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The University Of Sheffield.

The Abdus Salam International Centre for Theoretical Physics

International experience on vitrification

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Joint ICTP-IAEA International School on Nuclear Waste Vitrification

23 - 27 September 2019
Trieste, Italy

Imperial College London

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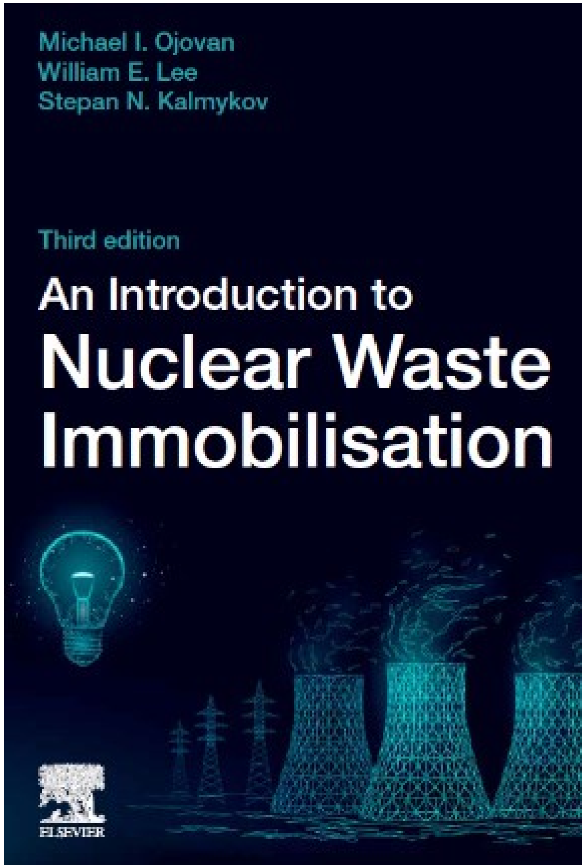

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I. Background

IAEA
International Atomic Energy Agency
Atoms for Peace and Development

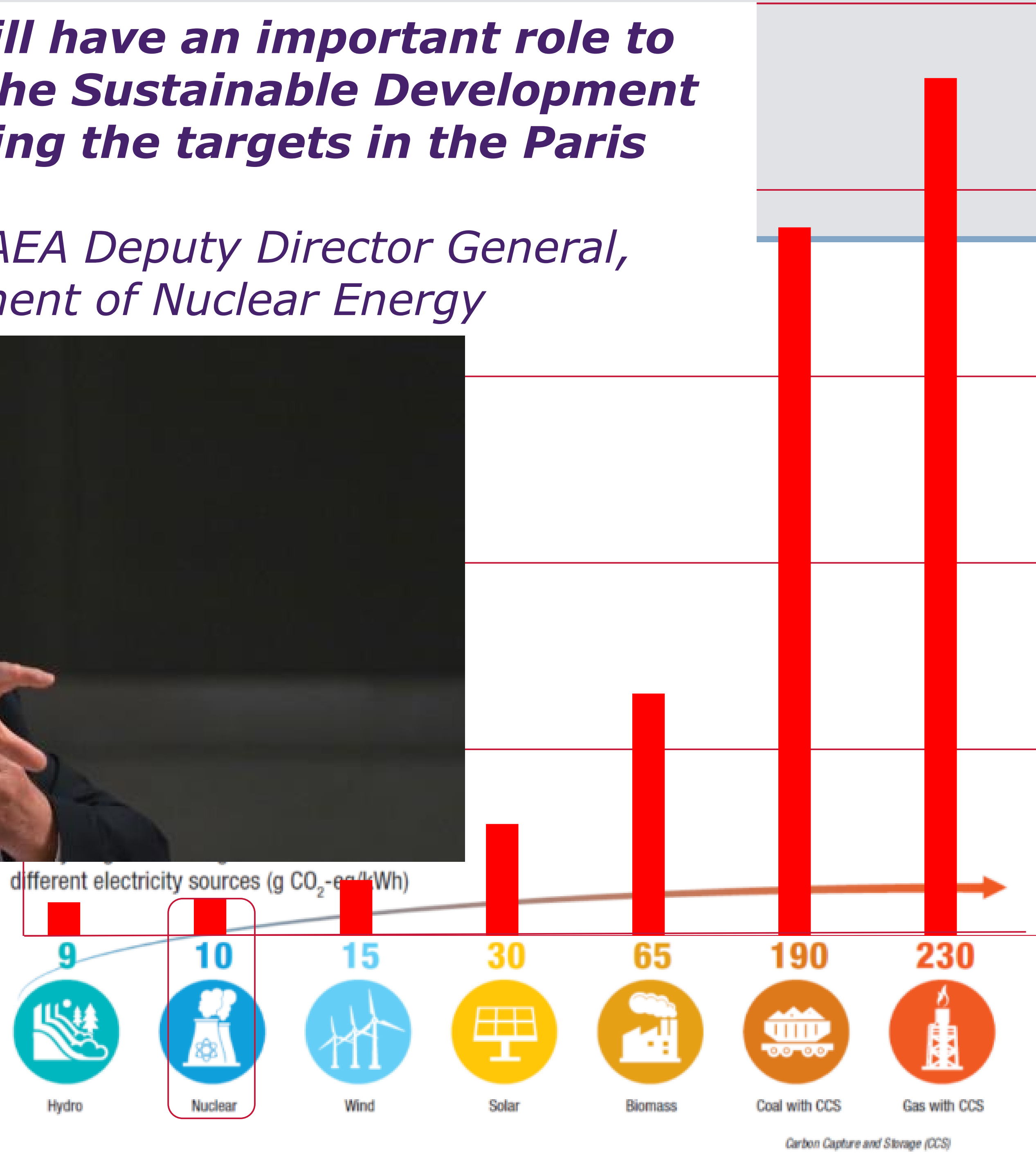
"It is difficult to see how the world will be able to meet the challenge of securing sufficient energy, and mitigating the impact of climate change, without making more use of nuclear power."

Yukiya Amano
IAEA Director General

The IAEA is the world's centre for cooperation in the nuclear field and seeks to promote the safe, secure and peaceful use of nuclear technologies.

"Nuclear power will have an important role to play in achieving the Sustainable Development Goals and in meeting the targets in the Paris Agreement."

Mikhail Chudakov, IAEA Deputy Director General, Head of the Department of Nuclear Energy



Life cycle GHG emissions, $g(CO_2)/kWh$

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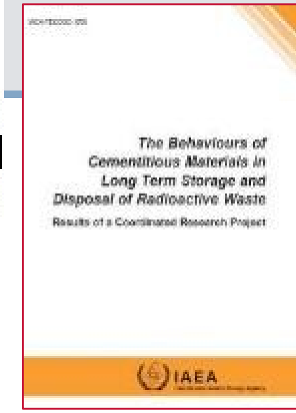
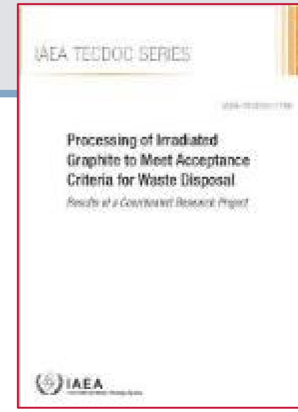
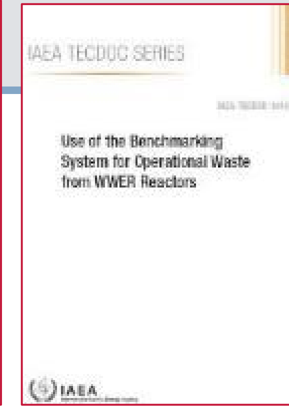
M Ojovan at IAEA, 2011-2018

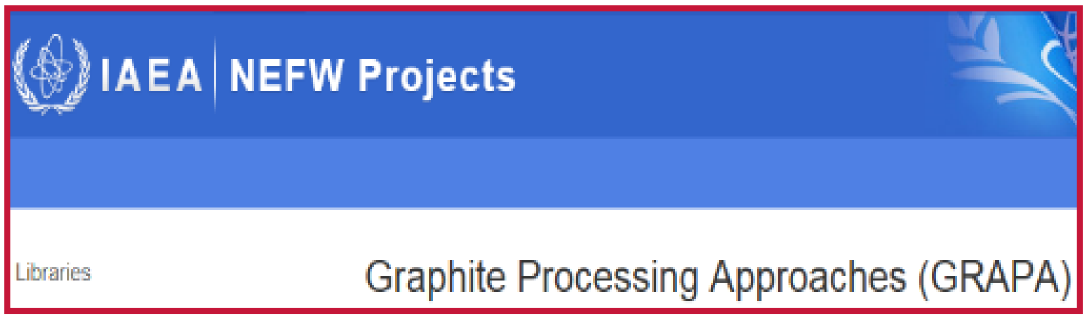
IPN

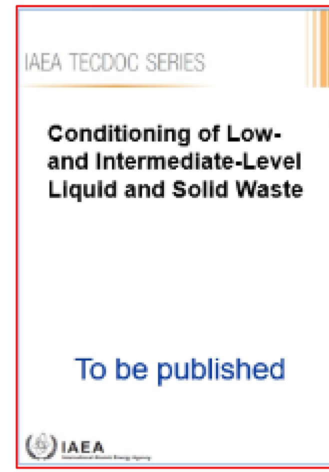
IMM











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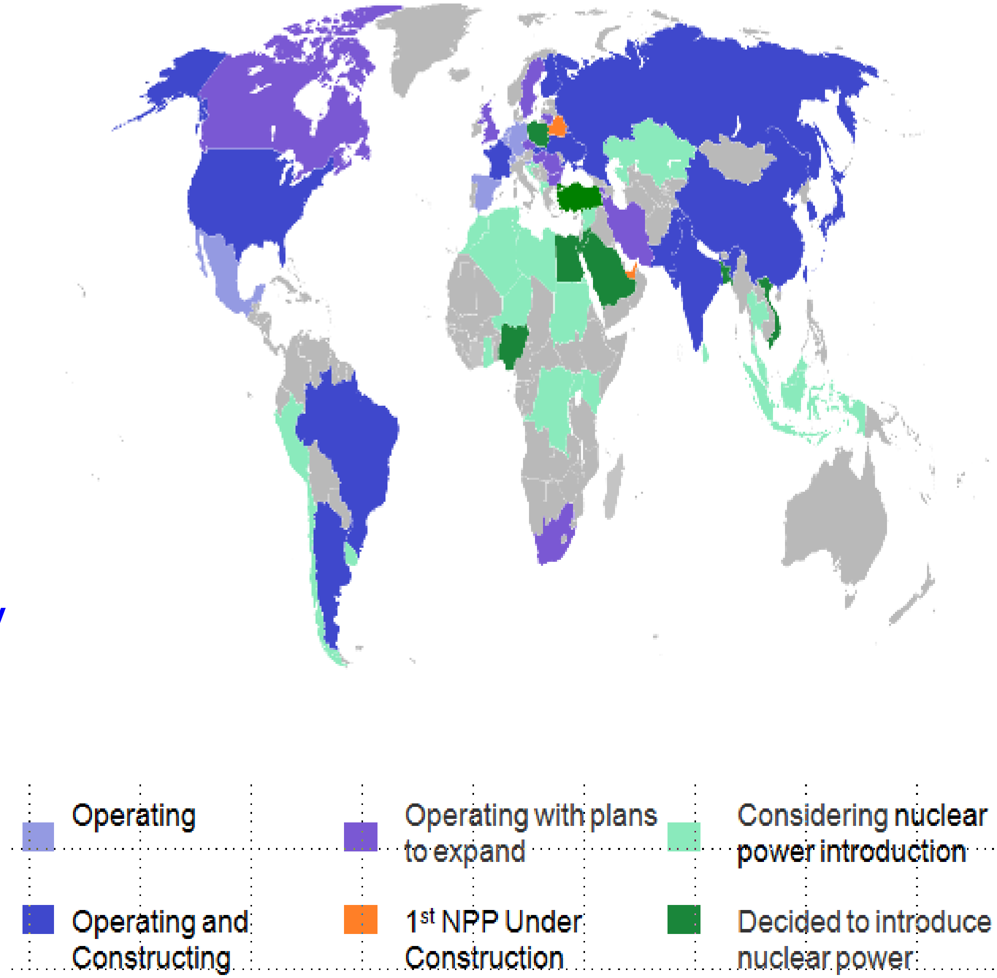
Unchanged drivers behind the nuclear power

- **Global energy demand is set to grow :** Nuclear power expands supply options
- **Environmental pressures are rising:** Nuclear power has low life-cycle GHG emissions
- **Energy supply security back on the political agenda:** Nuclear power contributes to energy security
- **Reliable base load electricity at predictable and affordable costs:** Nuclear power offers stable and predictable generation costs based on low resource costs



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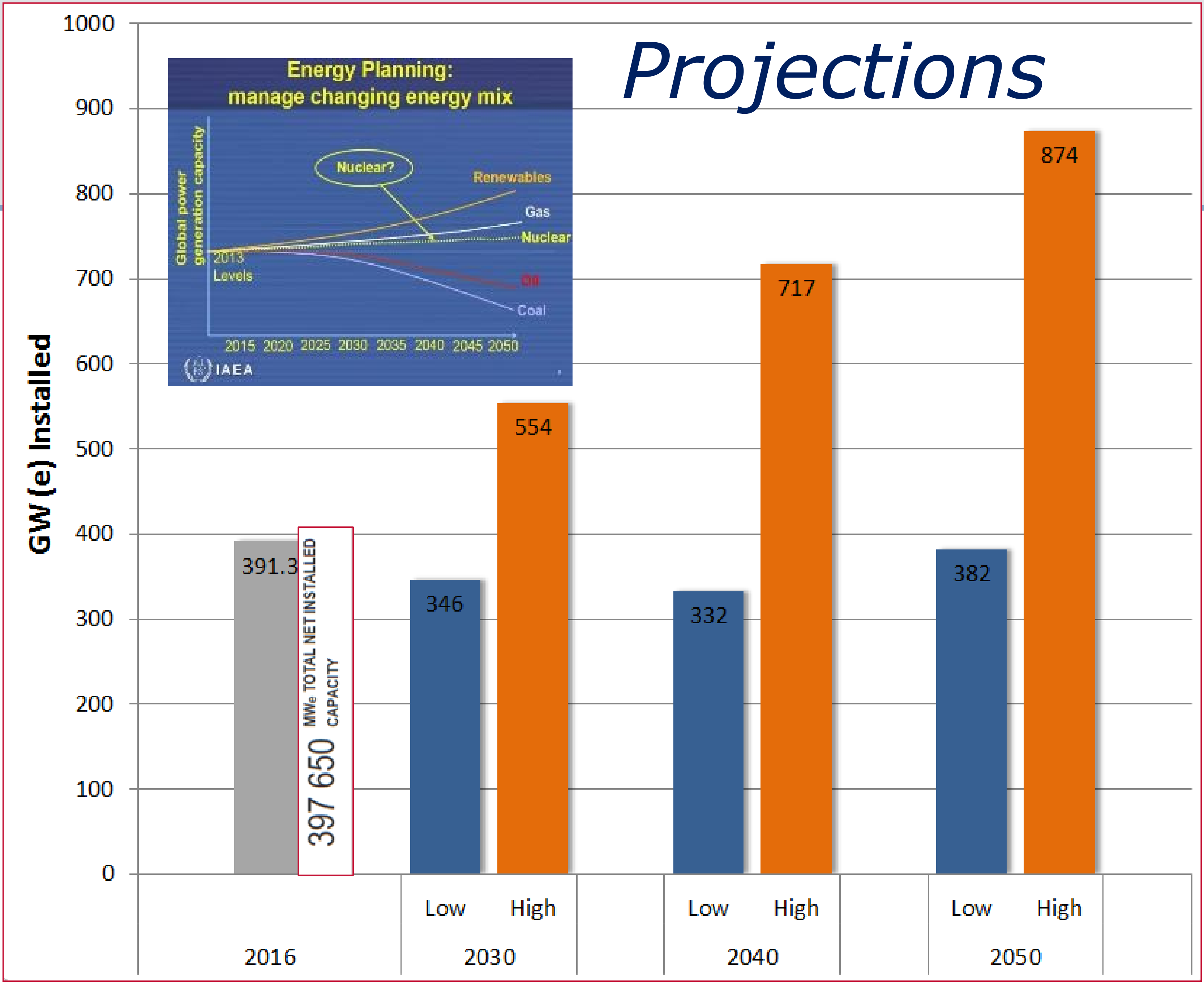
Projections



IAEA | PRIS Power Reactor Information System

World Statistics | Country Statistics | Publications | Glossary | About PRIS

PRIS

The Database on Nuclear Power Reactors

The Power Reactor Information System (PRIS), developed and maintained by the IAEA for over five decades, is a comprehensive database focusing on nuclear power plants worldwide. PRIS contains information on power reactors in operation, under construction, or those being... **READ MORE »**

Registered User ENTRY | How to Register

SHORTCUTS

Select Country

Select Reactor

- 2019: Nuclear Power Reactors in the...
- 2018: Operating Experience with NPP...
- PRIS STATISTICS – User's Manual

OVERVIEW

Current Status:

449 NUCLEAR POWER REACTORS IN OPERATION

397 650 MWe TOTAL NET INSTALLED CAPACITY

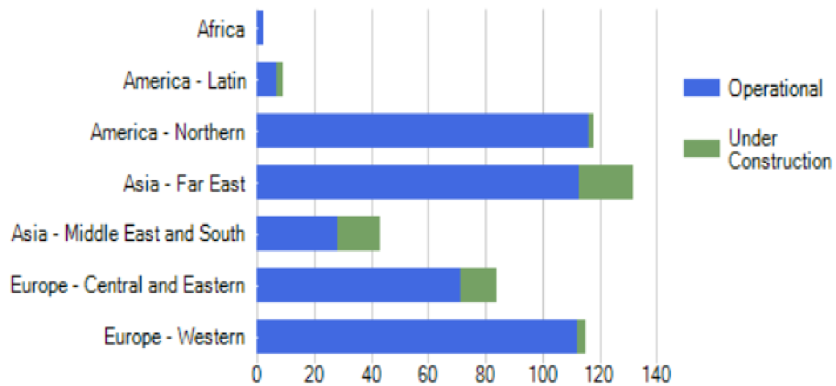
54 NUCLEAR POWER REACTORS UNDER CONSTRUCTION

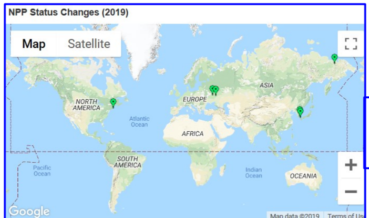
55 364 MWe TOTAL NET INSTALLED CAPACITY

18 108 REACTOR-YEARS OF OPERATION

Regional Distribution of Nuclear Power Plants

(Click on the chart for more statistics)

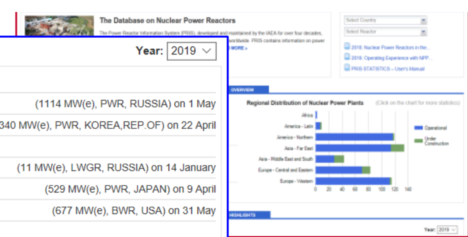




https://www.iaea.org/pris/

Year: 2019

New connections to the grid	
NOVOVORONEZH 2-2	(1114 MW(e), PWR, RUSSIA) on 1 May
SHIN-KORI-4	(1340 MW(e), PWR, KOREA,REP.OF) on 22 April
Permanent shutdowns	
BILIBINO-1	(11 MW(e), LWGR, RUSSIA) on 14 January
GENKAI-2	(529 MW(e), PWR, JAPAN) on 9 April
PILGRIM-1	(677 MW(e), BWR, USA) on 31 May
Construction starts	
KURSK 2-2	(1115 MW(e), PWR, RUSSIA) on 15 April



