuanian Energy Institute – Lithuania</td>
</tr>
<tr>
<td>NNL</td>
<td>National Nuclear Laboratory – UK</td>
</tr>
<tr>
<td>ONDRAF/NIRAS</td>
<td>Organisme National des Déchets RAadioactifs et des matières Fissiles enrichies – Belgium</td>
</tr>
<tr>
<td>OR</td>
<td>ORANO France</td>
</tr>
<tr>
<td>SCK•CEN</td>
<td>The Belgian Nuclear Research Centre – Belgium</td>
</tr>
<tr>
<td>USFD</td>
<td>University of Sheffield – UK</td>
</tr>
<tr>
<td>VTT</td>
<td>Teknologian Tutkimuskeskus VTT Oy (VTT Technical Research Centre of Finland Ltd)</td>
</tr>
<tr>
<td>VUJE</td>
<td>VUJE a.s. – Slovakia</td>
</tr>
</tbody>
</table>
## THERAMIN End User Group

<table>
<thead>
<tr>
<th>Organization</th>
<th>Full Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andra</td>
<td>Agence nationale pour la gestion des déchets radioactifs – France</td>
</tr>
<tr>
<td>AWE</td>
<td>Atomic Weapons Establishment - UK</td>
</tr>
<tr>
<td>CEA</td>
<td>Commissariat à l’énergie atomique et aux énergies alternatives – France</td>
</tr>
<tr>
<td>EDF</td>
<td>Electricité de France – France</td>
</tr>
<tr>
<td>Fortum</td>
<td>Fortum Oyj – Finland</td>
</tr>
<tr>
<td>INL</td>
<td>Idaho National Laboratory - USA</td>
</tr>
<tr>
<td>IGD-TP</td>
<td>Implementing Geological Disposal of Radioactive Waste Technology Platform</td>
</tr>
<tr>
<td>Nagra</td>
<td>Die Nationale Genossenschaft für die Lagerung Radioaktiver Abfälle – Switzerland</td>
</tr>
<tr>
<td>ONDRAF/NIRAS</td>
<td>Organisme National des Dérchets RAadioactifs et des matières Fissiles enrichies – Belgium</td>
</tr>
<tr>
<td>ORA</td>
<td>ORANO France</td>
</tr>
<tr>
<td>RWM</td>
<td>Radioactive Waste Management Ltd – UK</td>
</tr>
<tr>
<td>Sellafield</td>
<td>Sellafield Ltd – UK</td>
</tr>
<tr>
<td>TVO</td>
<td>Teollisuuden Voima Oyj – Finland</td>
</tr>
</tbody>
</table>
1. Introduction

The Thermal treatment for radioactive waste minimisation and hazard reduction (THERAMIN) project is a European Commission (EC) programme of work jointly funded by the Horizon 2020 Euratom research and innovation programme and European nuclear waste management organisations (WMOs). The THERAMIN project is running in the period June 2017 – May 2020. Twelve European WMOs and research and consultancy institutions from seven European countries are participating in THERAMIN.

The overall objective of THERAMIN is to demonstrate the efficacy of thermal treatment in providing improved safe long-term storage and disposal of intermediate-level wastes (ILW) and low-level wastes (LLW). The work programme provides a vehicle for coordinated EU wide research and technology demonstration designed to provide improved understanding and optimisation of the application of thermal treatment in radioactive waste management programmes across Europe and will move technologies higher up the Technology Readiness Level (TRL) scale. The THERAMIN project is being carried out in five work packages (WPs). WP1 includes project management and coordination and is being led by VTT. WP2 evaluates the potential for thermal treatment of particular waste streams across Europe; this WP is led by GSL. In WP3, the application of selected thermal treatment technologies to radioactive waste management is demonstrated and evaluated; this WP is led by NNL. In WP4, the disposability of the thermally treated waste products is assessed; this WP is led by Andra. WP5 concerns synthesis of the project outcomes and their dissemination to other interested organisations.
2. Scope

The main aim of this report is to provide a synopsis of the work that has been undertaken under WP3 and to collate summarised operational information for each demonstration trial in one document.

References to individual detailed operations reports for each participating technology will be provided.