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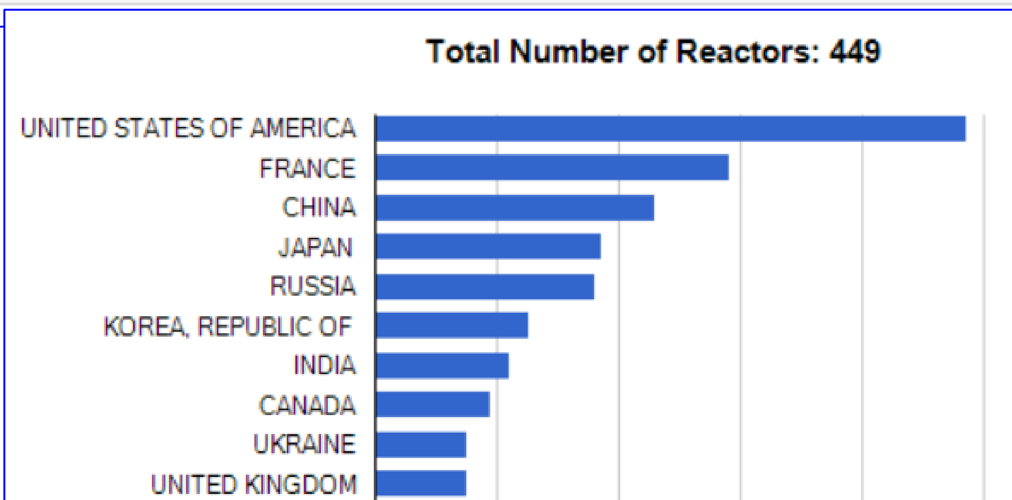
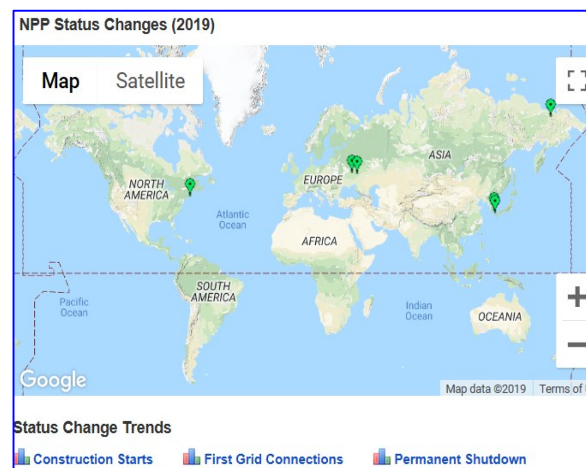
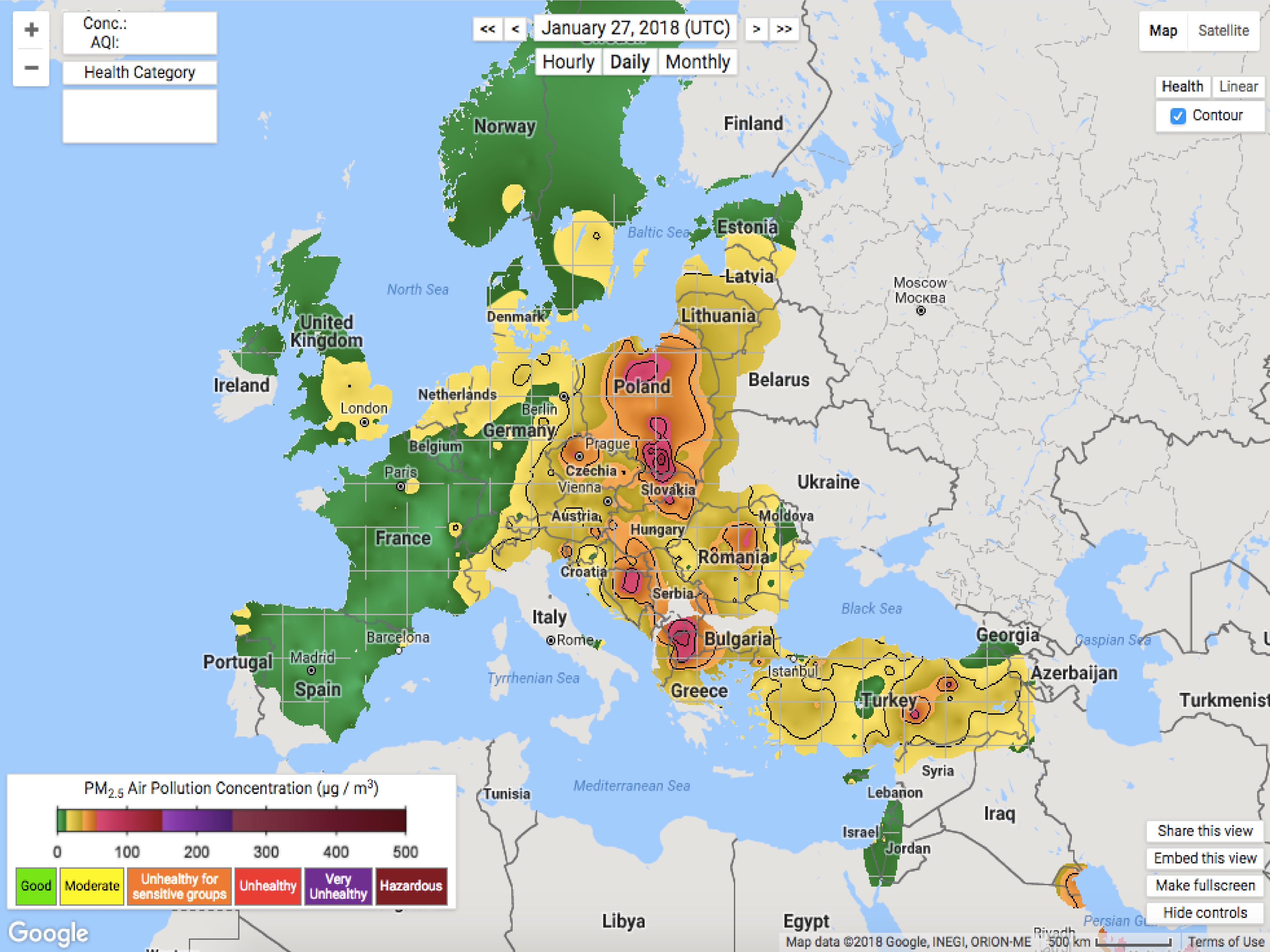
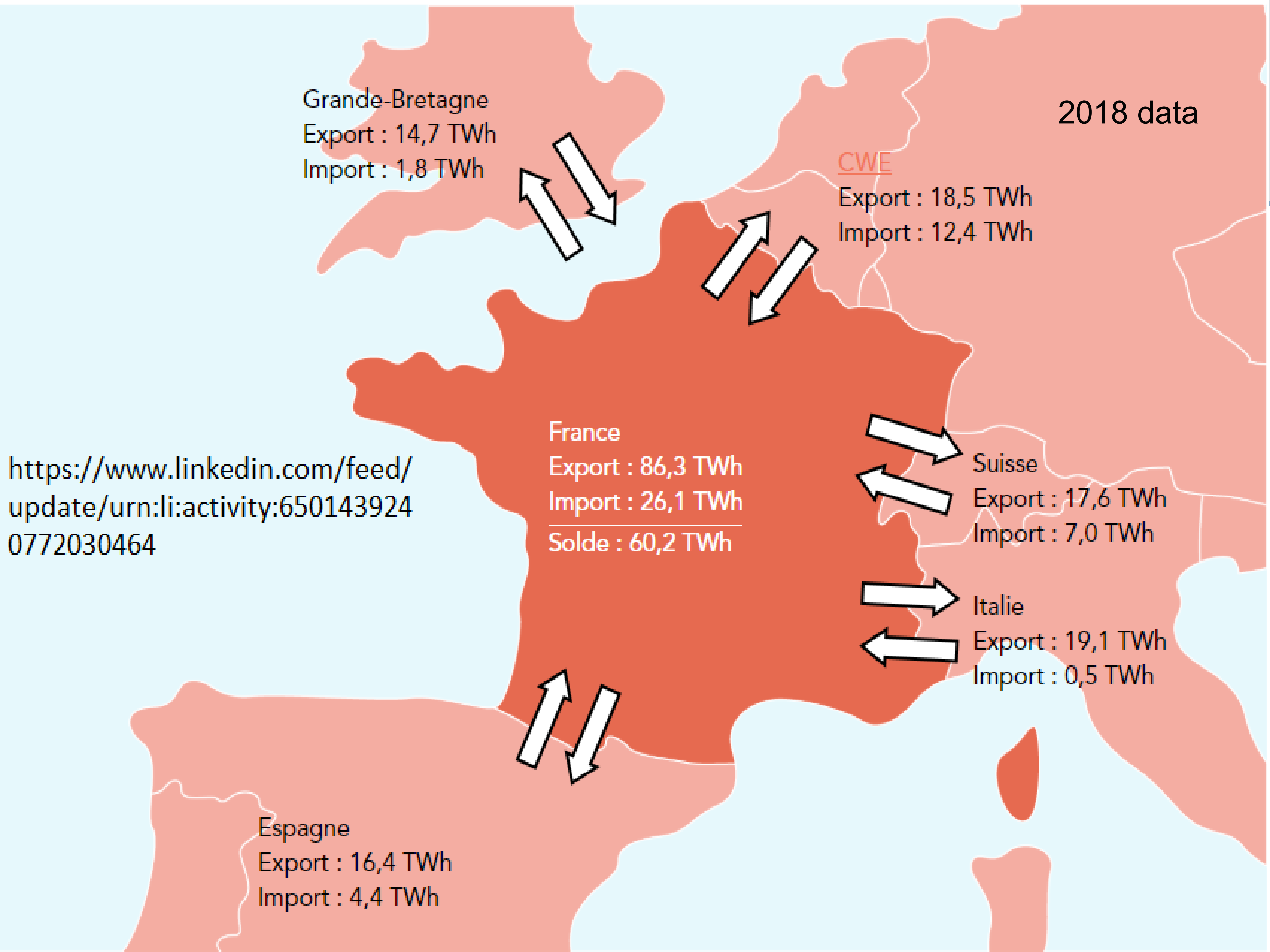
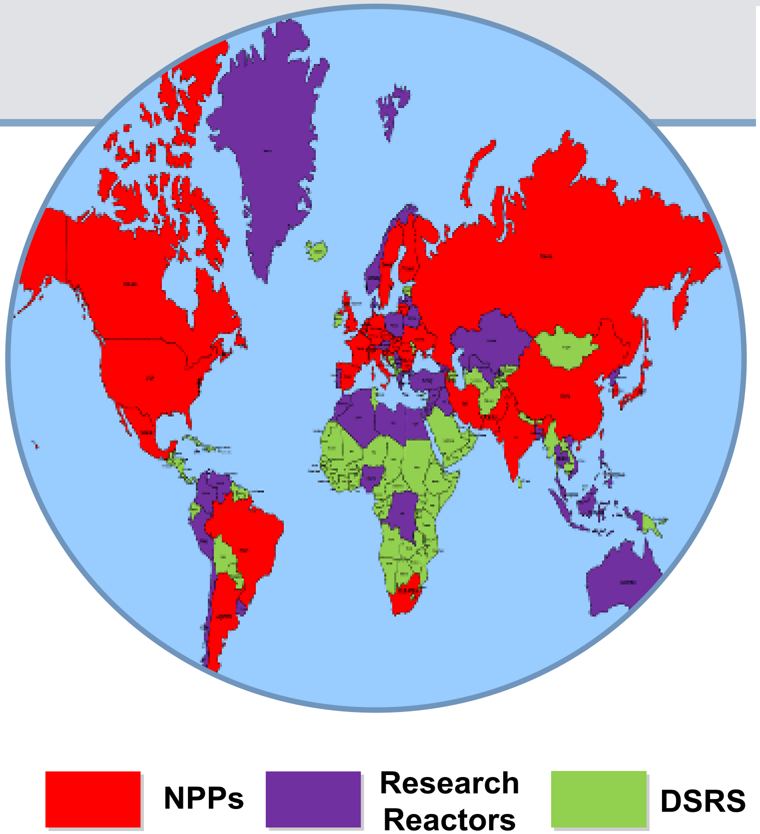




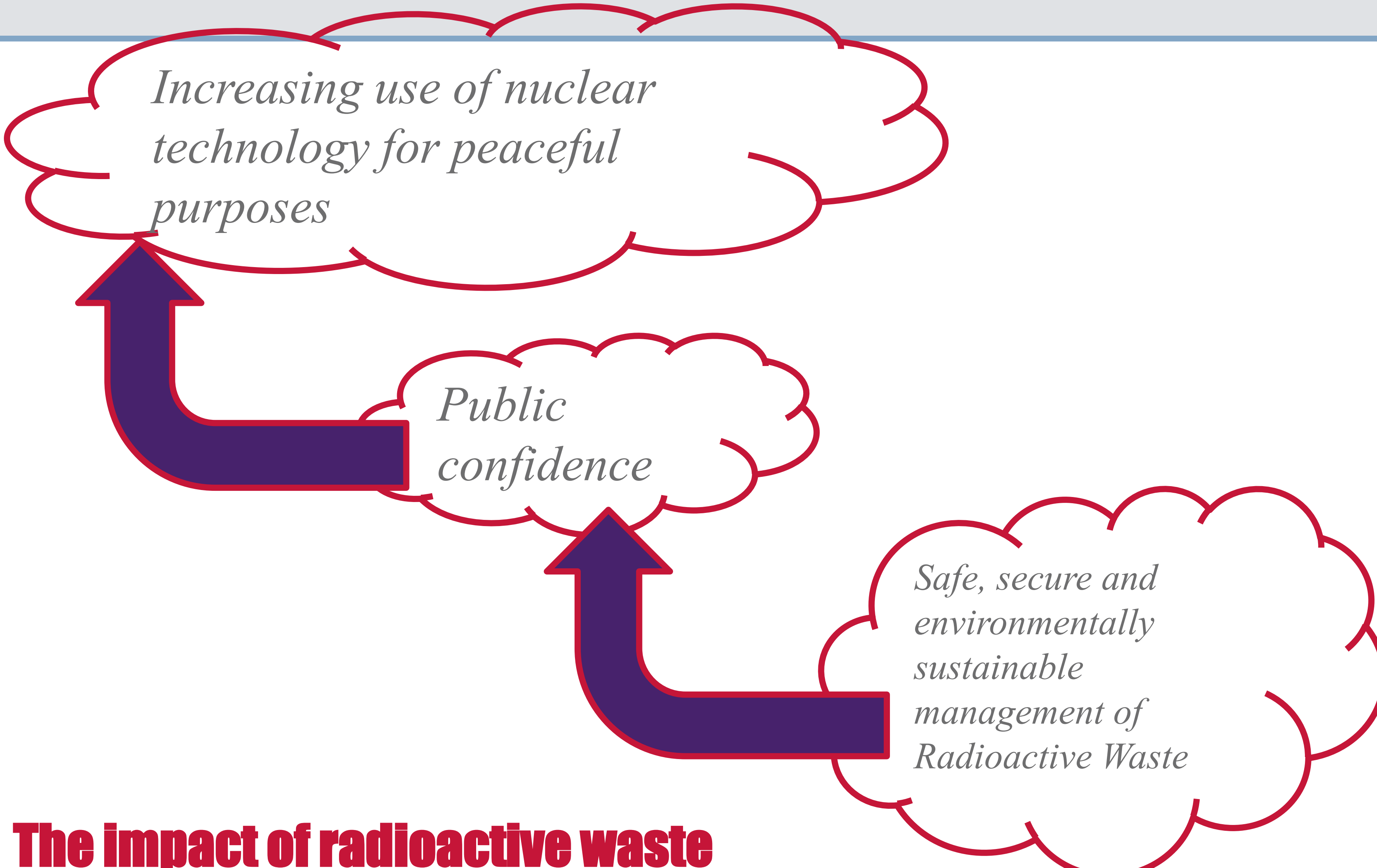

Conc.:
AQI:
Health Category
January 27, 2018 (UTC)
Hourly
Daily
Monthly
Map
Satellite
Health
Linear
Contour
Norway
Finland
Estonia
Latvia
Lithuania
Baltic Sea
North Sea
Denmark
United Kingdom
Ireland
London
Netherlands
Berlin
Germany
Belgium
Poland
Belarus
Moscow
Москва
Prague
Czechia
Vienna
Slovakia
Ukraine
Paris
France
Austria
Hungary
Moldova
Romania
Croatia
Serbia
Italy
Rome
Bulgaria
Black Sea
Georgia
Caspian Sea
Azerbaijan
Turkmenist
Barcelona
Madrid
Portugal
Spain
Tyrrhenian Sea
Istanbul
Greece
Turkey
Syria
Lebanon
Israel
Jordan
Iraq
Tunisia
Mediterranean Sea
Libya
Egypt
PM2.5 Air Pollution Concentration (μg / m3)
0
100
200
300
400
500
Good
Moderate
Unhealthy for sensitive groups
Unhealthy
Very Unhealthy
Hazardous
Share this view
Embed this view
Make fullscreen
Hide controls
Google
Map data ©2018 Google, INEGI, ORION-ME
500 km
Terms of Use


2018 data
Grande-Bretagne
Export : 14,7 TWh
Import : 1,8 TWh
CWE
Export : 18,5 TWh
Import : 12,4 TWh
France
Export : 86,3 TWh
Import : 26,1 TWh
Solde : 60,2 TWh
Suisse
Export : 17,6 TWh
Import : 7,0 TWh
Italie
Export : 19,1 TWh
Import : 0,5 TWh
Espagne
Export : 16,4 TWh
Import : 4,4 TWh
https://www.linkedin.com/feed/update/urn:li:activity:6501439240772030464

II. Nuclear waste



- Nuclear energy has a potentially exceedingly valuable role to play in securing electricity supplies, and can do it **safely**;
- When integrated with other power sources it gives both long-term security of supply against economic and political threats, and short-term load following capabilities with maximised efficiency;
- We need to build the trust of the public and an important way to do this is to demonstrate safe decommissioning of existing nuclear plants and safe management of all radioactive waste.



The impact of radioactive waste

Table 10.17 Global estimate of radioactive waste inventory for 2014

Waste class	Waste in storage ×10^3, m^3	Waste disposed of ×10^3, m^3
Very low level waste	173	273
Low level waste	56,703	65,192
Intermediate level waste	8745	10,589
High level waste	2745	72

An estimate of global radioactive waste inventory is given in Table 10.17 (IAEA, 2015). The estimate for very LLW (VLLW) is much lower than for LLW because many countries do not use a VLLW waste class. The annual accumulation of processed HLW is fairly constant, at an average accumulation rate of ~850 m^3/y worldwide (not including SNF).

Disposal

The generally preferred approach is to concentrate the waste and to contain the radionuclides in it by means of a waste form and waste container followed by disposal in an appropriate repository.

The effectiveness and safe isolation of radioactive waste depends on the performance of the overall disposal system which consists of three major components, namely:

I. The site (the host rock and surrounding geological media representing natural barriers aiding waste isolation);
II. The repository (the facility into which waste packages are emplaced for disposal, including any engineered barriers); and
III. The waste package (the wasteform in any suitable container).

Only waste packages, which comply with so called "waste acceptance criteria" (WAC) are accepted for disposal.

Radioactive Waste Management

- Nuclear Applications
- Nuclear Facility Operations
- Decommissioning
- Environmental Remediation
- DSRS

→ WASTE →

Predisposal → Disposal

Processing:
- Characterization
- Sorting, Segregation, Size Reduction & Decontamination
- Treatment
- Immobilization and/or Packaging

Storage

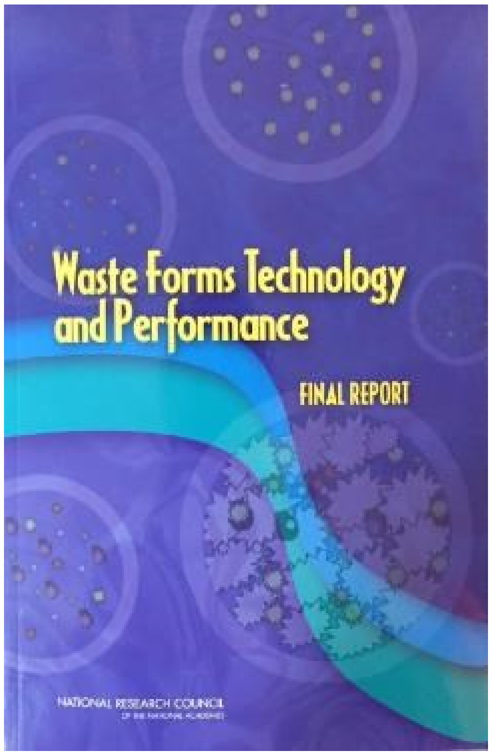


TABLE 2.1 Principal Waste Streams, Waste Forms, and Disposition Pathways for the DOE-EM Cleanup Program

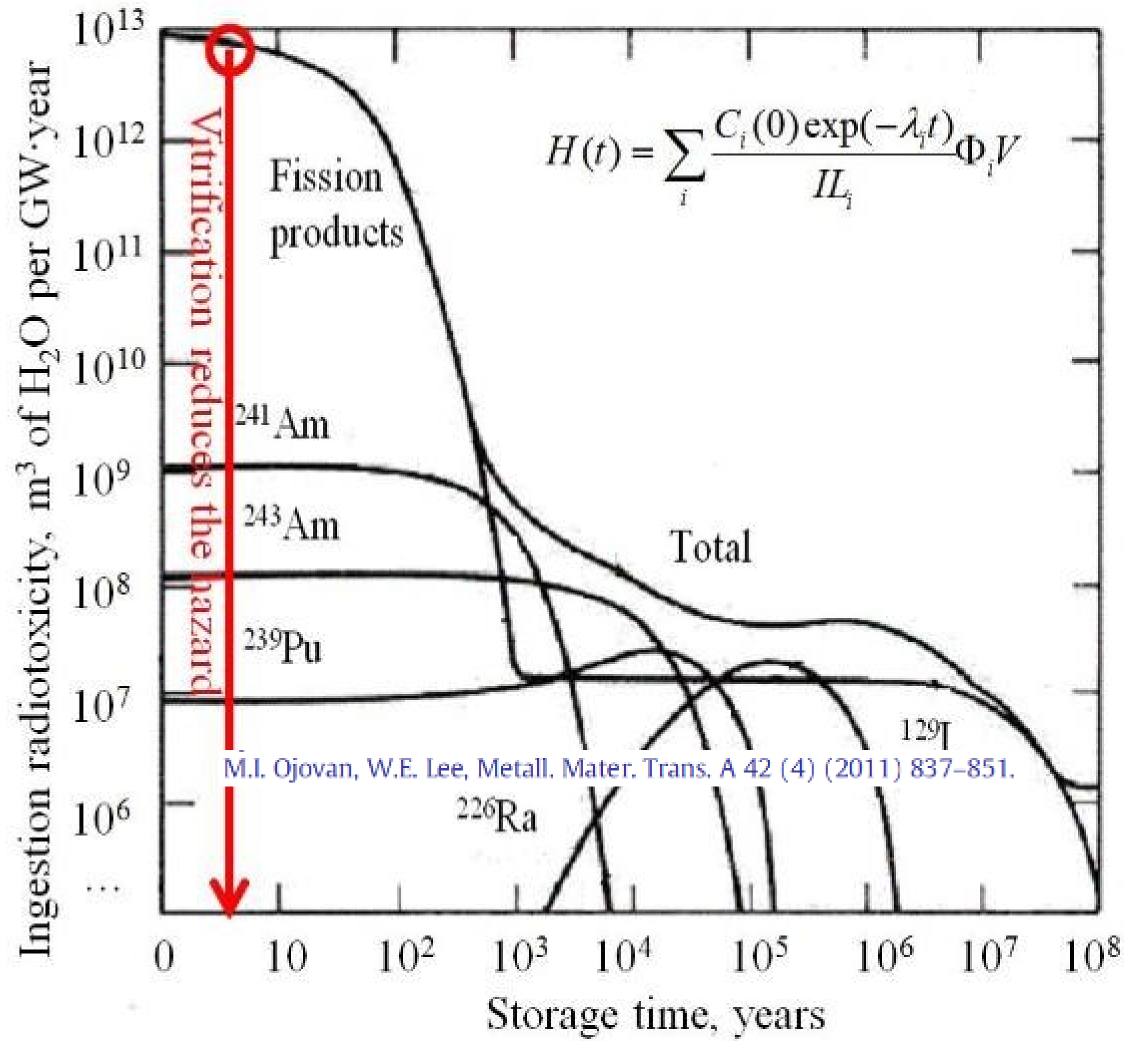
Waste Stream	Approximate Quantities	Current Principal Waste Forms[a]	Likely Disposition Pathways
Spent nuclear fuel	2,400 MTHM	As is[b]	Deep disposal (Federal repository)
High-level waste			
Tank waste	340,000 m^3	HAW: Glass LAW: Grout, glass, other	HAW: Deep disposal (Federal repository) LAW: Shallow disposal
Bin waste	4,400 m^3	Glass-ceramic	Deep disposal (Federal repository)
Transuranic waste	164,000 m^3	As is[c]	Deep disposal (WIPP)
Low-level waste (including mixed LLW)	1,400,000 m^3	LLW: As is[d] Mixed LLW: Grout, other[e]	Shallow disposal
Mill tailings (byproduct waste)	> 2 million m^3	As is	Shallow disposal
Depleted uranium	737,000 MT	Uranium oxide	Shallow disposal
Plutonium and uranium residues	108 MT	MOX fuel Glass	Deep disposal (Federal repository)
Excess facilities[f]	5,200	As is for decommissioning waste	Shallow disposal for LLW; WIPP for TRU waste
Orphan waste streams			
Cs and Sr capsules	5 m^3	TBD[g]	TBD
Other	various	TBD	TBD

III. Nuclear waste vitrification

Vitrification is the world-wide accepted technology for the immobilization of high level radioactive wastes (HLW).