The report includes an assessment of attributes for deployment which will be taken forward into the value assessment of WP2.
3. Definition of Work Programme

The initial task within WP3 was to collaboratively agree a group of recommended feed streams for the study. The waste streams were agreed at kick off meetings on 13th October 2017 and were grouped as follows:

**Conditioned Waste**
- Cemented (including cemented concentrates, concrete-lined drums, degraded packages, etc.)
- Bitumen (including various types of bituminised waste)

**Unconditioned Waste**
- Metals (pure or high content)
- Alpha waste (including PCM)
- Inorganic resin
- Organic resin
- Sludges
- PVC

**Liquid waste**
- Organic
- Oily
- Chrompik

The above selection provided a representative group of pre-treated and raw waste materials suitable for thermal treatment demonstration.

In addition to identifying the generic feed streams, the THERAMIN collaborators also identified existing rigs and facilities on which to carry out the demonstration trials. The project recognised that no new facilities would be constructed specifically for this work, therefore the study would need to be undertaken using technology demonstrators or processes that already existed. The list of technologies that available for demonstration are shown in table below where feeds streams were matched:
## Table 1 Thermal treatment programme

<table>
<thead>
<tr>
<th>Facility</th>
<th>Waste stream demonstration test</th>
<th>Waste Category</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHIVA</td>
<td>Organic ion Exchange material</td>
<td>Unconditioned waste</td>
<td>Vitrified</td>
</tr>
<tr>
<td>IN CAN</td>
<td>Sludges</td>
<td>Unconditioned waste</td>
<td>Vitrified</td>
</tr>
<tr>
<td>GEOMELT 1</td>
<td>Cementitious waste</td>
<td>Conditioned waste</td>
<td>Vitrified</td>
</tr>
<tr>
<td>GEOMELT 2</td>
<td>Heterogenous sludges</td>
<td>Unconditioned waste</td>
<td>Vitrified</td>
</tr>
<tr>
<td>THERMAL GASIFICATION</td>
<td>Organic ion exchange material</td>
<td>Unconditioned waste</td>
<td>Solid residue</td>
</tr>
<tr>
<td>HIP 1 UoS</td>
<td>Uranium containing feeds</td>
<td>Unconditioned waste</td>
<td>Vitrified/ceramic</td>
</tr>
<tr>
<td>HIP 2 NNL</td>
<td>Uranium surrogate containing feed</td>
<td>Unconditioned waste</td>
<td>Vitrified/ceramic</td>
</tr>
<tr>
<td>VICHR</td>
<td>Chrompik</td>
<td>Liquid wastes</td>
<td>Vitrified</td>
</tr>
</tbody>
</table>
4. Summary of Demonstration Trials

4.1 SHIVA Trial (CEA)

SHIVA consists of a water-cooled, stainless steel cylindrical reactor, equipped with a flat coil at the bottom and a transferred arc plasma system in the reactor chamber. The SHIVA bottom structure is built to be transparent to the electromagnetic field such that the glass is directly heated by the field while the cylindrical shell is not. The plasma torches were developed to minimize their maintenance requirements. The consumable electrodes are automatically fed. As oxygen is used and no secondary chamber is present, the off-gas treatment is simple. It consists of an electrostatic tubular filter and a gas scrubber. The dust in the filter is recovered in a bottom ashtray for recycling. The glass product is drained from the cold crucible.

SHIVA has been used in the THERAMIN program to demonstrate the processing of a waste stream containing organic ion exchange resins, chosen because of the capability of the plasma treatment facility to destroy the organic component. The resulting phases are subsequently vitrified by the induction heating system to generate a homogenous glass product.

![Figure 1(a)](image1.png) Simplified diagram of the SHIVA process and (b) artist's view of the reactor

The waste selected for this THERAMIN trial was a 25 kg mixture of inorganic and organic ion exchange media composed of zeolites, diatoms, strong acid Ion Exchange Resin (IER), and strong base IER. 40kg of a pre-formed glass frit was preloaded into the reactor to provide a melt pool to vitrify the residue from the plasma treatment. Inputs to the process were therefore composed of 38.5 % waste and 61.5 % glass frit.

The waste feed was introduced to the upper part of the reactor using a feeding hopper and a worm screw in three separate 8-hour feed campaigns. This
sequencing was used to allow a daytime operation for the waste incineration. The induction heating was started using a titanium starter ring and the generator power was incrementally increased from 40 kW up to 90 kW.

The SHIVA trial showed that the process was successfully used to demonstrate the thermal treatment of a mixture of organic and mineral waste composed of zeolites, diatoms and ion exchange resins. The waste load of 38 wt.% is high and could probably be increased in future. The vitrified product appeared to be homogenous be visual observation.

*Full detail of this test program is given in report D3.3 “SHIVA and In-Can Melting technologies and demonstration test trials” CEA, October 2018.*
4.2 In-Can Melting Trial (CEA)

In-Can system can be used to produce a vitrified waste package after in situ calcination of a liquid effluent. This process is simple and compact, and very well adapted for decommissioning waste: direct liquid feeding of the canister inside the furnace (without a separate calcination step). The In-Can Melter is a metallic crucible heated in a refractory furnace. The can is single use and forms the product container.

![Schematic of In Can melter system](image)

*Figure 2 Schematic of In Can melter system*

The waste selected for this vitrification trial was ash obtained from multiple incineration tests of surrogate technological waste (polyvinyl chloride, latex, neoprene, polyethylene, cotton.) produced by the CEA IRIS process. IRIS is a research facility for the incineration of solids developed to treat organic waste from glove boxes in the nuclear industry, contaminated with alpha bearing actinides and containing high quantities of chlorine. The feed material was formed into pellets with 10% bentonite to avoid clogging of the feeding pipe and dust carry over into the off-gas train.

Laboratory scale studies were carried out to determine the optimum waste to glass frit ration. The full-scale test was carried out using the In-Can mock-up (DIVA) equipped with a resistive furnace (35 kW), a complete gas treatment system and an Inconel 601 can with an outer diameter of 400 mm, a height of 600 mm and a wall thickness of 10 mm.

The can was preloaded with glass frit non-pelletized ash, then heated up to 1100 °C at a ramp-up rate of 300 °C·h⁻¹. Pelletised ash pellets were then introduced into the can by the solid feeding system at followed by 1 kg of glass frit. The mixture was soaked for 2 h. Two additional hours were added to recycle the dust scrubber deposits followed by a final soaking of 2 h at 1100 °C. The can was cooled down naturally to ambient temperature. During the process a mass loss of 2.3 wt.% was
observed, this was consistent with that measured during the bench scale test (2.5 wt.%).

The In-Can Melter trial showed this process could be successfully utilised for the vitrification of ash coming from the incineration of organic waste from glove boxes in the nuclear industry achieving a waste loading of 50 wt.%. This trial also made it possible to begin the technical investigation required to form pellets to enable processing of very powdery solids, avoiding excessive formation of dust.

Further detail of this test program is given in report D3.3 "SHIVA and In-Can Melting technologies and demonstration test trials” CEA, October 2018.
4.3 Thermal Gasification Trials (VTT)

Thermal gasification is a technology most often used to produce energy from carbon containing fuels. The process is used to produce fuel gas for direct combustion in power plants, industrial kilns and gas turbines etc. Gasification enables the production of a combustible gas from different wastes and following gas clean-up, the product gas can be combusted as a clean gas. This technology can be applied to utilise a variety of different wastes for energy production and can be applied to the treatment of certain radioactive waste. In addition to the production of a clean combustible gas, the process generates bottom ash from the fluidised bed reactor and filter dust from the off-gas abatement system as by-products.

The gasification test trials reported here were carried out with an atmospheric pressure pilot-scale Circulating Fluidised-Bed (CFB) gasification test rig at Bioruukki - VTT’s Piloting Center.

Figure 3 Pilot-scale Circulating Fluidised Bed (CFB) Gasification Test Rig

The gasification test trials were carried out with unused organic ion exchange resin (IER) which was impregnated with CsCl to simulate radio-Cs in a real spent IERs. Approximately 520 kg of IER was partially dried reducing the moisture content from 50 wt-% to about 40 wt-%. A measured amount of CsCl solution was added to the pre-dried batch of IER, stirred 1-2 hours before it was dried again resulting in a final moisture content of about 30 wt-%. Cs concentration was targeted to be 4 ppm.
A total of 325 kg of organic IER was treated during three test trial days in October 2018. The total duration of the trials was 26.5 hours. The average gasification temperature was 885-915°C, and the filtering temperature varied between 415 and 450°C. Inert Al2O3 (particle size of 0.18-0.25 mm) was used as a bed material in the CFB gasification reactor.

Efficiency of the removal of organic matter from the IER, i.e. carbon conversion, was calculated as conversion of feedstock carbon into the gaseous carbon compounds and tars in the product gas, which is conditioned further in the process. The verified carbon conversion to gas and tars was 92-96 wt-%, which confirms a successful conversion rate.