Glass can accommodate the range of constituents that are present in the waste into the glassy structure.

The excellent **durability** of vitrified radioactive waste ensures a high degree of environmental protection.



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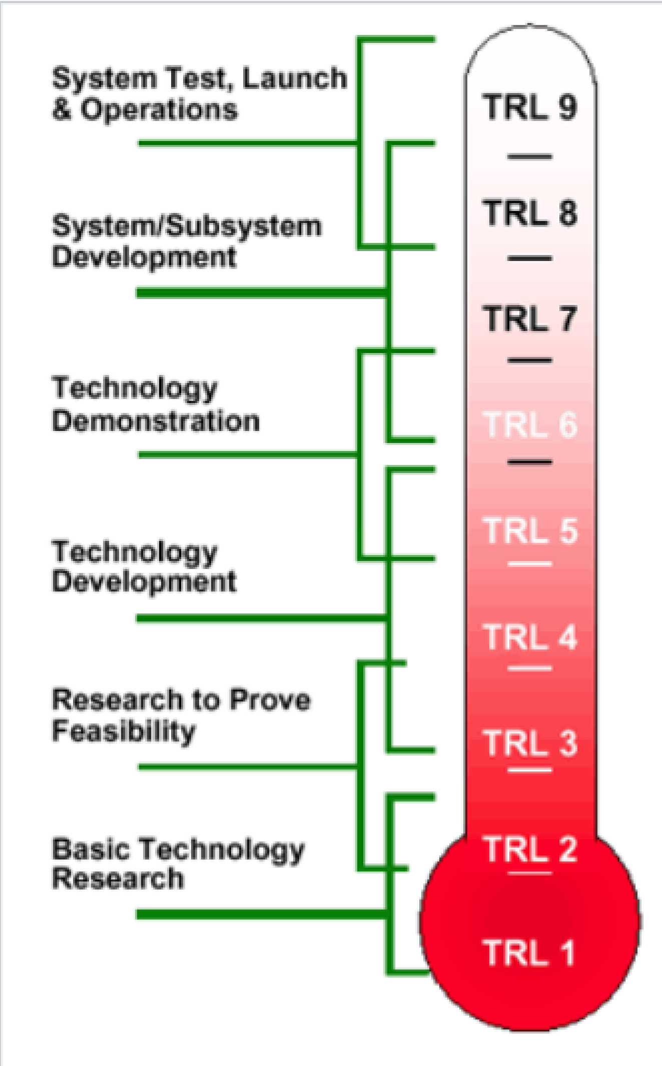
Waste vitrification is a mature technology at industrial scale.



NASA Technology Readiness Levels

- Continued advancements in glassy wasteforms and nuclear waste vitrification technologies will be keys in enabling widespread deployment of nuclear energy.
- Additionally, the pressing issues regarding hazardous waste disposal may also be effectively solved using vitrification technologies.
- Stricter regulations regarding waste characterization and land disposal for hazardous wastes will necessitate the need for effective waste treatment methods.

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Materials Research Society
DOI: 10.1557/adv.2017.209

Vitreous Materials for Nuclear Waste Immobilisation and IAEA Support Activities

Rebecca A. Robbins, Michael I. Ojovan

Table I. Operational data of vitrification programmes.

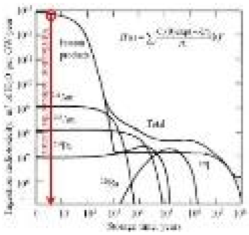
Facility	Waste type	Melting process	Operational period	Performance data
R7/T7, La Hague, France	HLW	IHC[1]	Since 1989/92	5573 tonnes in 14045 canisters to 2008, 6430 10^6 Ci
AVM, Marcoule, France	HLW	IHC	1978 – 2008	1138 tonnes in 3159 canisters, 45.67 10^6 Ci
R7, La Hague, France	HLW	CCM[2]	Since 2003	GCM: U-Mo glass
WVP, Sellafield, UK	HLW	IHC	Since 1991	1800 tonnes in 4319 canisters to 2007, 513 10^6 Ci
DWPF, Savannah River, USA	HLW	JHCM[3]	1996 – 2011	5850 tonnes in 3325 canisters, 40 10^6 Ci.
WVDP, West Valley, USA	HLW	JHCM	1996 – 2002	~500 tonnes in 275 canisters, 24·10^6 Ci
EP-500, Mayak, Russia	HLW	JHCM	Since 1987	~6200 tonnes to 2013, 643·10^6 Ci (P. Poluektov has earlier reported on 8000 tonnes and 900 10^6 Ci to 2009 [1])
CCM, Mayak, Russia	HLW	CCM	Pilot plant	18 kg/h by phosphate glass
Pamela, Mol, Belgium	HLW	JHCM	1985-1991	~500 tonnes in 2200 canisters, 12.1 10^6 Ci
VEK, Karlsruhe, Germany	HLW	JHCM	2010 – 2011	~60 m^3 of HLW (24 10^6 Ci)
Tokai, Japan	HLW	JHCM	Since 1995	> 100 tonnes in 241 canisters (110 L) to 2007, 0.4 10^6 Ci.
Radon, Russia	LILW	JHCM	1987-1998	10 tonnes
Radon, Russia	LILW	CCM	Since 1999	> 30 tonnes
Radon, Russia	ILW	SSV[4]	2001-2002	10 kg/h, incinerator ash
VICHR, Bohunice, Slovakia	HLW	IHC	1997-2001, upgrading work to restart operation	1.53 m^3 in 211 canisters
WIP, Trombay, India	HLW	IHPT[5]	Since 2002	18 tonnes to 2010 (110 10^3 Ci)
AVS, Tarapur, India	HLW	IHPT	Since 1985	
WIP, Kalpakkam, India	HLW	JHCM	Under testing & commissioning	
WTP, Hanford, USA	LLW	JHCM	Pilot plant since 1998. LLW/HLW vitrification plants under construction.	~ 1000 tonnes to 2000. Capacities: LLW plant 2 x 15 tonnes/day; HLW plant 2 x 3 tonnes/day
Taejon, Korea	LILW	CCM	Pilot plant, planned 2005	?
Saluggia, Italy	LILW	CCM	Planned	?

[1]IHC - Induction, hot crucible, [2]CCM – Cold crucible induction melter, [3]JHCM – Joule heated ceramic melter, [4]SSV - Self-sustaining vitrification, [5]IHPT – Induction heated pot type melter. Note that 1 Ci = 3.7 10^{10} Bq.

Vitrification technology

Vitrification is most suitable for aqueous radioactive wastes.

Waste vitrification is attractive because of:



- High capability of glass to immobilise various elements,
- Simple production technology adapted from glass production industry,
- Small volume of the resulting wasteform,
- High chemical durability of glasses in natural waters and
- High tolerance of glasses to radiation damage.

Vitrification of Radioactive Wastes

Nuclear energy continues to receive considerable attention as a potential solution to issues such as global warming. However, the management of radioactive nuclear waste remains an obstacle to a true 'Nuclear Renaissance.' James C. Marra* and Michael I. Ojovan** discuss.

Vitrification:

Vitrify: to convert (something) into glass or a glass-like substance, typically by exposure to heat.
Late Middle English: From French vitrifier or based on Latin vitrum 'glass'.

Glass International April 2014

Energy balance:

The vitrification process generally involves evaporating the liquid HLW, decomposing the volatile anions (e.g., nitrates) if not removed by calcining, fusing the waste with oxide glass additives, pouring the glass into canisters, and cooling to form the solid glass containing the waste.

The thermal energy required for the conditioning of **1 liter** of typical commercial HLW containing 120 g of salts is roughly **1.2 kWh**. The major portion of this energy (about 67%) is required for evaporation. The energies required for decomposition of nitrates and fusion amount to 20% and 13% of the total respectively.

The primary methods of heating:

Joule heating – the passing of a current through the resistive melt which generates heat within the melt as used in the Joule Heated Ceramic Melter (JHCM).

Low-frequency (≤ 4 kHz) **induction heating** – the use of a low frequency induction to couple to the melter body (Hot Wall Induction Melter and in-can melter).

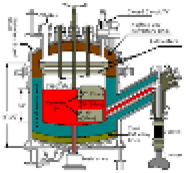
High-frequency (150 to 2,000 kHz) **induction heating** – the use of radio frequency to induce current directly into the glass melt which causes a Joule-heating effect.

Resistance heating – heating of the melt from an external or internal resistance heater. Heat transfer to the melt is generally by radiation heating.

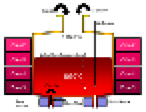
Microwave (0.3 to 300 GHz) heating – the use of higher frequency electromagnetic waves to couple directly to the melt. These waves excite different vibrational and rotational modes in the melt molecules which relax by conduction into the melt.

Plasma heating – The focusing of a plasma torch (partially ionized gas) on the melt which directly heats the melt primarily by radiative heat transfer.

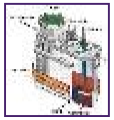
The melters:



Ceramic refractory melters – high temperature (typically fuse cast) ceramics. Refractory ceramics have the advantage of corrosion resistance, high thermal efficiency, high-temperature operation, and relatively high melter life. The disadvantages include the large size and weight of the refractories (which take up large hot-cell volume and require disposal), difficulty in decontamination after use, and difficulty in cooling and reheating due to thermal shock.

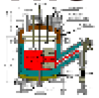


Metal melters – metal alloy glass melt containment materials. Metals have the advantages of high thermal conductivity, thermal shock resistance, low volume, and ability to decontaminate after use. The disadvantages include low temperature (or expensive alloys), microstructural changes at high temperature creating failure modes, welding flaws, and, in the case of induction heating, the potential for hot-spots.



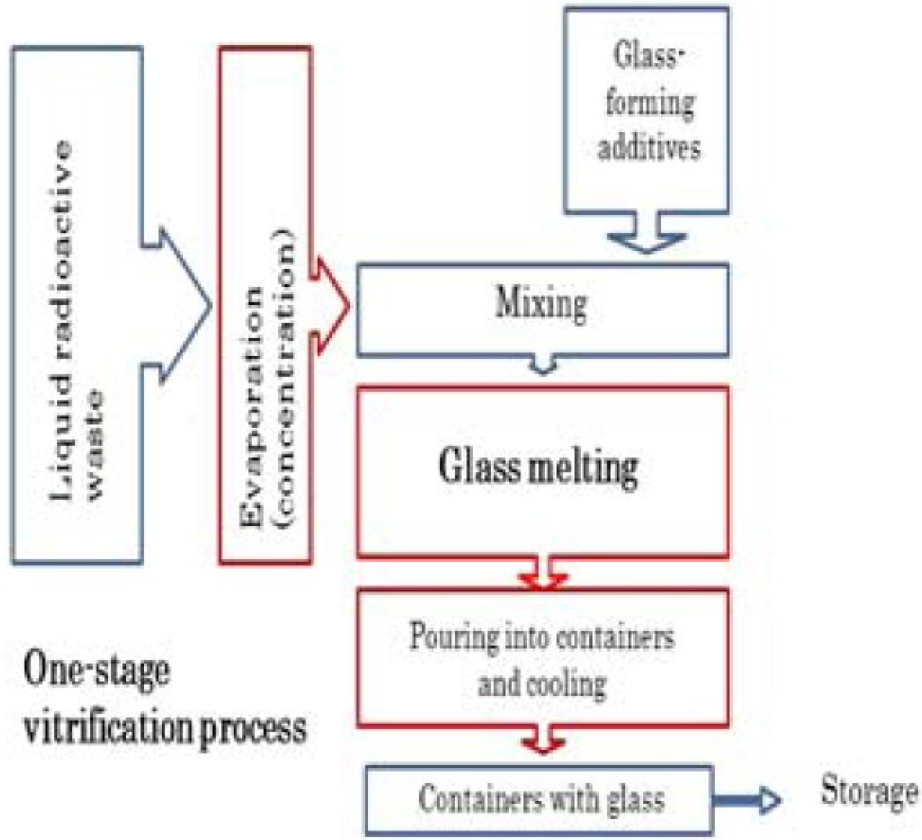
Cold wall melters – frozen glass contact materials maintained by active cooling (as in the case of cold crucible induction melters, CCIM). The advantage of this material is very-high temperature process capability, relatively low volume, and tolerance to corrosive melts.

The feeding system:

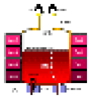


Direct liquid feeding or one step. The glass forming additives are either premixed with the liquid waste or fed separately onto the glass surface.

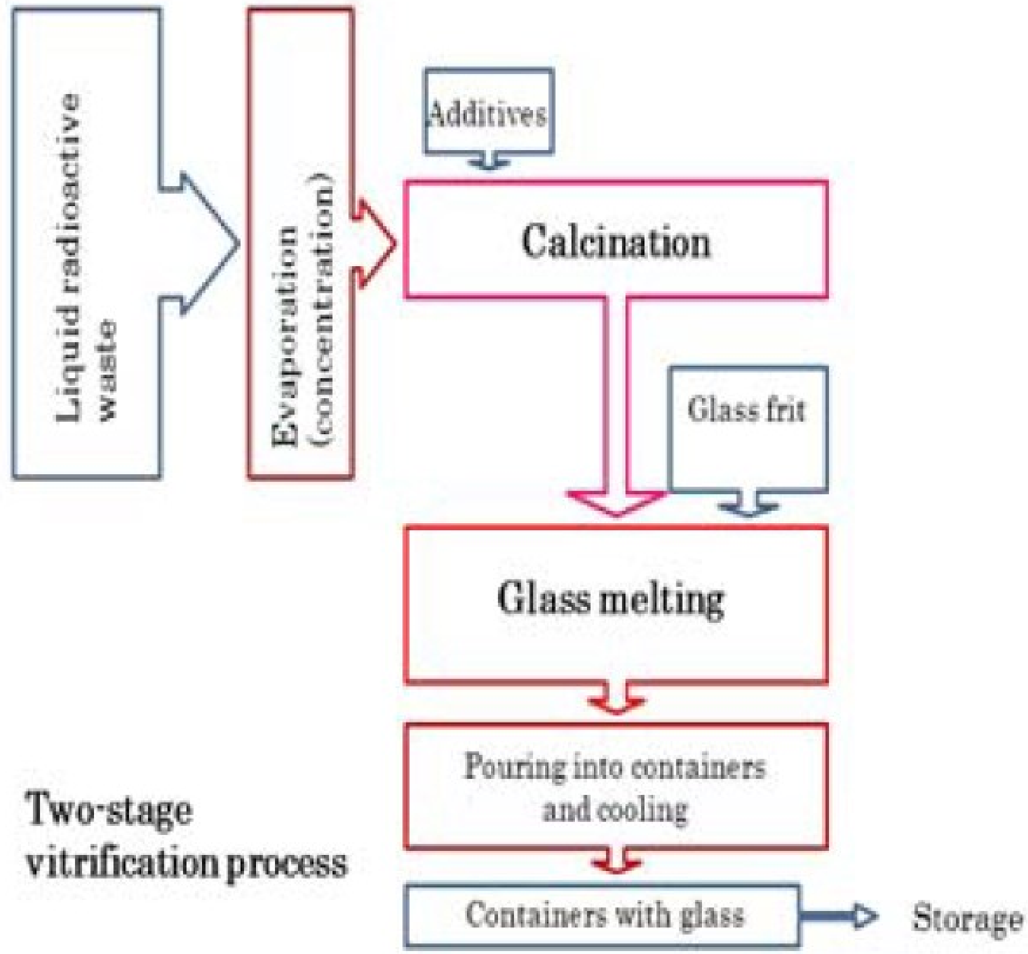
Evaporation on top of the melt results in cooling of the upper glass layers in the melter which helps to control the release of volatiles and semi-volatiles from the melt, but, may reduce melting rate.
In more recent applications stirring is implemented, either by sparging (*bubblers or an air lift glass pump*) or by mechanical stirrers to increase the heat transfer rate to the reacting batch and thereby increase production rate. Liquid feeding avoids dusting issues with radionuclides in the waste.



Dry feeding or two step.

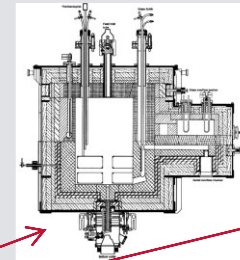


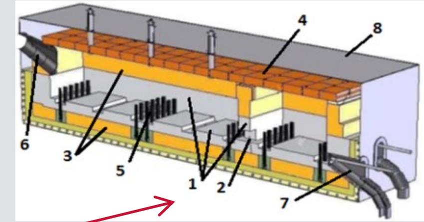
ter is removed and the waste feed is partially reacted in a calciner ahead of the melter. This generally increases the melt processing rate as calciners tend to be more efficient at removing water than are melters. *However, the calciners currently deployed in HLW vitrification facilities are rotary calciners which require significant maintenance and dusting control to prevent the spread of airborne radionuclides.*

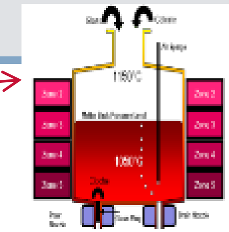


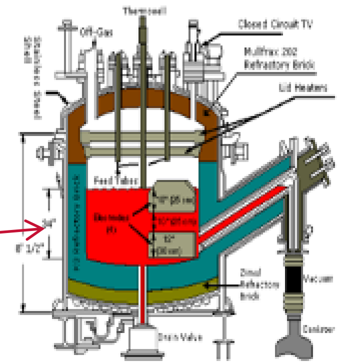
Plant	Location	Calciner	Melter	Radioactive Startup
AVM[1]	Marcoule, France	Yes	HWIM	1978
WIP[2]	Tarapur, India	No	HWIM	1985
Pamela	Mol, Belgium	No	JHCM	1985
MCC	Mayak, Russia	No	JHCM	1987
R7	LaHague, France	Yes Yes	HWIM CCIM	1989 2010
WVP[3]	Sellafield, UK	Yes	HWIM	1990
T7	LaHague, France	Yes	HWIM	1992
TRP[4]	Tokai, Japan	No	JHCM	1995
DWPF	Savannah River, USA	No	JHCM	1996
WVDP	West Valley, USA	No	JHCM	1996
VICHR	Bohunice, Slovakia	Yes	HWIM	1997
WIP[2]	Trombay, India	No	HWIM	2002
AVS[5]	Tarapur, India	No	JHCM	2008
VEK[6]	Karlsruhe, Germany	No	JHCM	2010
WIP[2]	Kalpakkam, India	No	JHCM	TBD
RRP[7]	Rokkasho, Japan	No	JHCM	TBD
WTP[8]	Richland, USA	No	JHCM	TBD

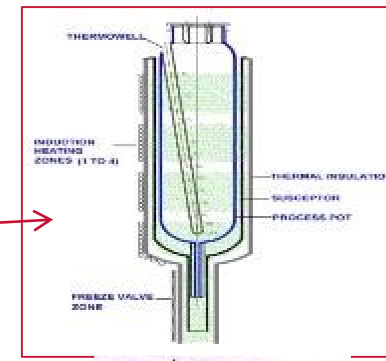
1-Atelier de Vitrification Marcoule; 2-Waste Immobilization Plant; 3-Waste Vitrification Plant; 4-Tokai Reprocessing Plant; 5-Advanced Vitrification System; 6-Verglasungseinrichtung Karlsruhe; 7-Rokkasho Reprocessing Facility; 8-Waste Treatment Plant

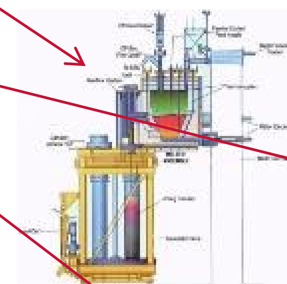


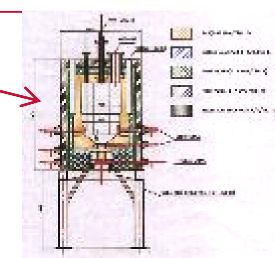


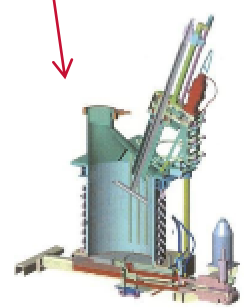






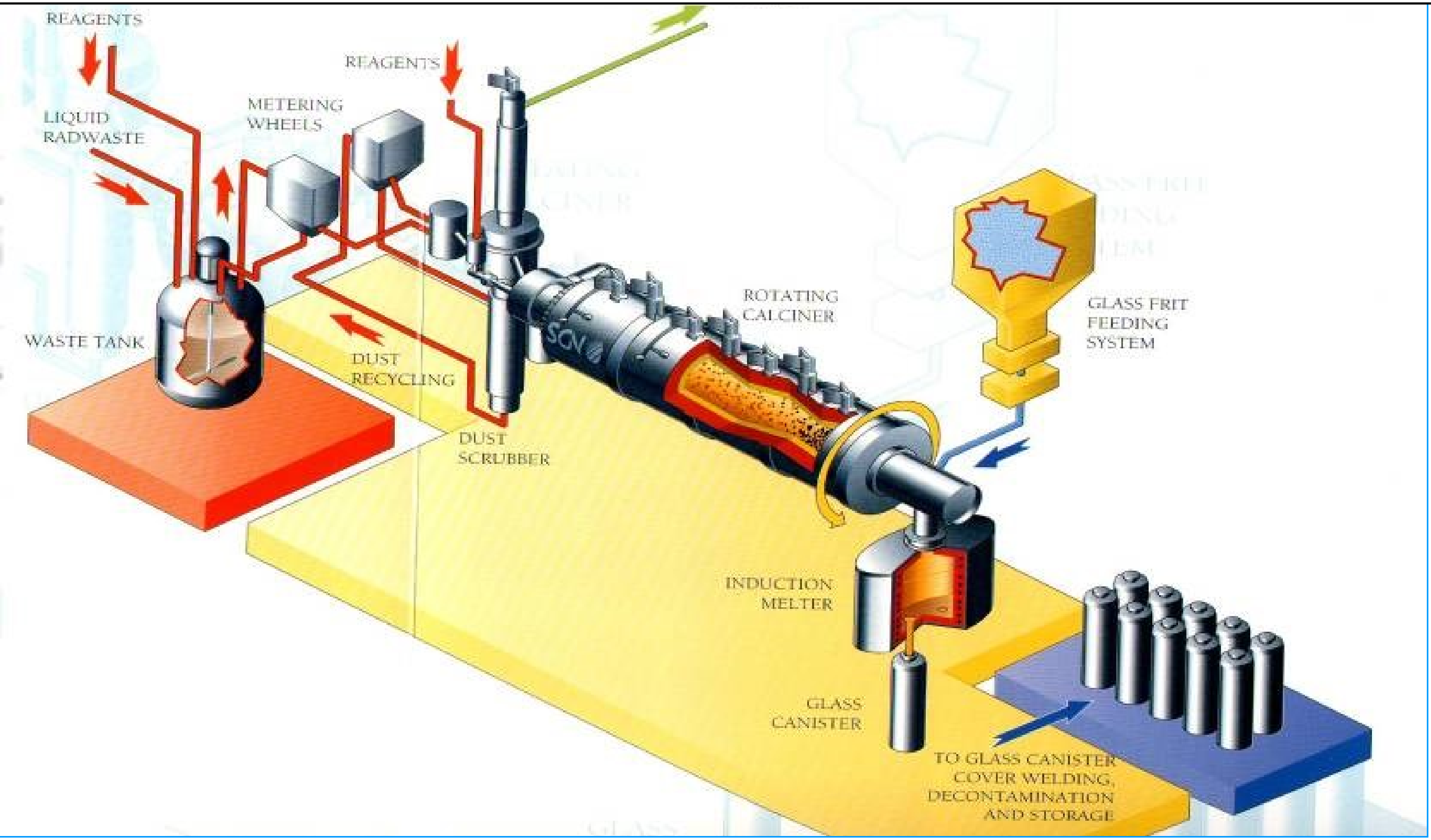




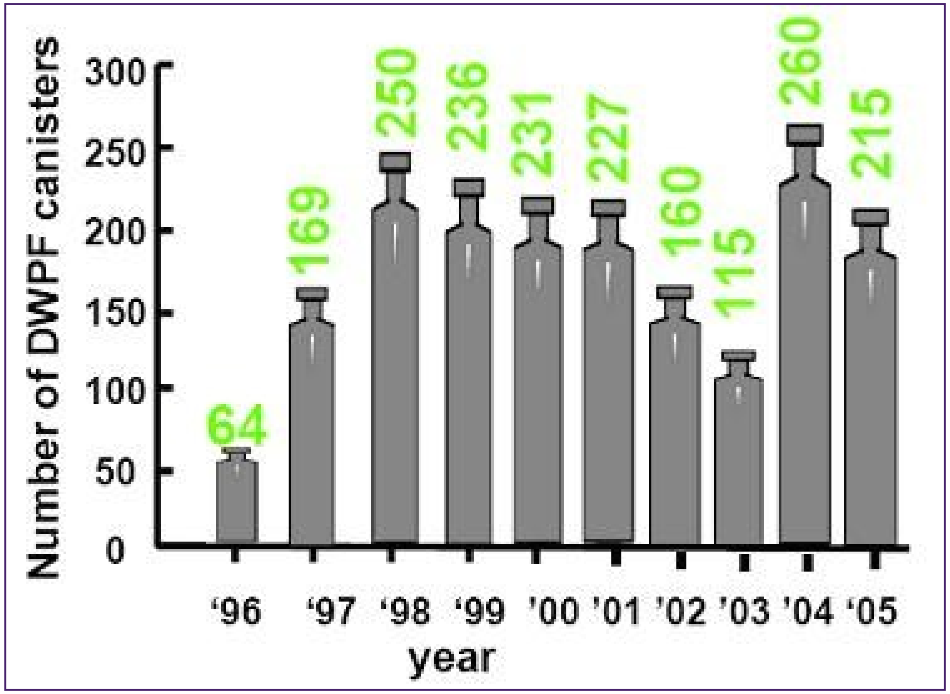


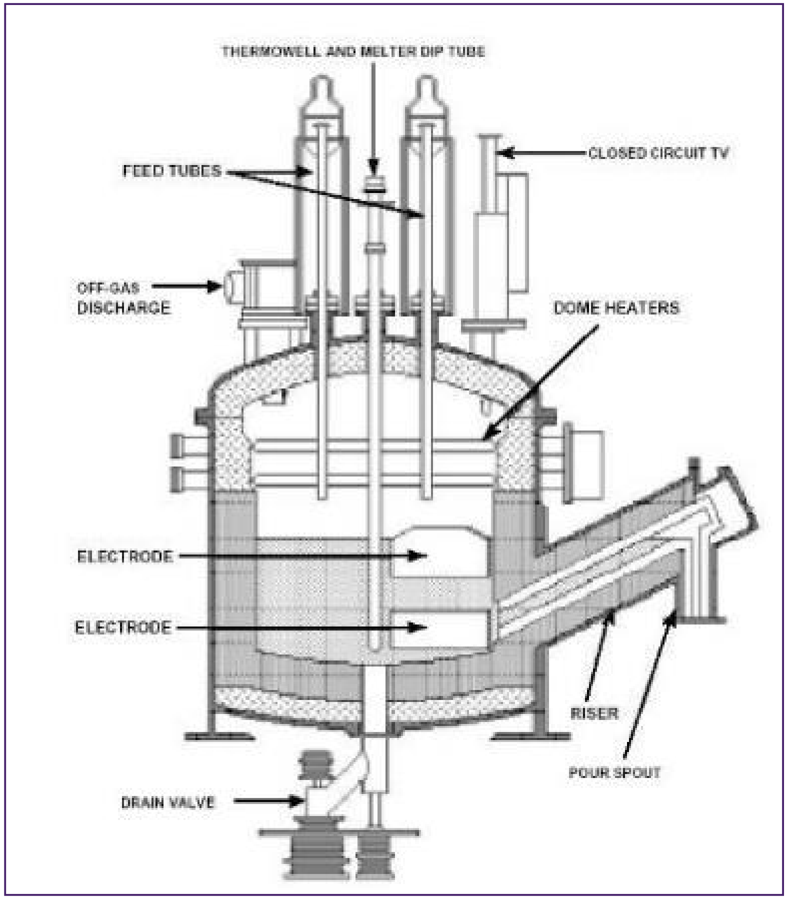
Source: Draft TECDOC "Handbook on the Treatment and Conditioning of High Level Waste (HLW) and Spent Nuclear Fuel Declared as Waste (SNFW)", IAEA, 2019.

Facility	Waste type	Melting process	Operational period	Performance
R7/T7, La Hague, France	HLW	IHC[1]	Since 1989/92	6555 tonnes in 16885 canisters, $262 \cdot 10^6$ TBq to 2012
AVM, Marcoule, France	HLW	IHC	Since 1978	1357 tonnes in 3306 canisters, $22 \cdot 10^6$ TBq to 2012



Facility	Waste type	Meting process	Operational period	Performance
DWPF, Savannah River, USA	HLW	JHCM[3]	Since 1996	6300 tonnes in 3591 canisters, $1.8 \cdot 10^6$ TBq to 2012





Savannah River Defence Waste Processing Facility **DWPF**

Imperial College London

Mission Impossible? Socio-Technical Integration of Nuclear Waste Geological Disposal Systems

François Diaz-Maurin [1,2,*] and Rodney C. Ewing [1,3]

[1] Center for International Security and Cooperation (CISAC), Stanford University, Stanford, CA 94305, USA
[2] Amphos 21 Consulting S.L., C/Venezuela 103, 08019 Barcelona, Spain
[3] Department of Geological Sciences, Stanford University, Stanford, CA 94305, USA

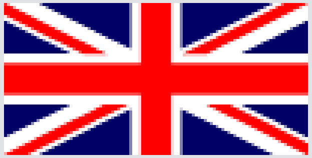
Table A1. Present waste types and projected waste forms and thermal output of defense HLW in the U.S. Source: [89], unless otherwise noted.

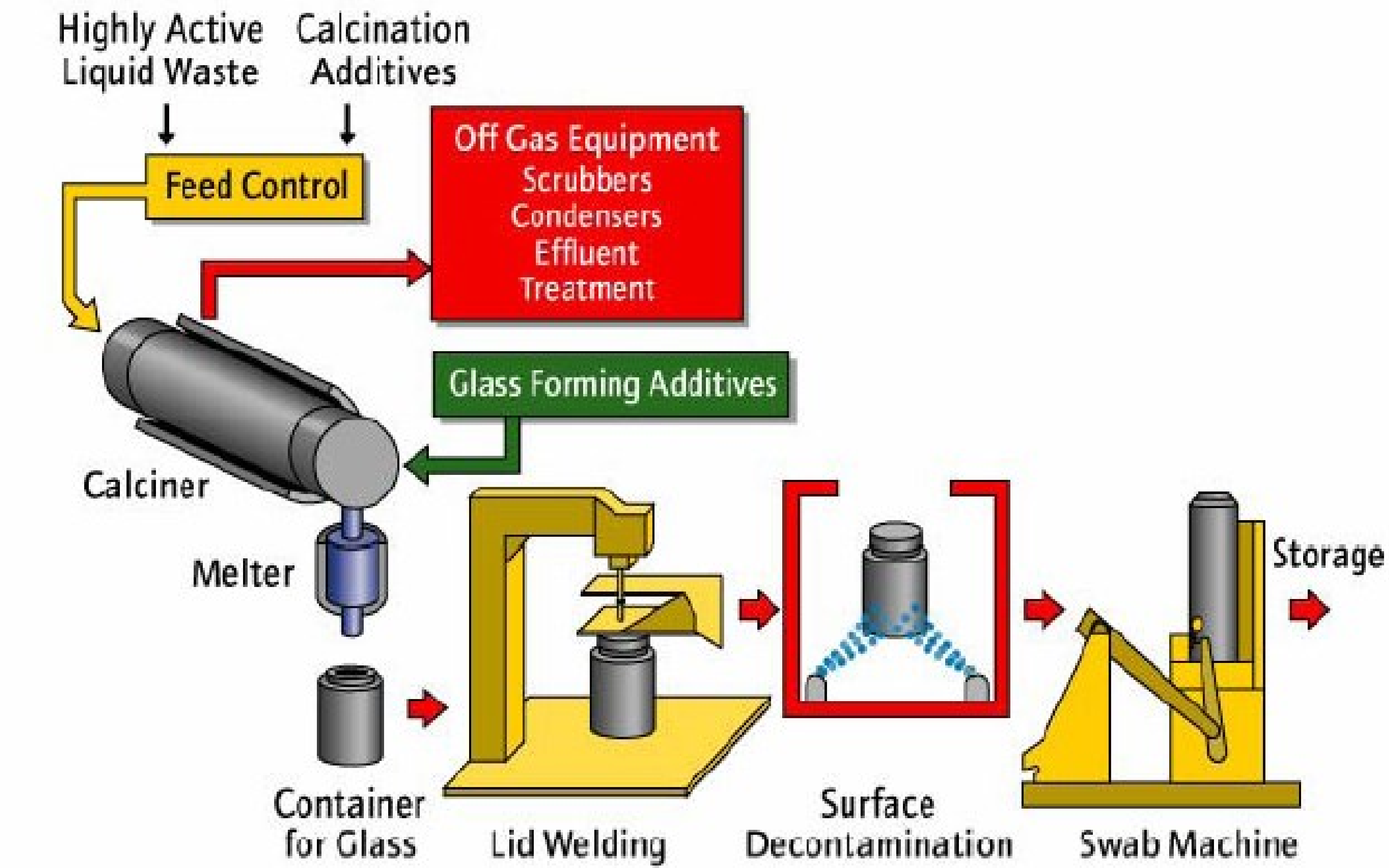
Waste Type	Present Quantity of Waste Type	Projected Quantity of Waste Packages in 2048	Physical Description of Projected Waste Type and Waste Form	Thermal Output of Projected Waste Type in 2048 (W/container)
		Existing defense HLW		
SRS HLW tank waste	3600 m^3 of vitrified waste in canisters (estimated) [(a)]	4050 canisters (estimated) [(a)]	glass in canisters	4 to 120 W/canister (at time of production, 1996–2012)
FRG glass at Hanford	34 canisters	34 canisters	glass in canisters (containing strontium and cesium) [(b)]	375 W/canister
		Projected defense HLW		
Hanford tank waste	~207,000 m^3 of reprocessing waste in tanks	10,586 canisters of glass, 3735 kg per canister (filled)	glass in canisters (planned)	360 W/canister
SRS HLW tank waste	98,000 m^3 of reprocessing HLW in tanks (estimated) [(a)]	4150 canisters (estimated) [(a)]	glass in canisters (planned)	Up to 500 W/canister (at time of production)
Calcine waste at INL	4400 m^3 of solid granular material (calcine) in six Calcine Solids Storage Facility (CSSF) bin sets	11,400 canisters (estimated)	glass in canisters (planned) [(c)]	1.2 to 15.4 W/canister (unknown time)
Cs/Sr capsules at Hanford	1335 Cs capsules, 601 Sr capsules stored underwater	340 canisters	glass in canisters (planned) [(d)]	349 W/canister
Sodium-bearing waste (SBW) at INL	3200 m^3 of liquid waste in tanks	688 canisters	solids and powders in canisters (planned) [(e)]	2.5 W/canister

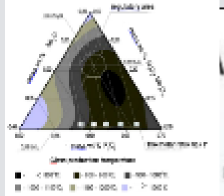
Abbreviations used: Cs, cesium; FRG, Federal Republic of Germany; INL, Idaho National Laboratory; kg, kilogram; m^3, cubic meter; Sr, strontium; SRS, Savannah River Site; W, watt. Notes: [(a)] Liquid waste processing at Savannah River has been on hold since February 2017. Values estimated including 17,000 m^3 expected additional volume by year 2019 through continued reprocessing at H Canyon facility [90–93]. [(b)] Contains known amounts of Cs-137 and Sr-90; contains an unknown amount of Cs-135. [(c)] This waste form disposal pathway is an alternative to the planned disposal pathway for this waste type. It assumes calcine waste can be vitrified. Calcine waste has also been proposed to be treated by hot isostatic pressing or disposed of without further treatment. Other possible waste forms include crystalline powder in canisters or glass ceramic in canisters. Disposal strategy not finalized. [(d)] This waste form assumes Cs and Sr from capsules can be vitrified. Cs/Sr capsules have also been proposed to be disposed as untreated overpacked capsules. Both of these waste form disposal pathways are alternative pathways, as neither has been finalized. [(e)] This waste form assumes sodium-bearing waste have been treated by fluidized bed steam reforming.

Special Issue "Nuclear Waste Management and Sustainability of Nuclear Systems" https://www.mdpi.com/journal/sustainability/special_issues/nuclear_systems

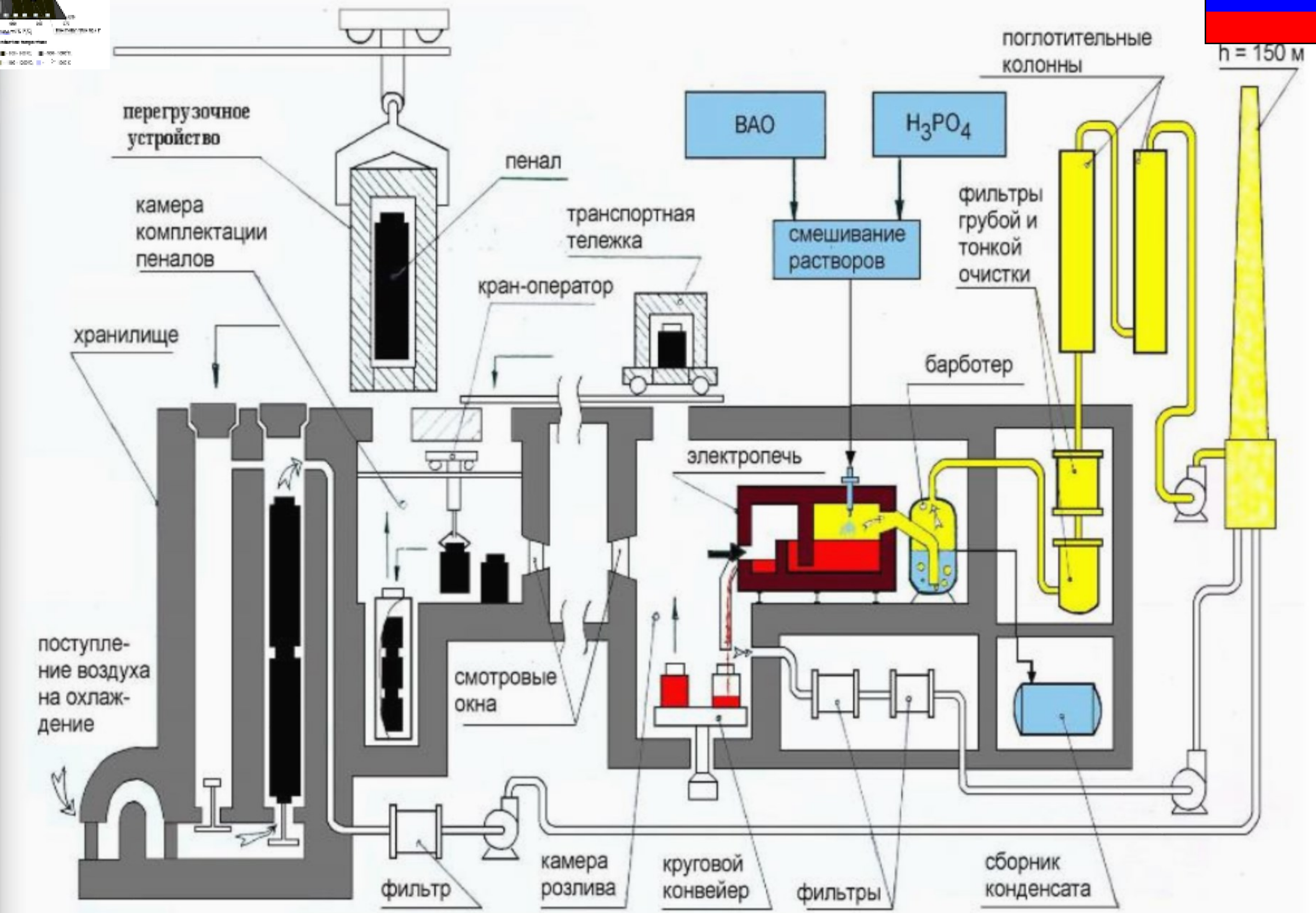
Facility	Waste type	Meting process	Operational period	Performance
WVP, Sellafield, UK	HLW	IHC	Since 1991	2200 tonnes in 5615 canisters, $33 \cdot 10^6$ TBq to 2012