The solid residues can then be immobilised by applying different technologies. In these test trials, VTT applied Geo-polymerisation for immobilisation of the processed IER (removed filter dust). Samples of the products from Geo-polymerisation were taken for characterisation, this data is reported in WP4.

Further detail of this test program is given in report D3.4 “Gasification based waste treatment” VTT, 31-01-2019.
4.4 GeoMelt Trials (NNL)

NNL and Veolia Nuclear Services (VNS) have an operational In-Container Vitrification (ICV) system, “GeoMelt”, situated in NNL’s active rig hall in the Central Laboratory on the Sellafield site. The system is configured to take active feeds. GeoMelt is a batch treatment process which uses Joule-heating to vitrify waste materials and glass forming precursor chemicals (or frit) into a stable vitrified product. GeoMelt treatment encompasses the following processes; immobilisation or encapsulation of none volatile waste components into a glass matrix, thermal destruction of organic materials and abatement of volatile materials in an off-gas system. Two trials were carried out under THERAMIN.

Figure 3 GeoMelt rig as installed in NNL Central lab.

THERAMIN 01

This was a demonstration of the thermal treatment of sea dump drums. The waste surrogate comprised 36 metal tins loaded with grout, aluminium metal and PVC. 25 MBq of Cs-137 was added into the waste mix. Fluxed soil was the main glass forming material. The test was carried out on 13/06/18. In total 279 kg of waste materials were processed in 15 hours at a rate of 18.6 kgh⁻¹. This included feeding an additional 61 kg of fluxed soil via the feed while melt system. The maximum temperature and power were 1400°C and ~70 kW respectively. On cooling the product was removed and weighed. The product mass was ~800 kg including a
glass monolith which weighed 236 kg. Approximately 1 kg of particulate was recovered from the sintered metal filter (SMF).

Active analysis data indicated a Cs-137 retention rate in the glass product of 76%. This retention rate could be improved following optimisation of the formulation and operation. Some residual metal encountered when core drilling suggests that not all of the cans melted and incorporated. However, the residual un-melted metal was encapsulated. Radioactivity analysis and the chemical analysis showed that the product was well mixed and homogenous.

This was a successful test which produced a vitrified monolith which contained all the waste materials except for a small amount of particulate carry over which was within expected norms. A waste loading of 49% was achieved.

**THERAMIN 02**

This was a demonstration of co-processing a blend of Corroded Magnesium Sludge (CMgS) and clinoptilolite ion exchange material. Contaminants were present plus glass formers. In total 195 kg of material was presented for treatment. Radio isotopes Cs-137 (25 MBq) and Sr-85 (16 MBq) were added into the waste mix.

A power application fault required the test to be terminated and the melter allowed to cool, before a restart procedure was put in place. This process test was re-started and 238 kg of waste materials were processed in 15 hours at a rate of 15.9 kg h⁻¹. The maximum temperature and power were 1260°C and ~70 kW respectively. On cooling the product was removed and weighed. The product mass was ~800 kg including a glass monolith which weighed 197 kg. Less than 1 kg of particulate was recovered from the SMF.

Analysis data indicated a Cs-137 retention rate in the glass product of 76%, similar to TH-01. Both the radioactivity analysis and the chemical analysis showed that the product was well mixed and homogenous.

This was also a successful test which produced a homogenous vitrified monolith which contained all the waste materials except for a small amount of particulate carry over which was within expected norms. A waste loading of 72% was achieved.

*Further detail of this test program is given in report D3.5 “Test Report on Demonstration of Geomelt Technology for THERAMIN Project”, issue 2, NNL, August 2019*
QR showing video of TH-01

QR Showing video of TH-02
4.5 **Hot Isostatic Pressing (HIP) Trials (NNL and USFD)**

These trials were carried out to demonstrate the efficacy of hot isostatic pressing for the immobilisation of corroded magnesium sludge as a surrogate for Corroded Magnox Sludge. The trials also demonstrated the potential of co-immobilisation of clinoptilolite an ion exchange medium used on the Sellafield site.

Production of wasteforms using HIP, requires a pre-treatment step in which water, organics and other volatiles are removed using calcination process after which glass/ceramic precursor is added. The mixture is then introduced into a HIP can which is subsequently evacuated of air and sealed before placing into the HIP where it is subject to temperature and pressure resulting in a consolidated wasteform suitable for ongoing storage and ultimate disposal.