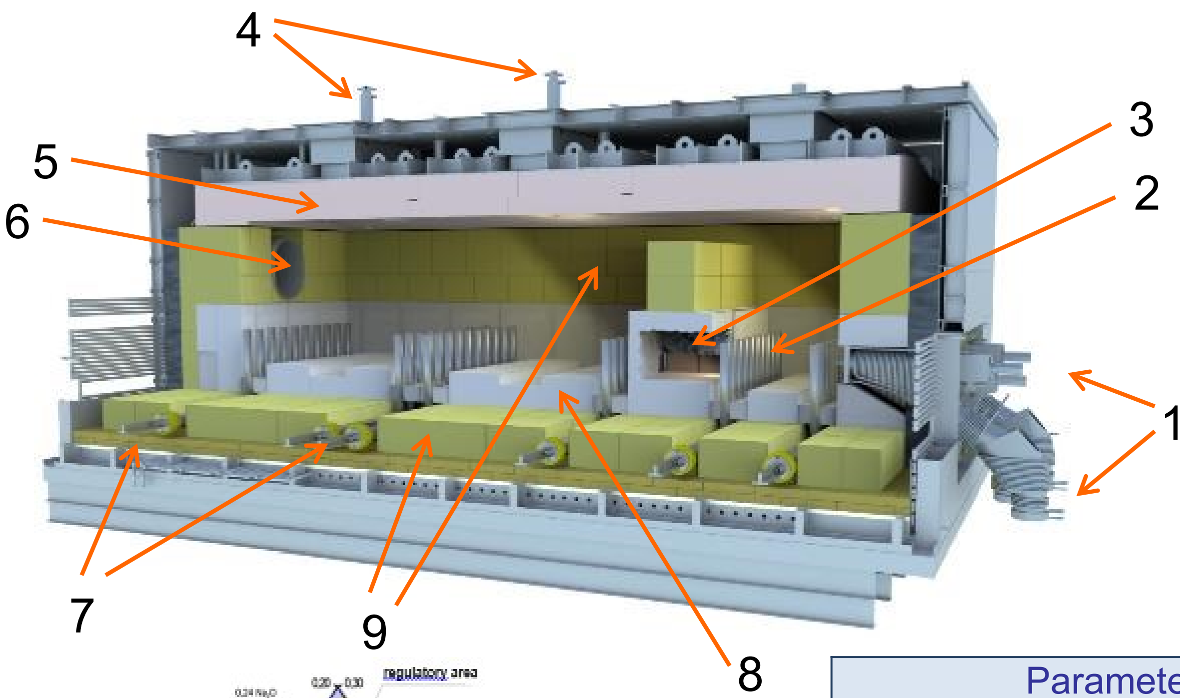




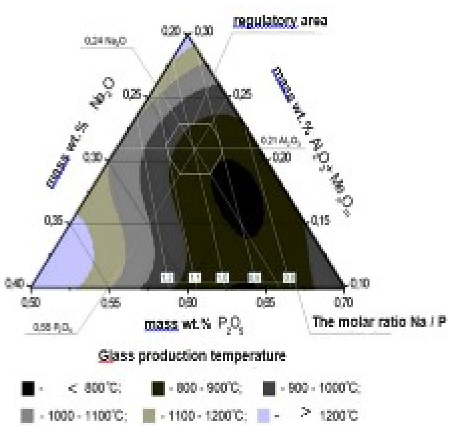


ппаратурно–технологическая схема остекловывания ВАО на ПО "Ма





1 - drainage devices;
2 - molybdenum electrodes;
3 - overflow window;
4 - feeders;
5 - arch;
6 - flue;
7 - water cooled electric power supply;
8 - bacor masonry;
9 - fireclay masonry

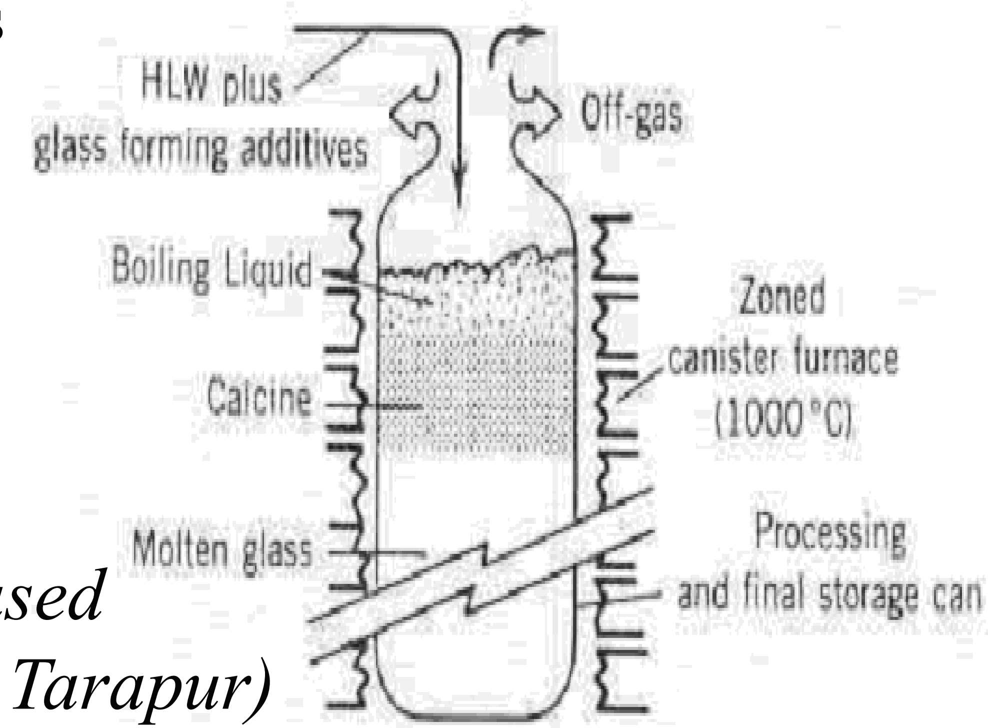


Parameter	Value
Feed rate of stock solution	**400 l/h**
Productivity on glass	**800 t/year**
Design life	**6 years**
Type of glass	**aluminophosphate**
Dosage of HLW and flux	**liquid**

Pot vitrification processes

Simple pot vitrification processes that do not employ a separate calcination stage have been initially considered (e.g. in Canada, France (Pilote Verre – PIVER), US, UK, Russia, India, Italy, Japan, China ..).

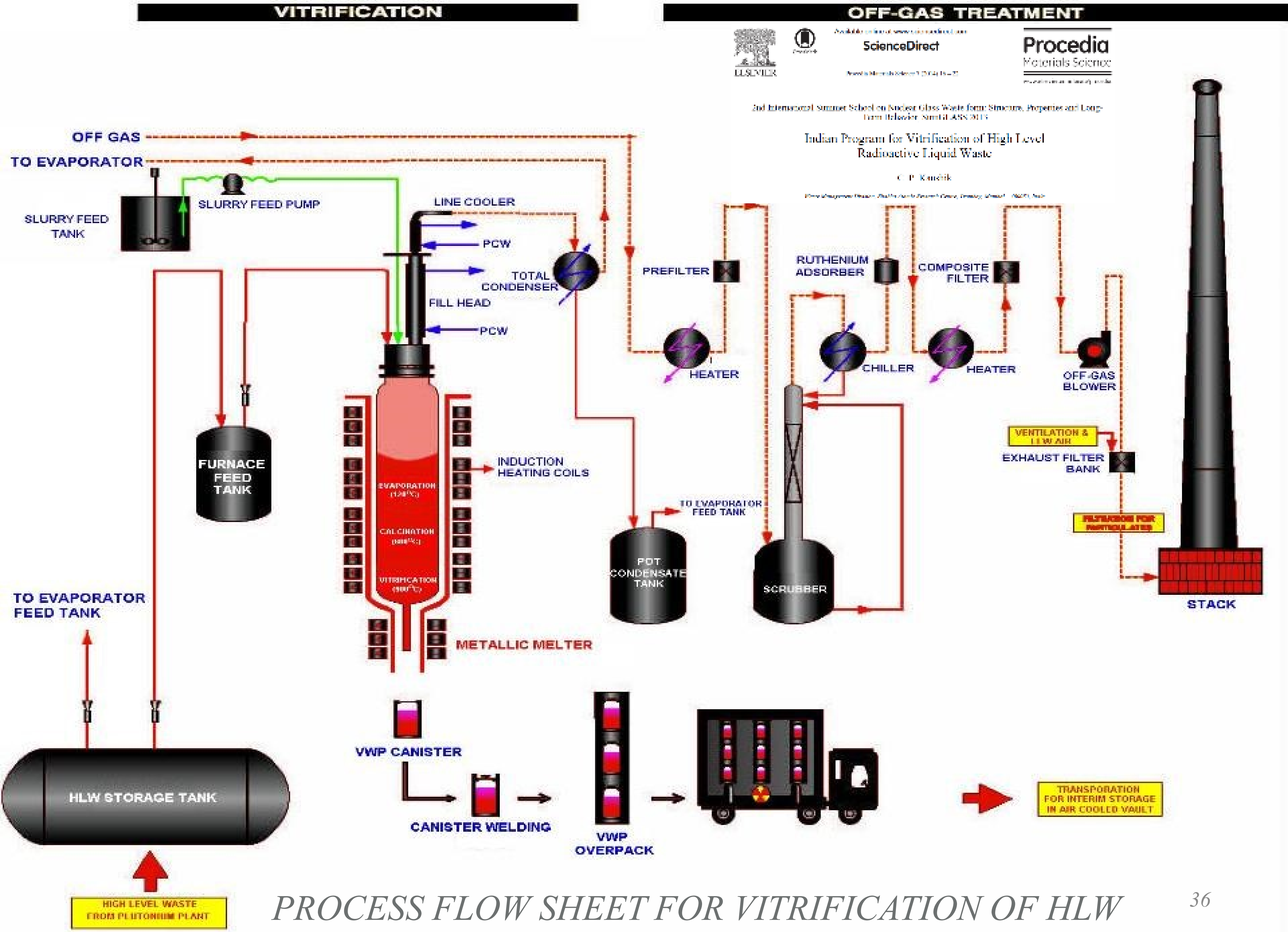
Such a process is currently used commercially in India (WIP, Tarapur) for the immobilization of HLW generated during the reprocessing of spent fuel.



Imperial College London

Waste vitrification plants in India

	WIP - TARAPUR	WIP - TROMBAY	WIP - KALPAKKAM
Commissioned Year	1985	2002	Under testing & commissioning Stage
Type of waste	Power reactor waste	Research reactor waste (sulphate issue)	Power Reactor waste
Layout concept	Single cell concept	Multiple cell concept	Multiple cell concept
Process steps	Evaporation followed by vitrification of HLW	Vitrification of HLW with pretreatment processes	Evaporation Followed by vitrification fof HLW
Glass matrix	Sodium Borosilicate	Barium Borosilicate	Sodium Borosilicate
Vitrification process	Pot type - with no freeze valve	Pot type - with Freeze valve concept	Ceramic melter
Off-Gas Treatment	Single off-gas treatment system	Two off-gas treatment Systems segregated as per specific activity handling	Multiple off-gas treatment systems segregated for each process



PROCESS FLOW SHEET FOR VITRIFICATION OF HLW

Imperial College London

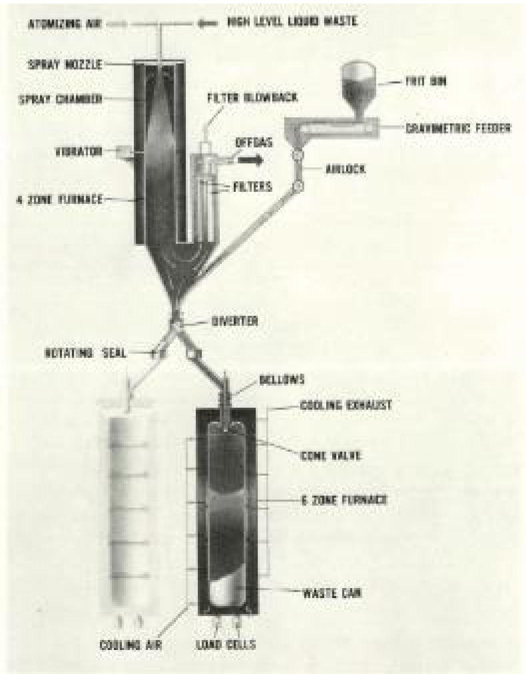
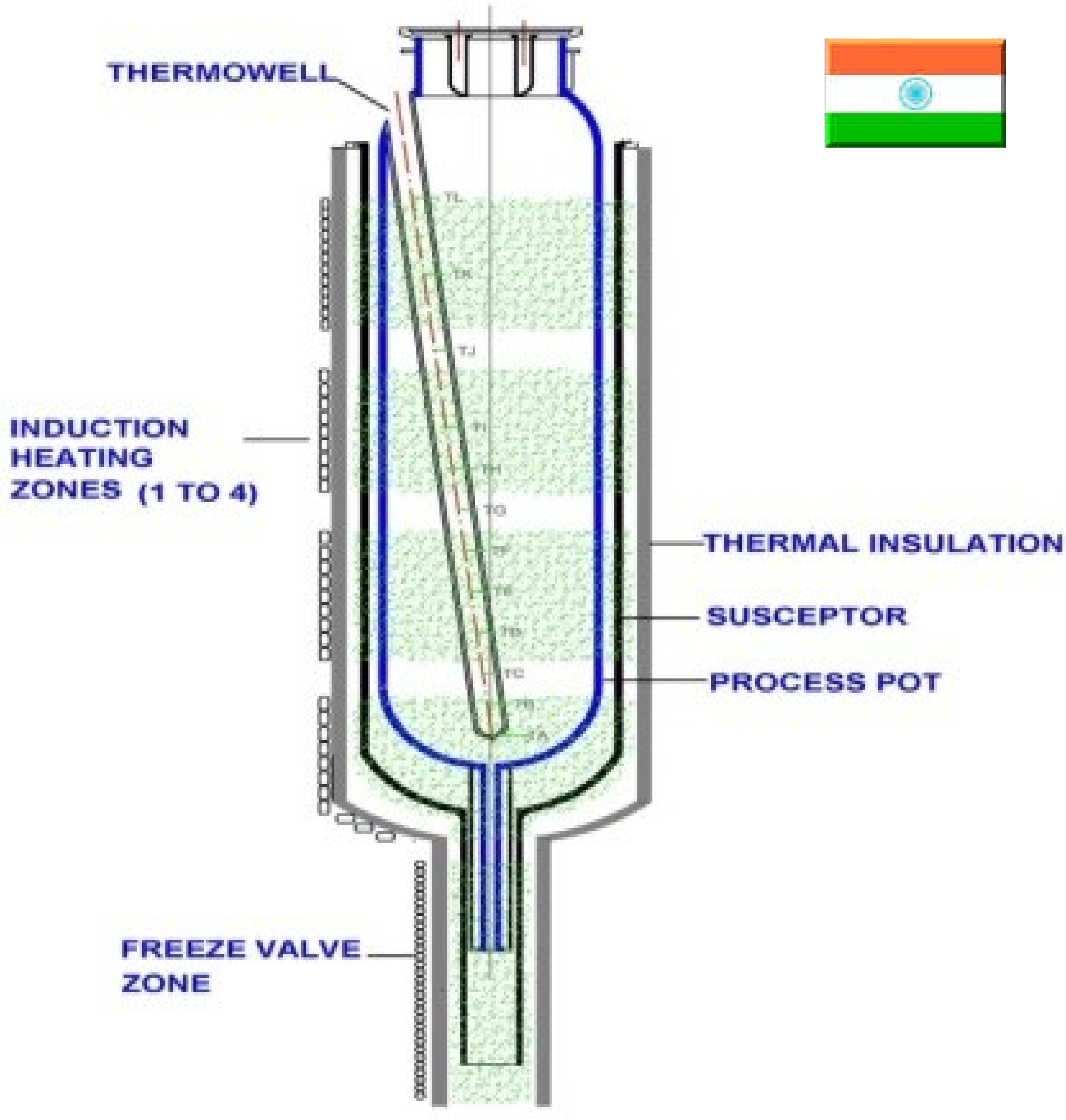
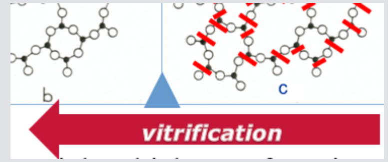
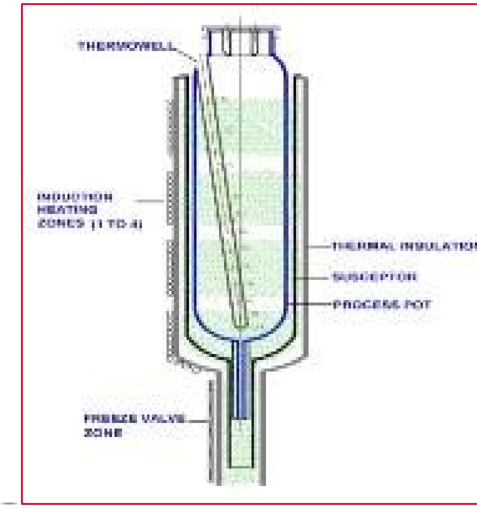


FIGURE 1. The Spray Calciner/In-Can Melter Process for High-Level Liquid Waste Solidification





Simple pot (in-can) vitrification processes are **currently** considered for immobilisation of legacy and decommission radioactive waste.



Pot vitrification is the most simple process for immobilisation of radioactive wastes in glass. In this method radioactive wastes (HLW, ILW or LLW) are mixed with glass-forming additives, and fed at a constant flow rate directly into vessels where water evaporation, calcination and vitrification occur.

In the in-can vitrification process the **melting pot is disposable** and serves as the primary canister for both metallic and the glassy wasteforms. Refractory canisters-containers are needed to ensure containment of radioactive waste during processing (glass melting), storage, transportation and disposal.

Morgan Advanced Materials

A revival of *in-can* vitrification technology

Full-Scale In-Can Melter Demonstration for Vitrification of Nuclear Waste

H. Thomas Blair

January 1979

1979

Prepared for the U.S. Department of Energy under Contract EY-76-C-06-1830

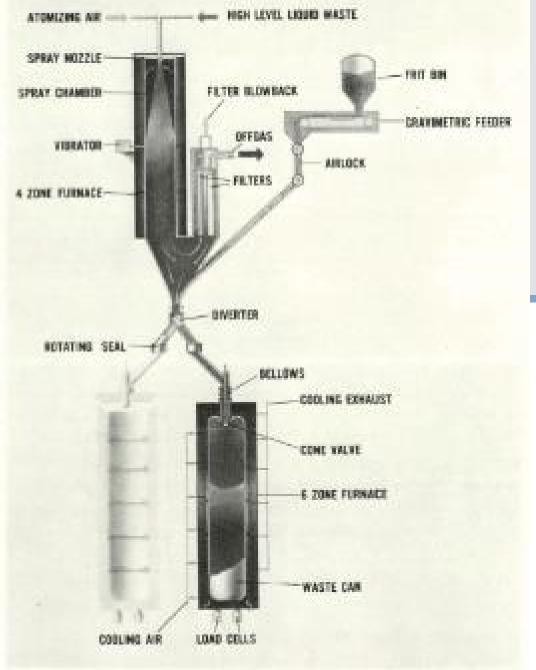


FIGURE 1. The Spray Calciner/In-Can Melter Process for High-Level Liquid Waste Solidification

WM2012 Conference, February 26-March 1, 2012, Phoenix, AZ

2012

Development of In-Can Melting Process Applied to Vitrification of High Activity Waste Solutions (HAWS): Glass characterizations and process tests results - 12442

P. Gruber, S. Lemonnier, J. Lacombe, Y. Papin, I. Hugon
CEA, Nuclear Energy Division - Marcoule
F-30207 Bagnols sur Cèze, France

B. Batifol, L. Pescayre
CEA,
F-21120 Is-sur-Tille, France

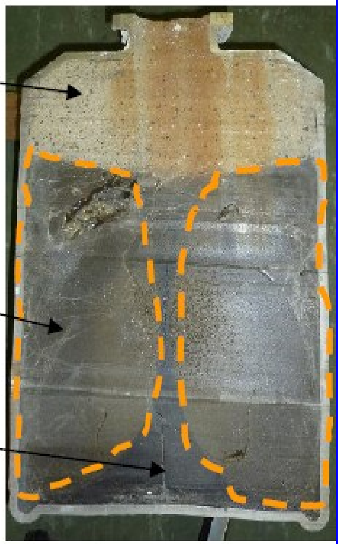


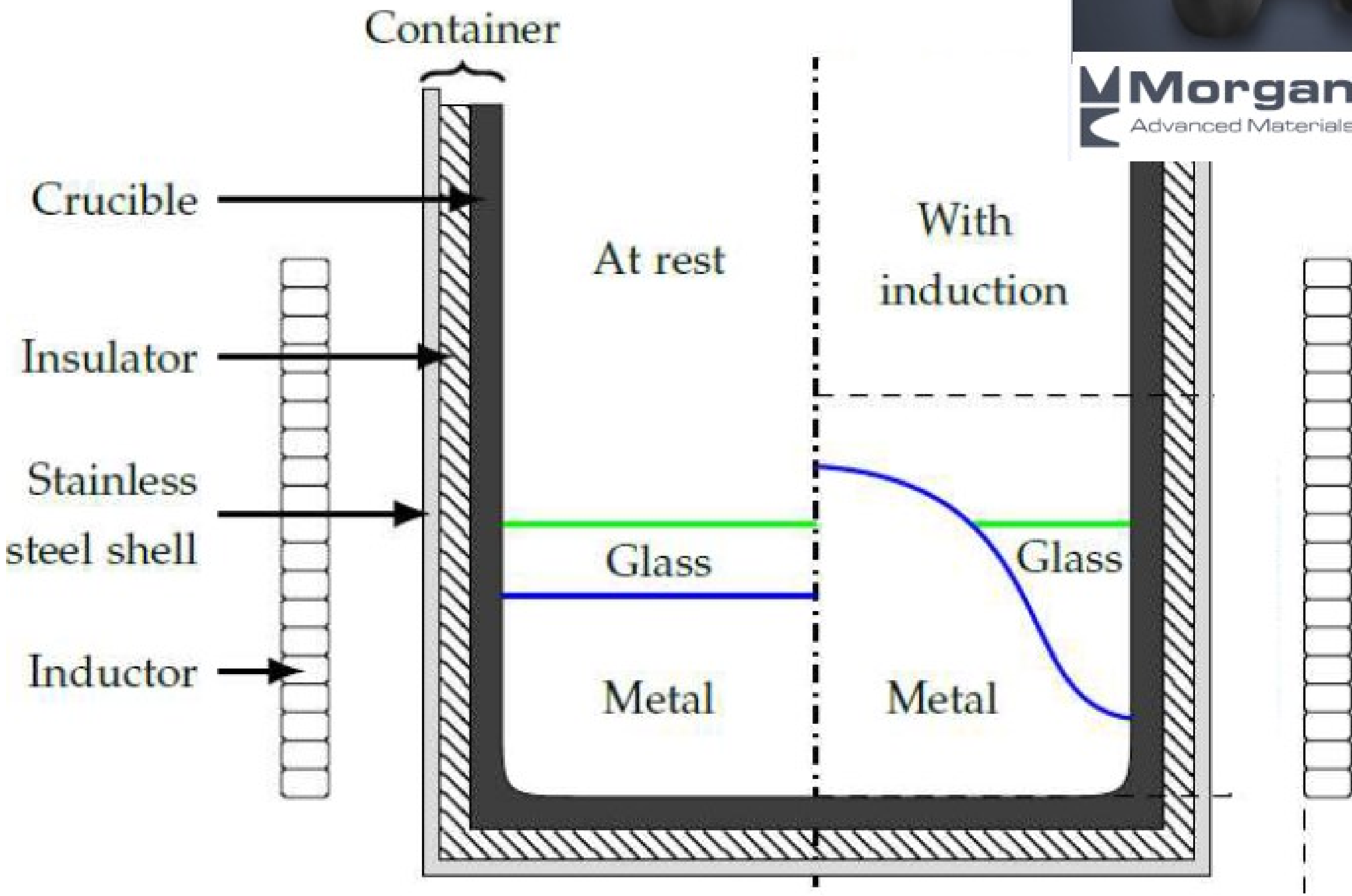
Figure 5. Cutaway melting pot – Run 2010#1

9th International Symposium on Electromagnetic Processing of Materials (EPM2018) IOP Publishing
IOP Conf. Series: Materials Science and Engineering **424** (2018) 012063 doi:10.1088/1757-899X/424/1/012063

Nuclear waste treatment by induction heating and stirring of a metal/glass bath: the PIVIC process

P. Charvin[1], F. Lemont[1], A. Russello[1]

Morgan Advanced Materials



' Conference, March 5-9, 2017, Phoenix, Arizona, USA

WM2017 Conference, March 5-9, 2017, Phoenix, Arizona, USA

Mixed Metallic and Organic Transuranic Waste Incineration / Vitrification - 17539

Christophe GIROLD*, Patrice CHARVIN*, Isabelle HUGON*,
Sabah BEN LAGHA+, Stéphane CATHERIN°

* **Commissariat à l'Énergie Atomique**, Nuclear Energy Division
Waste Treatment and Conditioning Research Department
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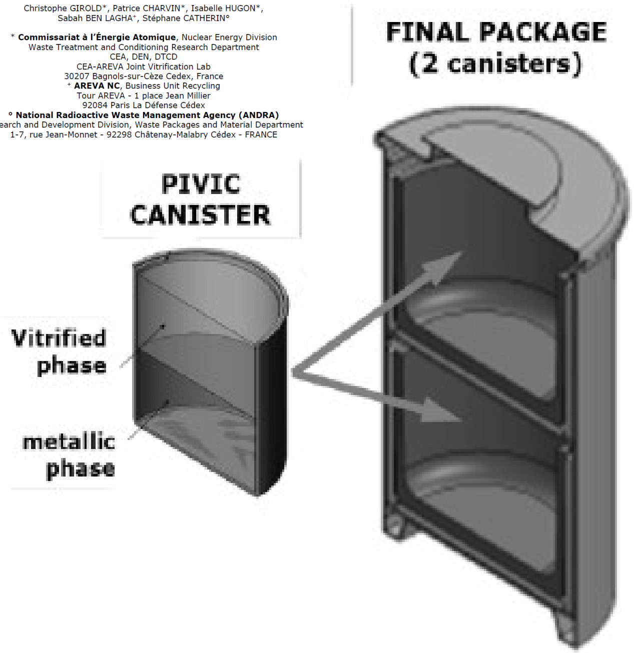
CEA-AREVA Joint Vitrification Lab
30207 Bagnols-sur-Cèze Cedex, France
+ **AREVA NC**, Business Unit Recycling
Tour AREVA - 1 place Jean Millier
92084 Paris La Défense Cédex
° **National Radioactive Waste Management Agency (ANDRA)**
Research and Development Division, Waste Packages and Material Department
1-7, rue Jean-Monnet - 92298 Châtenay-Malabry Cédex - FRANCE



PIVIC Package concept and vertical cut of a scale 1 the first prototype of the project.

world nuclear news

Energy & Environment | New Nuclear | Regulation & Safety | Nuclear Policies | Corporate | Uranium & Fuel |

France presents vitrification process for Fukushima

23 October 2018

Share

A project to demonstrate the use of innovative radioactive waste vitrification technology, developed in France, at the damaged Fukushima Daiichi nuclear power plant in Japan has been under way for the past six months.

An in-can prototype developed at CEA Marcoule (Image: CEA)

2019

http://www.world-nuclear-news.org/Articles/France-touts-vitrification-process-for-Fukushima

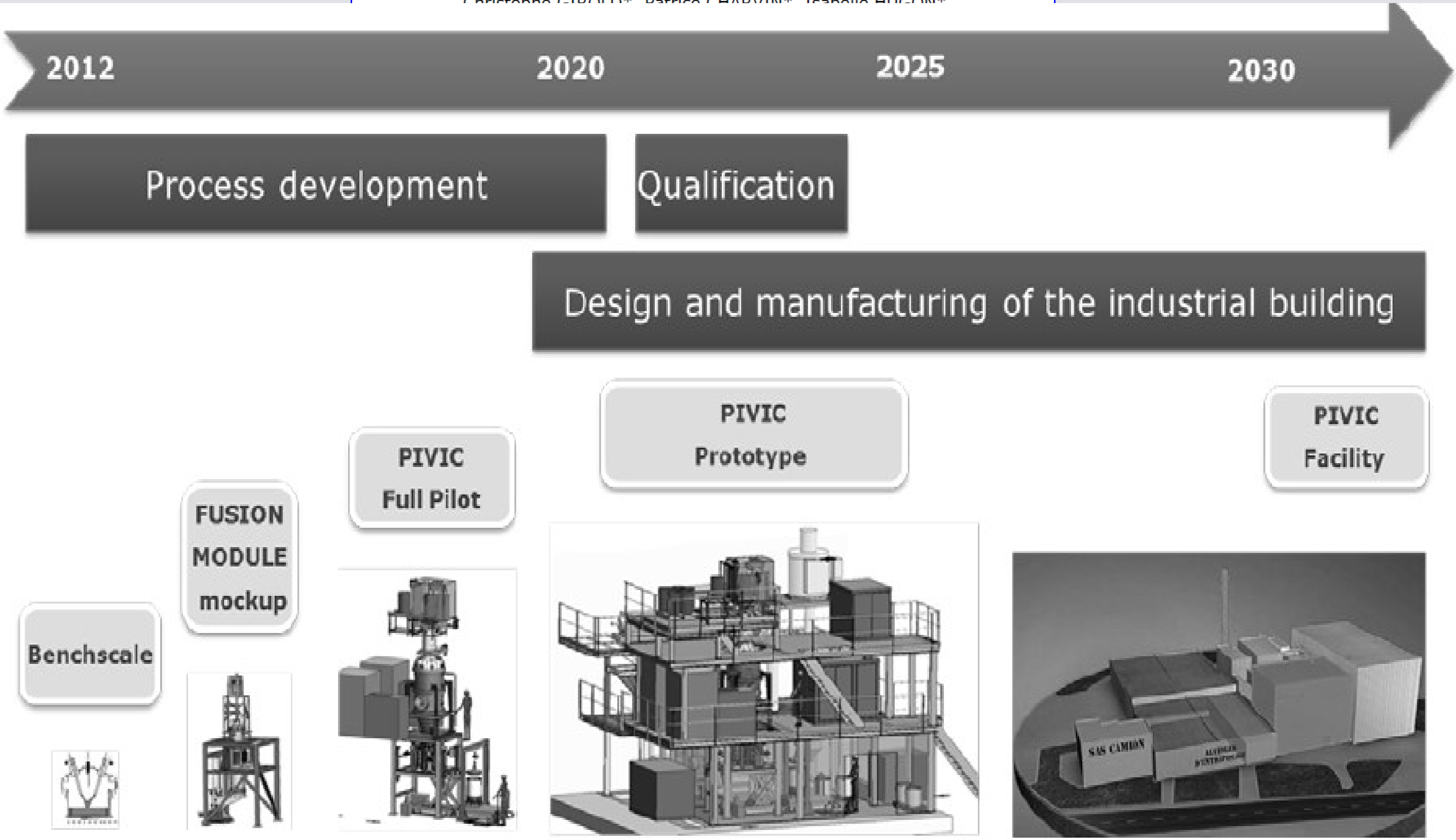
Proceedings of FDR2019
International Topical Workshop on Fukushima Decommissioning Research
May 24-26, 2019. J-Village, Naraha, Fukushima, Japan

Imperial College London

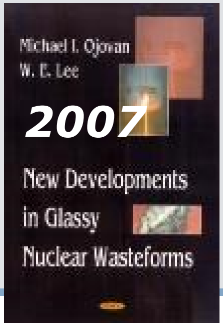
WM2017 Conference, March 5-9, 2017, Phoenix, Arizona, USA

Mixed Metallic and Organic Transuranic Waste Incineration / Vitrification - 17539

Christophe GIROLD*, Patrice CHARVIN*, Isabelle HUGON*



IV. LILW vitrification



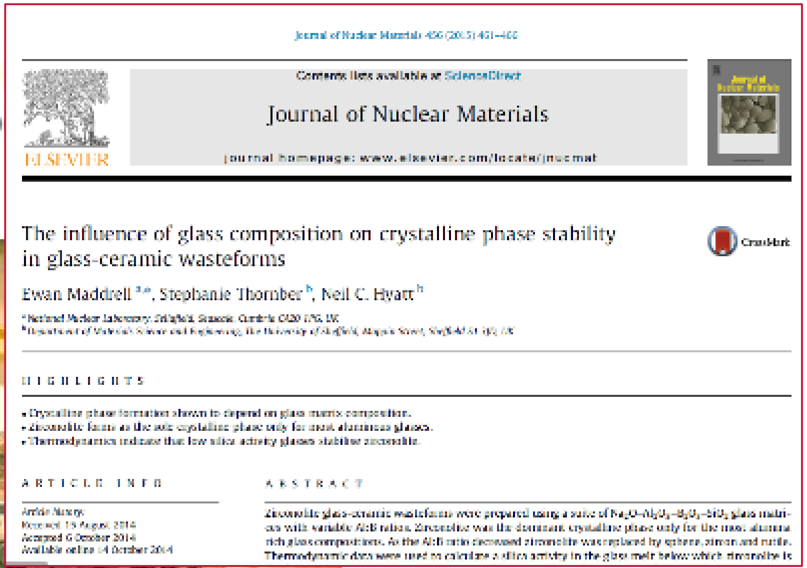
Glass offers improved means of storing intermediate level nuclear waste

22 August 2012

A method of storing nuclear waste, normally used only for could provide a safer, more efficient, and potentially cheap Intermediate Level Waste.

Intermediate Level Waste (ILW) makes up more than three quarters of the volume of material destined for geological disposal in the UK. Currently the UK's preferred method is to encapsulate ILW in specially formulated cement. The waste is mixed with cement and sealed in steel drums, in preparation for disposal deep underground.

Two studies, published in the latest issues of ***The Journal of Nuclear** Materials* and ***European Journal of Glass Science and Techno***



Journal of Nuclear Materials 456 (2015) 461–466

Contents lists available at ScienceDirect

Journal of Nuclear Materials

journal homepage: www.elsevier.com/locate/jnucmat

The influence of glass composition on crystalline phase stability in glass-ceramic wasteforms

Ewan Maddrell [a,*], Stephanie Thornber [b], Neil C. Hyatt [b]

[a] National Nuclear Laboratory, Sellafield, Seascale, Cumbria CA20 1PG, UK

[b] Department of Materials Science and Engineering, The University of Sheffield, Mappin Street, Sheffield S1 3JD, UK

HIGHLIGHTS

- Crystalline phase formation shown to depend on glass matrix composition.
- Zirconolite forms as the sole crystalline phase only for most aluminous glasses.
- Thermodynamics indicate that low silica activity glasses stabilise zirconolite.

ARTICLE INFO

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Available online 14 October 2014

ABSTRACT

Zirconolite glass-ceramic wasteforms were prepared using a suite of $Na_2O–Al_2O_3–B_2O_3–SiO_2$ glass matrices with variable Al:B ratios. Zirconolite was the dominant crystalline phase only for the most alumina rich glass compositions. As the Al:B ratio decreased zirconolite was replaced by sphene, zircon and rutile. Thermodynamic data were used to calculate a silica activity in the glass melt below which zirconolite is

Journal of Nuclear Materials 485 (2017) 253–261

Contents lists available at ScienceDirect

Journal of Nuclear Materials

journal homepage: www.elsevier.com/locate/jnucmat

The effect of pre-treatment parameters on the quality of glass-ceramic wasteforms for plutonium immobilisation, consolidated by hot isostatic pressing

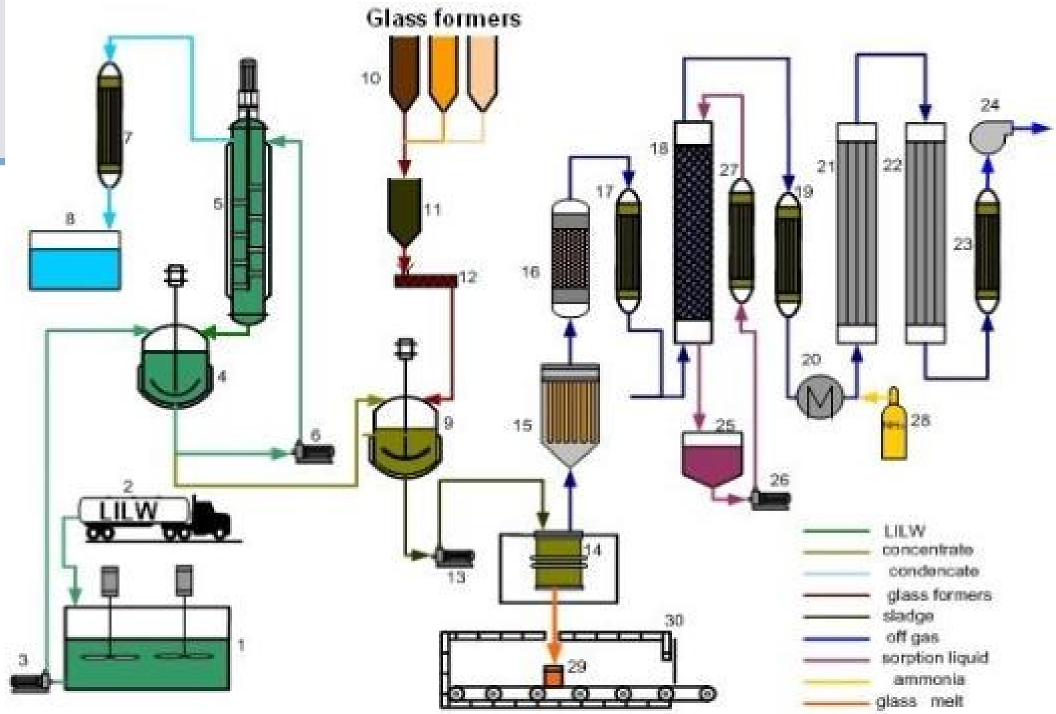
Stephanie M. Thornber [a], Paul G. Heath [a], Gabriel P. Da Costa [a,b], Martin C. Stennett [a], Neil C. Hyatt [a,*]

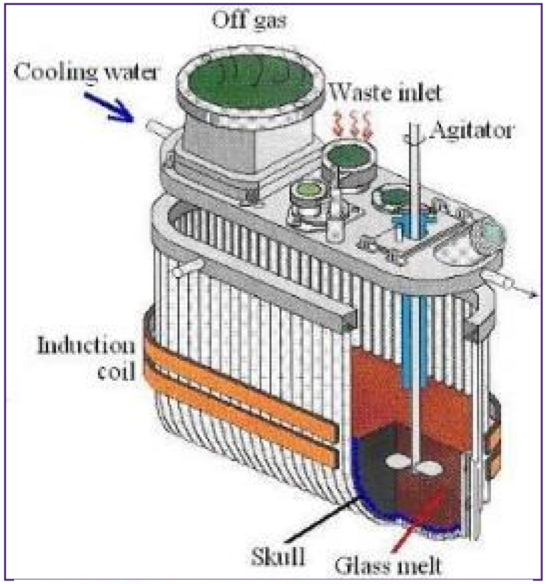
[a] Immobilisation Science Laboratory, Department of Materials Science & Engineering, The University of Sheffield, Sir Robert Hadfield Building, Mappin Street, Sheffield S1 3JD, UK

[b] Department of Chemical Engineering & Petroleum Engineering, Universidade Federal Fluminense, Rua Passo da Pátria 156, CEP 24210-240, Niterói, RJ, Brazil

http://www.dpaonthenet.net/article/52704/Glass-offers-improved-means-of-storing-intermediate-level-nuclear-waste.aspx

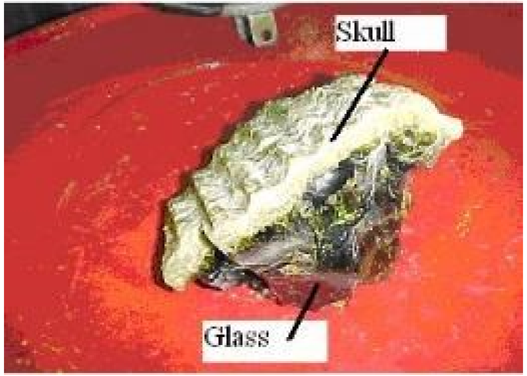
RADON LILW Vitrification Plant





FGUP RADON LILW vitrification plant: 1–LILW interim storage tank; 2–LILW transportation vehicle; 3–pump; 4–concentrate collector; 5–rotary film evaporator; 6, 13, 26– pumps; 7– condenser; 8–condensate collector; 9–batch (feed) mixer; 10–glass formers bins; 11–glass formers mixture bin; 12–screw feeder; 14–cold crucible; 15–bag filter; 16–HEPA filter; 17, 19, 23, 27–heat exchangers; 18–scrubber; 20– heater; 21–catalytic reactor for reduction of nitrogen oxides; 22–catalytic reactor for oxidation of ammonia; 24–fan; 25–sorbent bin; 26-Pump; 28– ammonia balloon; 29–glass canister;

Glass productivity (single crucible), kg/hr	**≤ 25**
Glass productivity (three crucibles), kg/hr	**≤ 75**
Melting ratio, kW•hr/kg	**4-6**
Glass block weight, kg	**50**
Glass specific activity, Bq/kg	**10^5-10^7**
Installed electric capacity, kW	**1500**
Overall dimensions, m	**9×12×24**

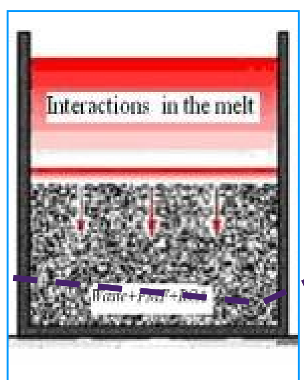


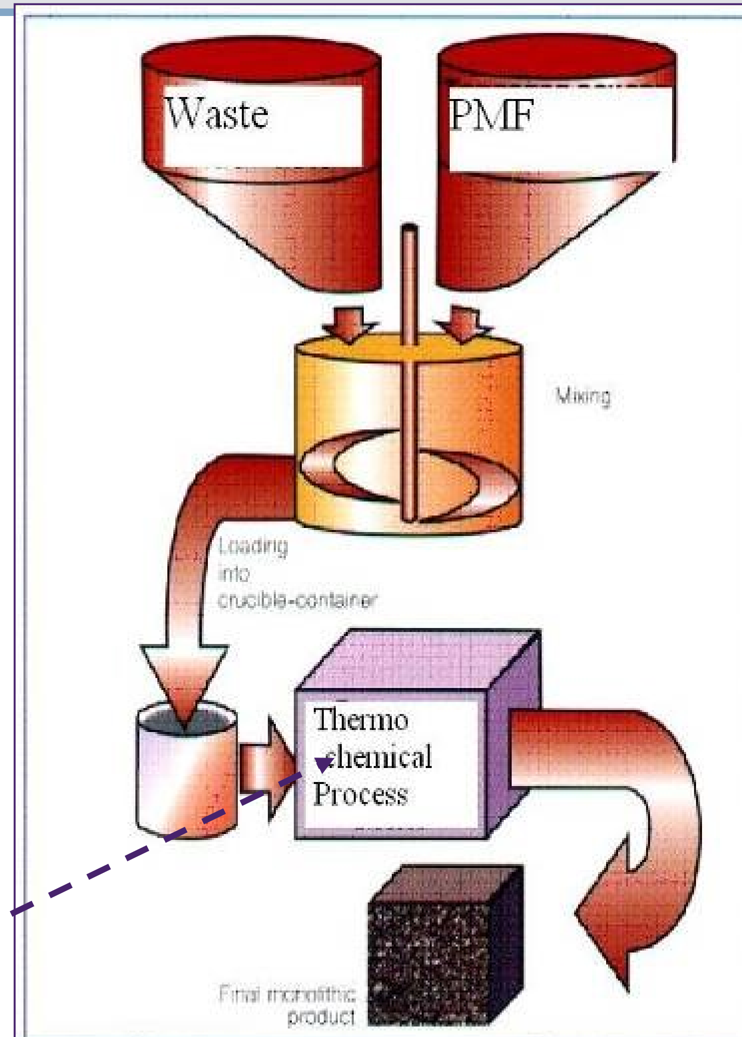
Self-sustaining vitrification

Facility	Waste type	Process	Operational period	Performance
Torch, Radon, Russia	LILW	SSV	2001 – 2005	10 kg/h, incinerator ash