The demonstration of hot isostatic pressing was carried out in two facilities, the HIP installed at UFSD which has a hot zone of 125mm by 75mm has the capacity to treat feeds containing uranium oxide/metal and the larger HIP installed at the NNL Workington Laboratory has a hot zone of 400mm by 250mm processing non-active feeds only. The use of the two facilities enabled the demonstration of treatment of actinide containing feeds and the scalability of this process.

![Figure 4 NNL large HIP (l) USFD HIP (r)](image)

**HIP trials (NNL)**

Two surrogates for corroded Magnox sludge and clinoptilolite were prepared at NNL; a formulation containing 33% CMgS, 57% clinoptilolite and 10% alkali borosilicate glass frit and one containing 45% CMgS, 45% clinoptilolite and 10%
borax. The clinoptilolite was pre-loaded with stable Cs and CeO$_2$ was added as a surrogate for actinides.

Calcination was carried out at 950 °C for 3 hours, some material was loaded into cans and prepared for HIP at NNL and a smaller amount was sent to Sheffield where uranium oxide was added to one of the batches and materials prepared for small scale HIP.

The large HIP cans were subjected to a simultaneous application of a pressure of > 75MPa and a temperature of 1250°C for 2 hours. Both HIP trials were successfully consolidated, the shrinkage being evidence that the can has retained its seal throughout the HIPing process. The HIP cans were then sampled for characterisation in WP4.

**Small scale HIP trials (UFSD)**

A study investigating formation of magnesium borosilicate glasses was also carried out. Waste simulants were prepared using a combination of magnesium metal and magnesium hydroxide to simulate the Magnox sludge waste stream located on the Sellafield site. U$_3$O$_8$ was used to simulate the actinide oxides present in the waste.

The final waste form investigated was magnesium hydroxide and alkali borosilicate (ABS) glass batched with and without U$_3$O$_8$. To produce the required wasteform, the glass frit to Mg(OH)$_2$ ratio was targeted at 18 %.

For all samples discussed cycle conditions were 1250 °C and 100 MPa with a 2-hour dwell at peak temperature and pressure.

All canisters were visually confirmed to have been successfully consolidated. No loss of containment was observed and the canisters remained hermetically sealed (no weld failures). Characterisation of waste forms was carried out in Work Package 4.

*Full detail of this test program is given in report “Hot Isostatic Pressing (HIP) demonstration NNL/USFD” WP3.6, 28/01/19.*
4.6  VICHRI Studies. (VUJE)

Vitrification technology has been chosen for the treatment and conditioning of a liquid radioactive waste material known as “chrompik”, main contaminant $^{137}$Cs. The owner and operator of the vitrification facility is JAVYS, Inc. Jaslovske Bohunice, Slovakia.

During the period 1996 to 2001, the entire volume of chrompik I (18.5 m$^3$) was conditioned by vitrification technology on VICHRI facility with 211 glass products manufactured with total volume of 1.53 m$^3$.

The VICHRI vitrification line is a discontinuous batch process. Processing one batch of 50 dm$^3$ of chrompik takes 24 hours. Dilute liquid waste is initially concentrated before added to glass frit in an inductively heated melting crucible. Water is evaporated at $\sim$130°C before heating to a maximum temperature of 1050°C over a period of approximately 3 hours to produce a vitrified product. Cr salts are reduced to Chromium III Oxide ($\text{Cr}_2\text{O}_3$) which is soluble in the glass matrix. The resultant vitrified product is poured into a storage container by opening a pour valve using a plunger mechanism. Two pours are added to one container. Off-gas from the vitrification process is drawn into an off-gas treatment system producing a condensate which is decontaminated via a sorption column prior to further treatment.

Figure 6. Model of vitrification facility
Vitrification of Chrompik III.

Due to the higher Cs-137 contamination levels associated with chrompik III, the VICHR vitrification line required several modifications to improve the vitrification process.

The scope of work undertaken in this WP3 THERAMIN project was to report on the following ongoing activities:

- Lab scale studies to optimise the vitrification conditions, glass chemistry and to minimise Cs-137 volatilisation for processing chrompik III
- Technological modifications to the vitrification line prior to processing chrompik III
- Full-scale glass making trials with low active chrompik surrogates followed by full-scale active trials using real chrompik waste.

The treatment of the chrompik III commenced on the modified VICHR facility after trials in 2016.

Chemical analyses of chrompik III showed that the level of soluble Cr in chrompik III is 1% that in the original solution and much lower than in chrompik I. This suggests that a significant amount of chromate was reduced into insoluble compounds of Cr(III) which subsequently settled in a sludge phase at the bottom of the chrompik storage tank. Due to this fact, reduction of Cr (IV) to Cr (III) was not required, so no difficulties were expected in using LKU frit during vitrification. The use of chemical additives to absorb Cs and thereby minimise Cs losses from the melter crucible during drying and melting was investigated.

Work was required to minimise the separation of Chromium salts from the glass frit during drying in the crucible. Small scale laboratory melts led to a modified drying and melting temperature profile. Glass chemistry was modified to achieve a glass viscosity to facilitate pouring.

During full scale active trials Cs-absorption additives were seen to reduce the Cs-137 activity in the off-gas scrubber system 5-fold.

The outcome of lab scale studies and full-scale trials resulted in the following temperature regime for drying and melting:

- Drying phase - evaporation of water up to 95°C with a heating rate of 10°C/min.
- Chrompik decomposition phase - heating rate 10°C/min to a temperature of 650°C, holding time 2h.
- CO₂ release phase - heating rate 10°C/ min. After reaching a temperature of 800°C holding time 2h.
- Vitrification phase - heating rate 10°C/ min. After reaching a temperature of 960- 990°C, a time of 2 hours.
- After the above temperature regime steps have elapsed, the melting process is complete, and the melt can be drained from the melting crucible.
The glass manufactured during the trials poured from the melter without difficulty and under visual inspection typical of a good vitrified product. The vitrified product meets the local quality requirements for storage and disposal. The glass samples produced from chrompik III surrogate solution will be characterized in the framework of THERAMIN WP4.

In summary, Thermal treatment of chrompik III was successfully demonstrated using the vitrification facility in NPP A1 Jaslovske Bohunice, Slovakia. Work undertaken to reduce Cs-137 volatility was successful when tested at full scale. Modifications to the glass chemistry and to the heating profile resulted in a satisfactory glass product and reduced Cs-137 doses in the off-gas system.

*Further detail of this work program is given in VICH Technology D3.7 Report, VUJE, 23.5.2019*
5. Assessment of Attributes for Deployment

The successful trials carried out under this programme of work have necessarily been limited by the availability of the demonstrators involved and the limitations placed on their operation. Each trial is effectively a one-off demonstration and does not represent the level of maturity that may be achievable should a dedicated development programme be undertaken against a specific goal identified by a site operator with a need to treat an inventory of waste into a form suitable for ongoing storage and ultimate disposal.

Nonetheless, the success of these trials has shown the range of waste streams that can be treated and processed into a form suitable for safe storage and ultimate disposal, a conclusion which will be informed through WP 4.

Conceptual design of treatment plants aimed at a specified waste inventory on identified nuclear sites in differing regulatory regimes is beyond the scope of this project and rightly rests with waste owner. However, some qualitative information can be derived from these trials and associated knowledge of the technology operators which could inform potential waste owners as to the benefits of thermal treatment for their wastes.

The information requested by WP2 for the value assessment is shown in table 2 and covers technologies which could be made commercially available.
Table 2 Qualitative assessment of technologies demonstrated against specific attributes
6. Conclusions

A range of waste streams from across the EU have been identified and surrogates selected for the demonstration of thermal treatment using existing technologies installed in member states’ facilities.

The following demonstrations were successfully carried out:

- Thermal treatment of a mix of organic and inorganic ion exchangers using the SHIVA at CEA producing a vitrified waste form.
- The In-Can Melter at CEA has vitrified ash arising from the incineration of organic waste from glove boxes in the nuclear industry.
- The Geomelt ICV installed at NNL Sellafield has vitrified two waste feeds: a surrogate for a conditioned waste, sea dump drums and a surrogate for a sludge/ion exchange media mix.
- The Pilot-scale Circulating Fluidised Bed (CFB) Gasification Test Rig at VTT has treated organic ion exchange resins, the residue from which has been immobilised using a geopolymer.
- Hot isostatic pressing has been deployed to treat and immobilise Magnox sludge and clinoptilolite surrogates. Small scale trails have demonstrated that uranium can be immobilised in the wasteform using this technique.
- Trails at VUJE have demonstrated the vitrification of chrompik III using the vitrification facility at NPP A1 Jaslovske Bohunice, Slovakia.

It is important to recognise that these trials were carried out on a one-off basis and as such their operation has not been optimised.

Samples from the trials have been provided to WP 4 to support testing for general suitability for storage and disposal.