Parameters of SSI

Waste content, wt. %			Maximum process temperature, °C	Aerosols carryover, wt. %	^{137}Cs carryover, %
Ash residue	Soil	Clinoptilolite			
50 -	-	-	1530	1.9	0.9
56 -	-	-	1350	1.4	0.4
60 -	-	-	1200	1.0	0.3
-	45	-	1900	2.2	3.1
-	50	-	1620	1.8	1.9
-	56	-	1530	1.0	1.3
-	-	50	1564	3.6	0.8
-	-	55	1476	2.4	1.1





Hanford Tank Waste Treatment and Immobilization Plant (WTP)

WTP will be the world's largest nuclear waste vitrification facility

Design, construction, and commissioning:

- Bechtel: 2001 – 2019 (22), ~$13 B
- BNFL: 1996 - 2000

Operations: 2019(22) – 2050?, ~$30 – 50 B

- However, delays are expected

Treat 56 million gallons of liquid nuclear waste stored in 177 underground tanks at DOE's Hanford site

Imperial College London

WTP LAW Melters

LAW Production = 30 MT glass/day with ES-VSL bubbler technology

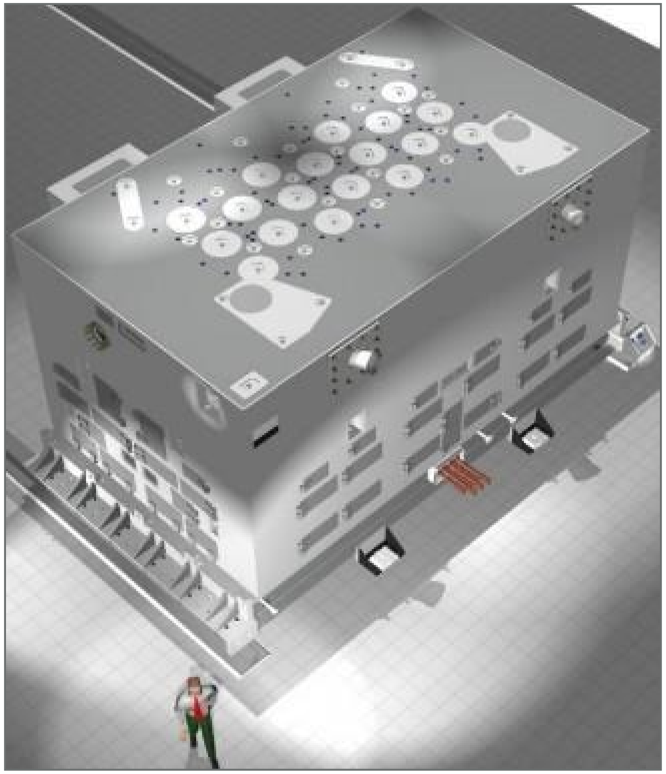
Weight: 330 tons

Exterior Dimensions: 29'-6" (L) x 21'-6" (W) x 15'-9" (H)

10 m^2 glass pool surface area

7630 L molten glass pool

Design production rate **15 tonnes of glass/day**



LAW Melter During Installation

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V. Vitreous wasteforms

Development of glasses for the solidification of HLW began at different times in the US, Canada, Europe, and the USSR. Different glass formulations (**borosilicate, aluminosilicate, and phosphate glasses**) and processing strategies were developed.

- The borosilicate glass formulations were developed in the US between 1956 and 1957.
- The aluminosilicate (nepheline syenite based) glass formulations were simultaneously being developed in Canada in 1957.
- Phosphate-based glasses were the last to be investigated for solidification of nuclear waste.

A systems evaluation of phosphate glasses demonstrated that the positive aspects of processing, e.g. low melting temperatures, were outweighed by other negative processing aspects, e.g. melt corrosivity, and by poor product performance. The aluminosilicate glasses and ceramic wasteforms are still being investigated for certain types of nuclear wastes.

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Glass has become widely used for waste immobilisation because of the amorphous and less rigid structure of glasses. Glasses possesses short range order (SRO) and medium range order (MRO) compared to ceramics that have SRO, MRO, and long range order (LRO). Glass structure enables the incorporation of a very large range of elements that are atomically bonded in the flexible glass. Thus glasses can accommodate larger waste composition variations than most ceramic wasteforms.

The MRO encompasses second- and third-neighbour environments around a central atom (radius of influence ~3-6 Å).

LRO extends beyond third-neighbour environments and gives crystalline ceramic/mineral structures their crystallographic periodicity.

Immobilisation of Radioactive Waste in Glass 249

Table 17.1 Compositions of Nuclear Waste Glasses

Glass/Country Oxide (wt%)	SiO_2	P_2O_5	B_2O_3	Al_2O_3	CaO	MgO	Na_2O	Misc	Waste Oxides
R7/T7, France	47.2	–	14.9	4.4	4.1	–	10.6	18.8	28
DWPF, USA	49.8	–	8.0	4.0	1.0	1.4	8.7	27.1	33
SRNL, USA	30.5	1.1	15.2	25.0	6.1	0.1	9.6	13.5	45[a]
WVP, UK	47.2	–	16.9	4.8	–	5.3	8.4	17.4	25 (up to 35–38)
Pamela, Germany–Belgium	52.7	–	13.2	2.7	4.6	2.2	5.9	18.7	30
Mayak, Russia	–	52.0	–	19.0	–	–	21.2	7.8	33[b]
Radon K-26, Russia	43	–	6.6	3.0	13.7	–	23.9	9.8	35[c]
P0798, Japan	46.6	–	14.2	5.0	3.0	–	10.0	20.2	
GC-12/9B, China	46.2	–	13.4	4.2	2.5	1.5	9.1	23.1	

DWPF – Defence Waste Processing Facility, Savannah River Site, US; SRNL – Savannah River National Laboratory, US; WVP – Waste Vitrification Plant, Sellafield, UK.

[a]This glass has been developed to host Hanford high-Al radioactive waste.

[b] ≤10 for fission products and minor actinide oxides.

[c]This glass is designed for sodium-containing LLW and ILW.

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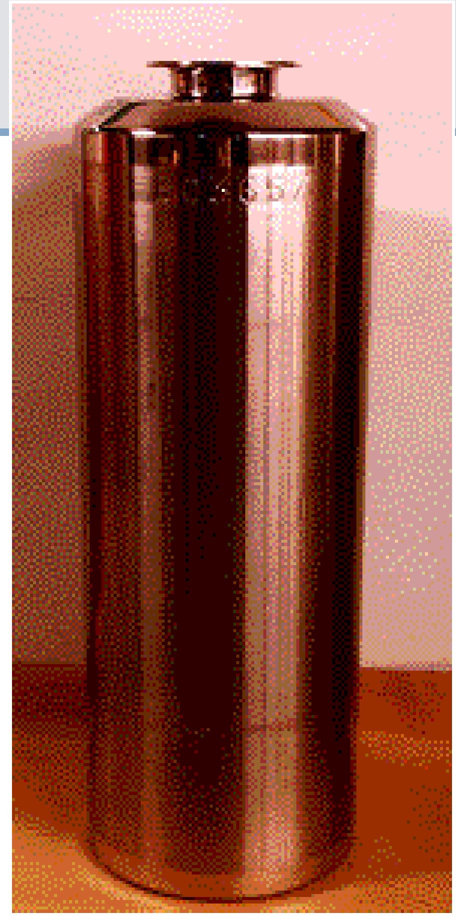
VI. Safety of vitrified waste

news feature

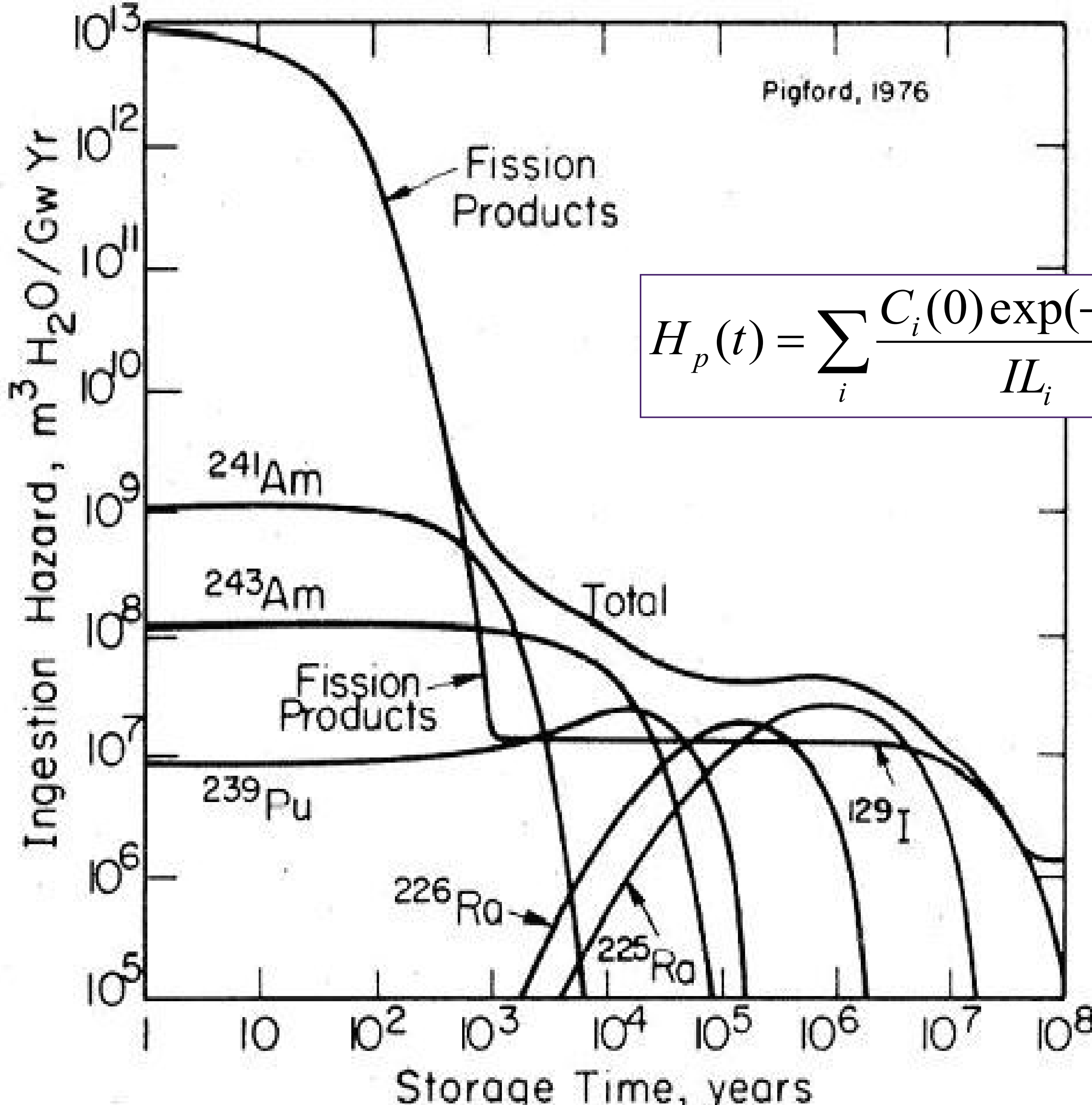
To the heart of glass

How do you run an experiment that takes thousands of years? As scientists studying nuclear-waste disposal are finding out, the answer is to look back in time. Philip Ball reports.



Volume Reduction Factor depends on initial concentration of salts in the aqueous waste. At about 200 g/L the volume reduction factor VRF is about 4.5

Ingestion radiotoxicity of Liquid HLW



$$H_p(t) = \sum_i \frac{C_i(0)\exp(-\lambda_i t)}{IL_i} V$$

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Real (residual) radiotoxicity of vitrified waste.

Radiotoxicity: *volume of water (m^3), in which the initial material has to be diluted to obtain permitted contamination levels.*

$$H(t) = \sum_i \frac{C_i(0)\exp(-\lambda_i t)}{IL_i}\Phi_i V$$

Coefficients $\mathbf{\Phi_i}$, account for the real releases of radionuclides.

Aqueous solutions (liquid wastes) have $\Phi_i = 1$.

Durable waste forms have Φ_i <<1.

Borosilicate and phosphate glasses are extremely durable materials which do not dissolve in water, thus they hold $\mathbf{\Phi_i}$ **<<1**

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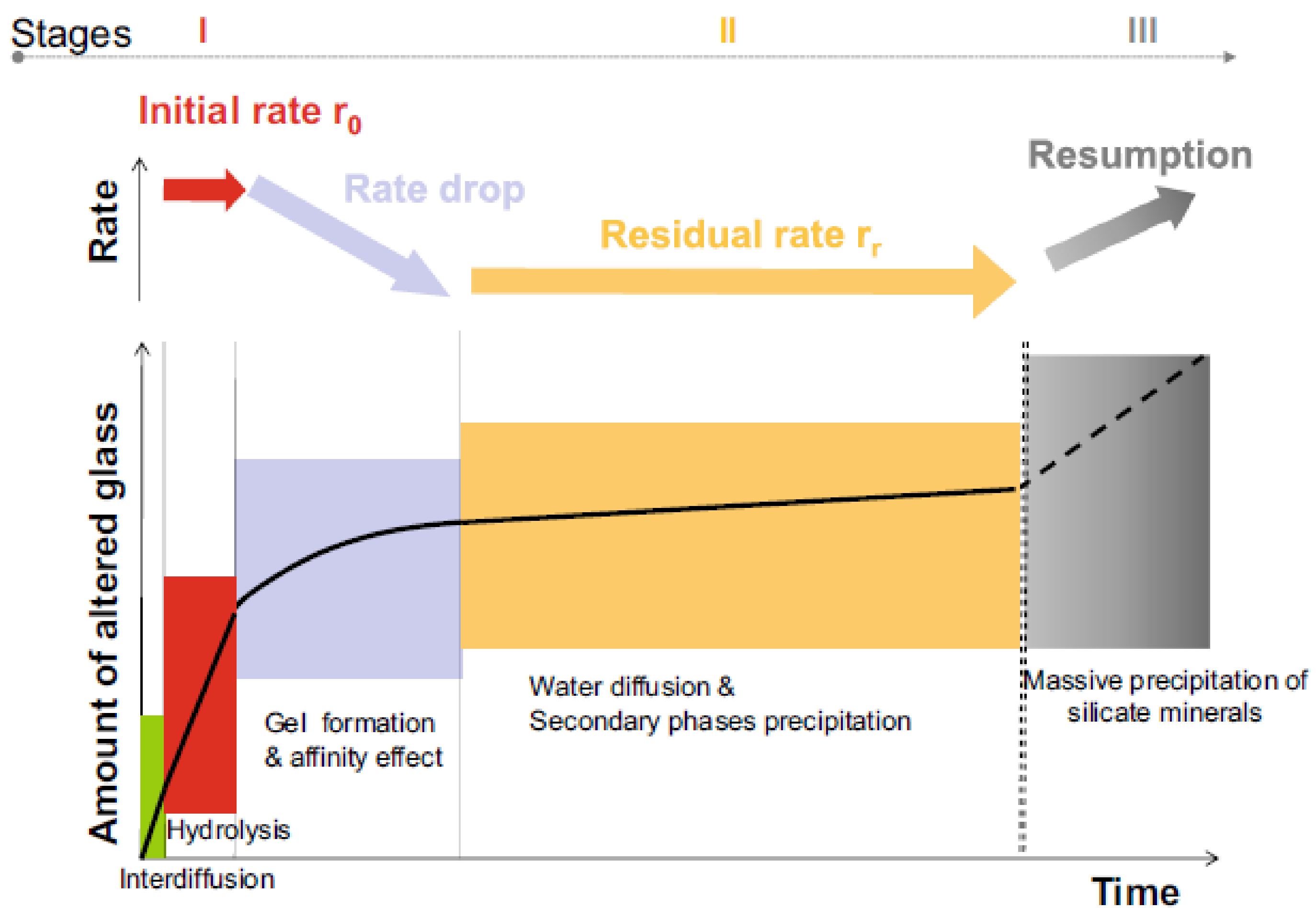
Table 17.2 Typical Properties of Glasses for Nuclear Waste Immobilisation

Glass Type	Density (g/cm^3)	Compressive Strength, (MPa)	NR[a] (10^{-6} g/cm^2 day)	TEC[b], (1/K)	T_{max}[c], K (°C)	Damaging Dose[d] (Gy)
Borosilicate	2.7	22–54	0.3 (Cs) 0.2 (Sr)	8×10^{-6}	≥823 (550)	$>10^9$
Phosphate	2.6	9–14	1.1 (Cs) 0.4 (Sr)	1.5×10^{-6}	≥723 (450)	$>10^9$

[a]IAEA test protocol for 28th day.
[b]TEC – thermal expansion coefficient.
[c]T_{max} is the maximum allowed temperature of glass representing the limit of its thermal stability. T_{max} is defined as the temperature above which the radionuclide NR's increase $>10^2$ times. By definition $T_{max} < T_g$.
[d]Irradiation has a small impact on glasses and the damaging dose is the absorbed dose above which the radionuclide NRs increase several times.



REVIEW ARTICLE OPEN

A comparative review of the aqueous corrosion of glasses, crystalline ceramics, and metals

Gerald S. Frankel[1], John D. Vienna[2], Jie Lian[3], John R. Scully[4], Stephane Gin[5], Joseph V. Ryan[2], Jianwei Wang[6], Seong H. Kim[7], Wolfgang Windl[1] and Jincheng Du[8]

All materials can suffer from environmental degradation; the rate and extent of degradation depend on the details of the material composition and structure as well as the environment. The corrosion of silicate glasses, crystalline ceramics, and metals, particularly as related to nuclear waste forms, has received a lot of attention. The corrosion phenomena and mechanisms of these materials are different, but also have many similarities. This review compares and contrasts the mechanisms of environmental degradation of glass, crystalline ceramics, and metals, with the goal of identifying commonalities that can seed synergistic activities and advance the current knowledge in each area.

npj Materials Degradation (2018)2:15 ; doi:10.1038/s41529-018-0037-2

Contents lists available at ScienceDirect

Journal of Nuclear Materials

journal homepage: www.elsevier.com/locate/jnucmat

Modelling aqueous corrosion of nuclear waste phosphate glass

Pavel P. Poluektov [a], Olga V. Schmidt [a], Vladimir A. Kascheev [a], Michael I. Ojovan [b,*]

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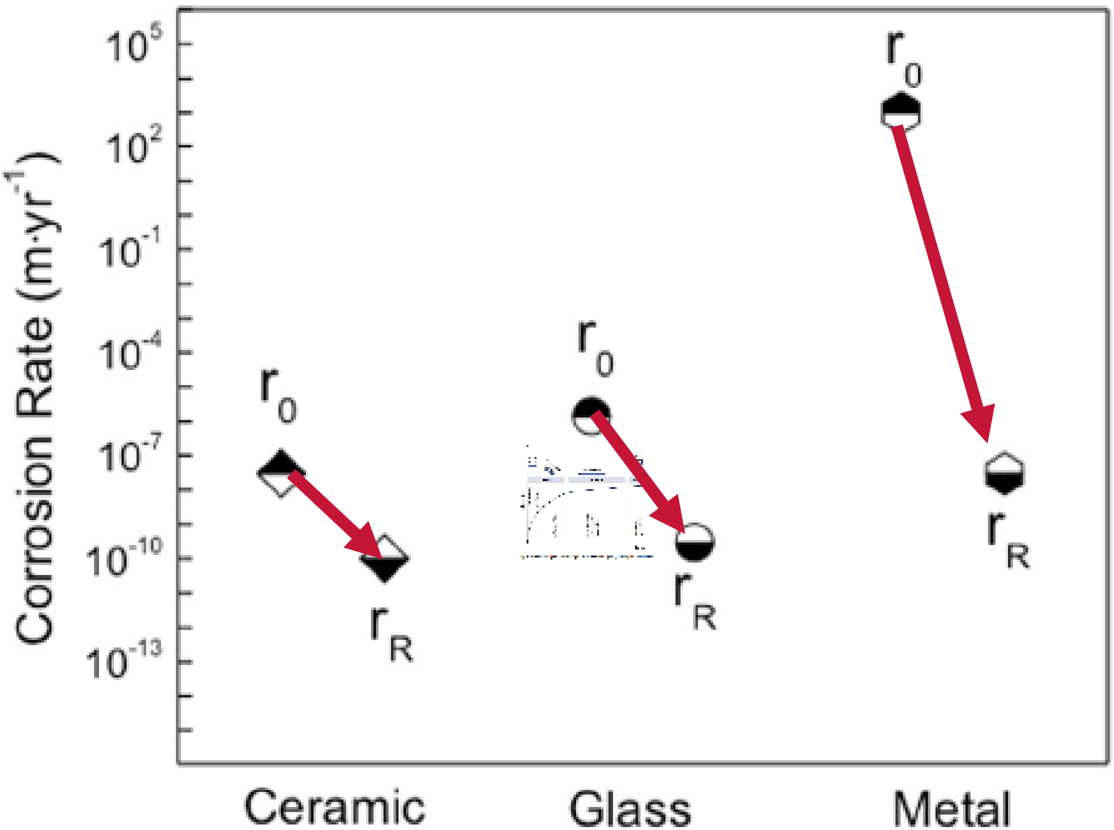
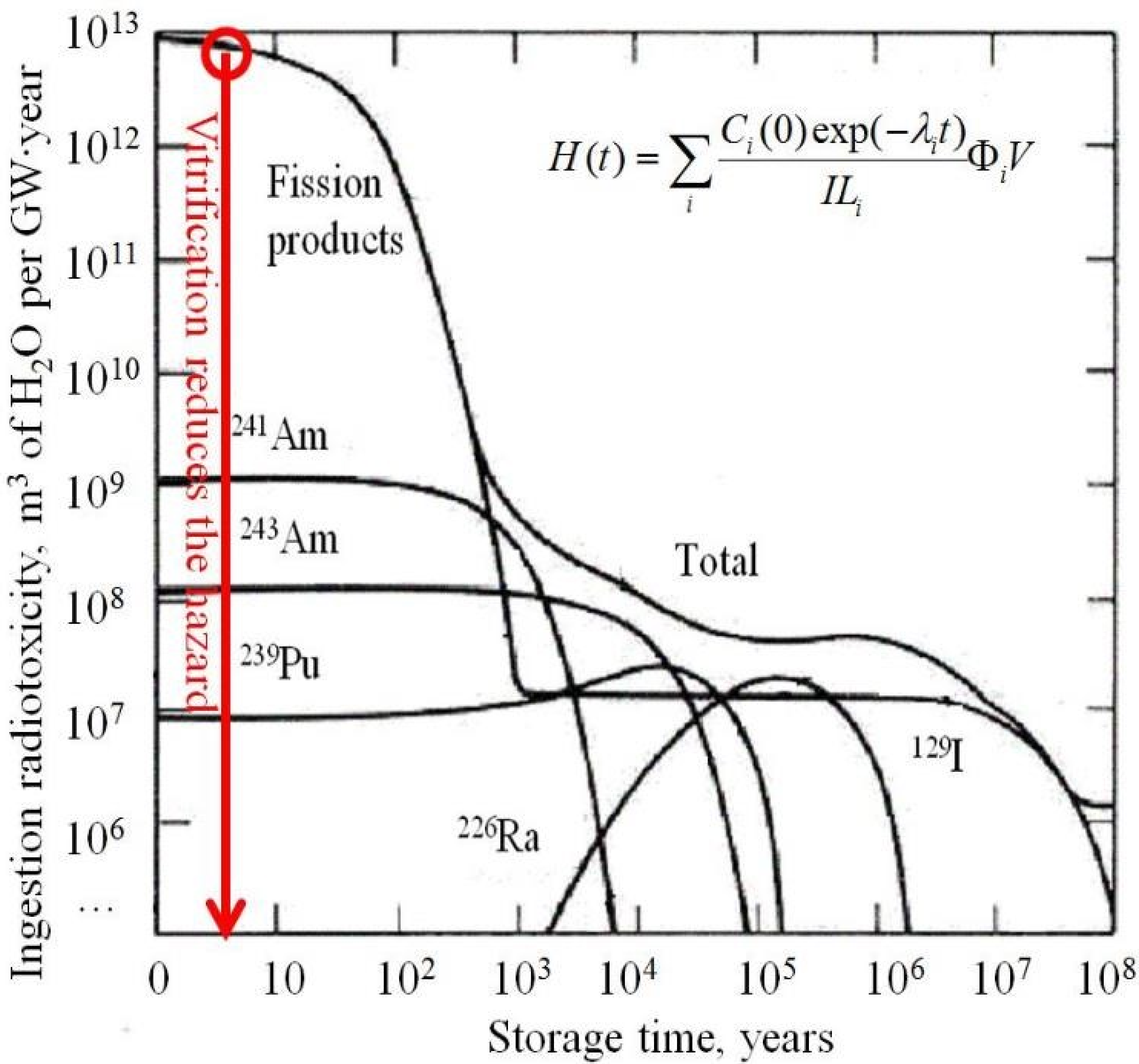


Fig. 7 Summary of estimates of initial rates of corrosion, r_0, and residual or steady state rates, r_R, for ceramics, glasses and corrosion-resistant metal alloys. The very high initial rate shown for metal passivation is a consequence of the very short timescale (μs) over which such rates can be measured for metals


$$H(t) = \sum_i \frac{C_i(0)\exp(-\lambda_i t)}{IL_i}\Phi_i V$$
Vitrification reduces the hazard
Fission products
^{241}Am
^{243}Am
^{239}Pu
Total
^{129}I
^{226}Ra
Ingestion radiotoxicity, m^3 of H_2O per GW·year
Storage time, years
10^{13}
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
...
0
10
10^2
10^3
10^4
10^5
10^6
10^7
10^8

VII. Some IAEA support activities

IAEA Support: Networks

https://nucleus.iaea.org/sites/connect/Pages/default.aspx

Networks

URF
Geological Disposal
Underground Research Facilities for Geological Disposal
Learn More / Join URF

IDN
International Decommissioning Network
Decommissioning of Nuclear Facilities
Learn More / Join IDN

MSN
Management System Network of Excellence
Management System Network
Learn More / Join MSN

ENV
Network on Environmental Management and Remediation
ENVIRONET - Environmental Remediation and NORM Management Network
Learn More / Join ENVIRONET

DISP
International Low Level Waste Disposal Network
Near Surface Disposal of Low Level Radioactive Waste
Learn More / Join DISPONET

CGULS
Coordination Group for Uranium Legacy Sites
Coordination Group for Uranium Legacy Sites
Learn More / Join CGULS

LAB
International Network of Laboratories for Nuclear Waste Characterization
LABONET - International Network of Laboratories for Nuclear Waste Characterization
Learn More / Join LABONET

bDN
beta-Delayed Neutron Emission
beta-Delayed Neutron Emission
Learn More / Join bDN

SFM
Spent Fuel Management
International Network on Spent Fuel Management
Learn More / Join SFM

ICT
I&C Technologies
Instrumenation and Control Technologies Network
Learn More / Join ICT

NKM
Nuclear Knowledge Management Network
Nuclear Knowledge Management Network
Learn More / Join NKM

RSLS
Regulatory Supervision of Legacy sites
International Working Forum

NNE
Networking Nuclear Education
Community of Practice

IPN
International Predisposal Network
forum for the sharing of practical experience
and international developments on radioactive waste management activities before disposal.

IAEA.org NUCLEUS

OJOVAN, Michael

IAEA | IPN

IPN

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Welcome to the IAEA International Predisposal Network - IPN

Prior to disposal, the radioactive waste usually goes through a number of steps such as pre-treatment, treatment, conditioning, storage and transport with characterization utilised within the entire cycle of radioactive waste. Predisposal management encompasses all of these steps that collectively cover the activities from waste generation up to final disposal.
The International Predisposal Network (IPN) is a forum for the sharing of practical experience and international developments on radioactive waste management activities before disposal.

The IPN is being established to increase efficiency in sharing international experience in the application of proven, quality assured practices for the predisposal management of radioactive waste including used nuclear fuel declared as waste.

The IAEA intends to support Member States either currently engaged in or seeking to develop predisposal technologies through their inclusion in the IPN to cooperate and coordinate relevant actions, training and technical advances. IPN members will include organisations and communities with current and future interest in radioactive waste management with focus on predisposal management. These include operators and regulatory bodies, as well as supporting organisations and scientific institutions and organizations that are involved with education and training.

For further information or questions please contact: IPN.Contact-Point@iaea.org

Members' area

Not a member yet?

Partnering Organizations

NEA NUCLEAR ENERGY AGENCY

European Commission

Current Highlights

- The 43rd MRS Symposium on Scientific Basis for Nuclear Waste Management organized in cooperation with the International Atomic Energy Agency will be held at IAEA, Vienna on 21 – 24 October 2019.
- New CRP "Long-lived Alpha Bearing Waste Management - Characterization, Processing and Storage" to start in 2018.

Events

- Regional Workshop RER9142 on t

The Abdus Salam International Centre for Theoretical Physics
www.ictp.it

Joint ICTP/IAEA Workshop on Radioactive waste management – solutions for countries without nuclear power programme

2 – 6 November 2015

(Miramare - Trieste, Italy)

The Workshop on radioactive waste management – solutions for countries without nuclear power programme is jointly organized by The Abdus Salam International Centre for Theoretical Physics (ICTP) and the International Atomic Energy Agency (IAEA).

Purpose

The Workshop aims to advise countries having small amount of waste from different research, medical, and industrial sources (institutional waste) which physico-chemical characteristics of radioactive waste should be considered and how to interpret them to effectively create infrastructure for safe collection, processing, storage and disposals of their radioactive waste, including intermediate level waste and spent fuel from research reactors, NORM and disused sealed sources.

Focus

This workshop will focus mainly on waste management professionals, both operators and regulators, from countries without nuclear power programme to create awareness of the technical inputs and physical and chemical waste characteristics necessary for establishing or upgrading national infrastructure for safe and efficient management of radioactive waste.

The Abdus Salam International Centre for Theoretical Physics
www.ictp.it

Joint ICTP/IAEA Workshop on radiation effects in nuclear waste forms and their consequences for storage and disposal

12 - 16 September 2016

Miramare, Trieste, Italy

The Workshop on radiation effects in nuclear waste forms and their consequences for storage and disposal is jointly organized by The Abdus Salam International Centre for Theoretical Physics (ICTP) and the International Atomic Energy Agency (IAEA).

PURPOSE

The Workshop aims to gain awareness on the most recent findings of research into radiation effects in nuclear waste forms and their role for waste storage and disposal. It aims to contribute to the transfer of specific knowledge to Member States towards their capacity building efforts and competence in nuclear waste immobilisation and disposal.

FOCUS

The workshop will focus mainly on experts on radiation effects in materials to explore the potential of both experimental and theoretical/computational approaches aiming to understand the consequences of irradiation of materials under extreme conditions, particularly focusing on long-term irradiation conditions envisaged for nuclear waste forms containing long lived fission products and actinides.

TOPICS

The main topics of the Workshop are:

- Fission and fusion power generation: challenges in the use of materials;
- Role of irradiation at different stages of material use in the nuclear industry;
- Nuclear waste forms and envisaged irradiation storage and disposal conditions;
- Behaviour of materials containing actinides and long lived radionuclides;
- Experimental techniques to investigate and simulate radiation effects;
- Theoretical/computational methods to investigate and simulate radiation effects;

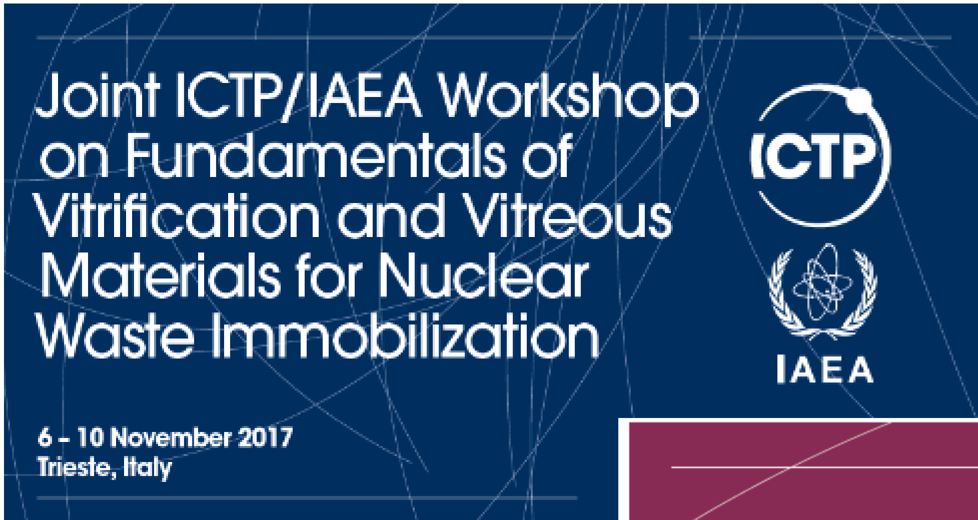
Co-Sponsors

International Atomic Energy Agency
(IAEA)
Vienna, Austria

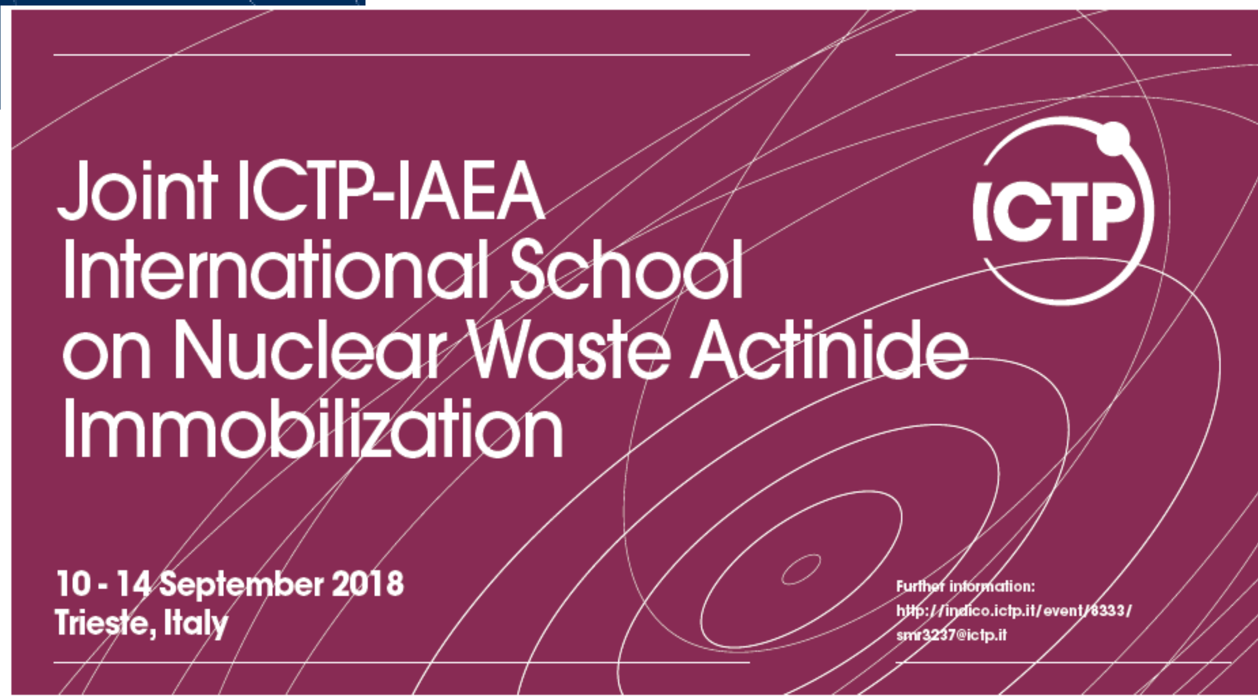
Directors

Michael I. OJOVAN
(IAEA, Austria)

Neil C. HYATT
(University of Sheffield, UK)



The Workshop is devoted to advances in understanding fundamentals of vitrification and utilization of vitreous materials in nuclear applications focusing on topics related to immobilization of nuclear wastes.



Joint ICTP-IAEA International School on Nuclear Waste Vitrification

23 - 27 September 2019
Trieste, Italy

Further information:
http://indico.ictp.it/event/8772/
smr3325@ictp.it

Nuclear waste management is a core issue for sustainable development and long-term viability of nuclear energy as energy supply. Glass is the overwhelming worldwide choice for the immobilisation of radioactive waste resulting from nuclear fuel reprocessing and other nuclear activities. The main goal of this School is the dissemination of knowledge on optimal methods of utilization of vitreous wasteforms for the immobilization of dangerous radionuclides. Another goal is transferring experience of vitrification technologies from leading centers and specialists to participants.

Course Directors:

Isabelle Hugon
Nuclear Research Division, CEA,
Bagnols-sur-Ceze Cedex, France

Willie Meyer
IAEA, Vienna - Austria

Michael I. Ojovan
Imperial College London - UK

indico.ictp.it/event/8772

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Atoms for Peace and Development

The 43rd MRS

Symposium on Scientific Basis for Nuclear Waste Management

organized in cooperation with the International Atomic Energy Agency will be held at IAEA, Vienna on 21 – 24 October 2019 (EVT1801370, BR A, MOE 68,67,69)

Symposium proceedings to be published by "MRS Advances" (Cambridge University Press). Special Volume Editors M.I. Ojovan and R.A. Robbins.

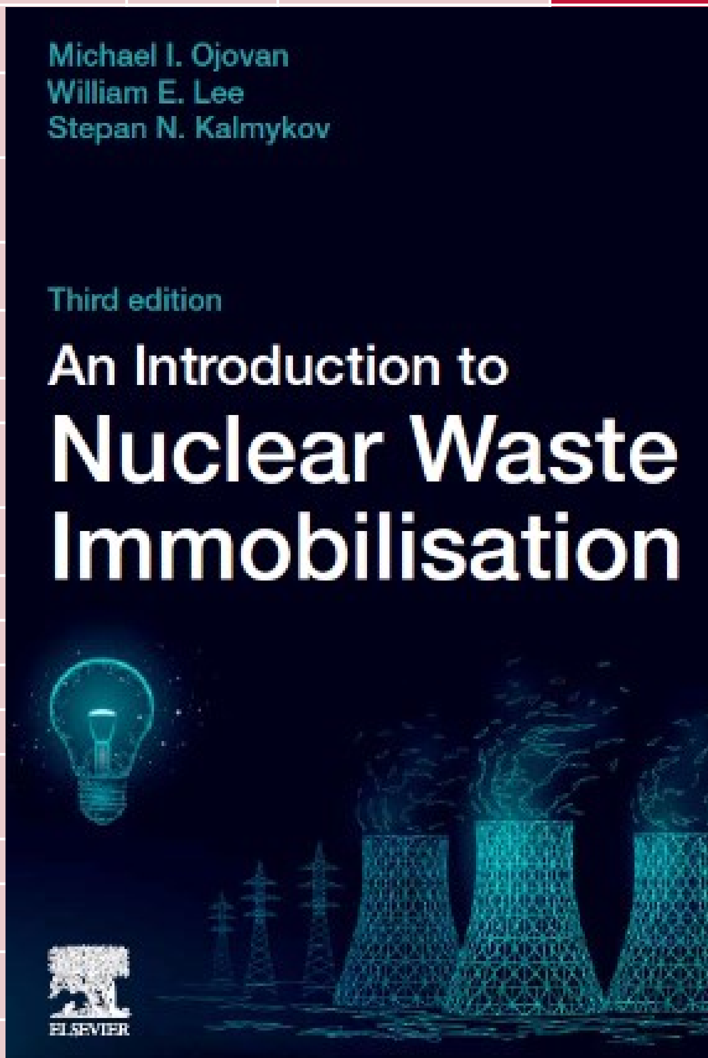
MRS Advances

Scientific Basis for Nuclear Waste Management

VIII. Summary

- Vitrification is the world-wide accepted technology for the immobilization of radioactive waste.
- Vitreous wasteforms provide a high degree of environmental protection.
- The IAEA conducts important activities aiming to share best waste management practice including vitrification technologies.

Facility	Waste type	Melting process	Operational period	Performance
R7/T7, La Hague, France	HLW	IHC[1]	1989/1992	6555 tonnes in 16885 canisters, $262 \cdot 10^6$ TBq to 2012
AVM, Marcoule, France	HLW	IHC	1978 – 2012	1357 tonnes in 3306 canisters, $22 \cdot 10^6$ TBq to 2012
R7, La Hague, France	HLW	CCM[2]	2010 –	GCM: U-Mo glass 76 tonnes in 190 canisters to 2012
WVP, Sellafield, UK				nes in 5615 canisters, $33 \cdot 10^6$ TBq to 2012
DWPF, Savannah River, USA				6300 tonnes in 3591 canisters, $1.8 \cdot 10^6$ TBq to 2012
WVDP, West Valley, USA				570 tonnes in 570 canisters, $0.9 \cdot 10^6$ TBq
EP-500, Mayak, Russia				~6200 tonnes, 643 10^6 Ci
CCM, Mayak, Russia				18 kg/h by phosphate glass
Pamela, Mol, Belgium				tonnes in 2201 canisters, $0.5 \cdot 10^6$ TBq
Karlsruhe, Germany				55 tonnes in 140 canisters, $0.8 \cdot 10^6$ TBq
Tokai, Japan				in 241 canisters (110 L), $0.4 \cdot 10^6$ Ci to 2007
Radon, Russia				10 tonnes
Radon, Russia				> 30 tonnes
Radon, Russia				10 kg/h, incinerator ash
Bohunice, Slovakia				1.53 m^3 in 211 canisters
WIP, Trombay, India				18 tonnes, $110 \cdot 10^3$ Ci to 2012
AVS, Tarapur, India				onnes in 100 canisters, $0.15 \cdot 10^6$ TBq
WIP, Kalpakkam, India				
WTP, Hanford, USA				~ 1000 tonnes to 2000
VPC, SEPEC Site, China				
Taejon, Korea	LILW	CCM	Testing	



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References:

1. ***An Introduction to Nuclear Waste Immobilisation**, M.I. Ojovan, W.E. Lee, S.N. Kalmykov. Elsevier, Amsterdam, 3rd Edition (2019).*
2. ***Radionuclides containment in nuclear glasses: an overview.** Gin S., Jollivet P., Tribet M., Peuget S., Schuller S. Radiochim. Acta 2017; 105(11): 927–959 (2017).*
3. ***Radioactive Waste Management and Contaminated Site Clean-up: Processes, Technologies and International Experience**, W.E. Lee, M.I. Ojovan, C.M. Jantzen. Woodhead, Cambridge (2013).*
4. ***Handbook of Advanced Radioactive Waste Conditioning Technologies**. M.I. Ojovan (Ed.). Woodhead, Cambridge (2011).*
5. ***Waste Immobilisation in Glass and Ceramic Based Hosts.** I.W. Donald Wiley, Chichester (2010).*

Thank you!