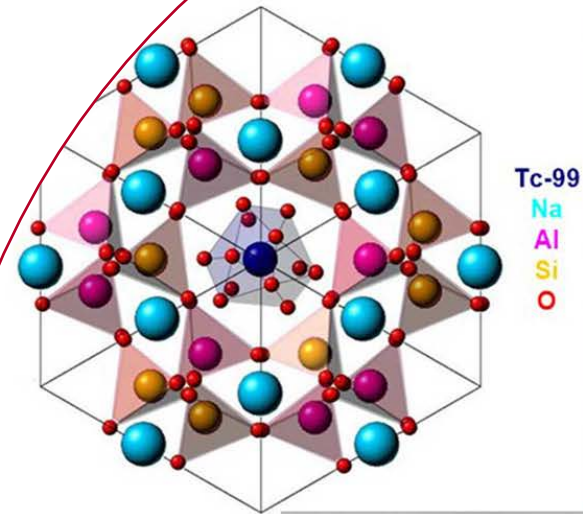


Leachability of THOR Residues

IGD-TP Exchange Forum

04 November 2015

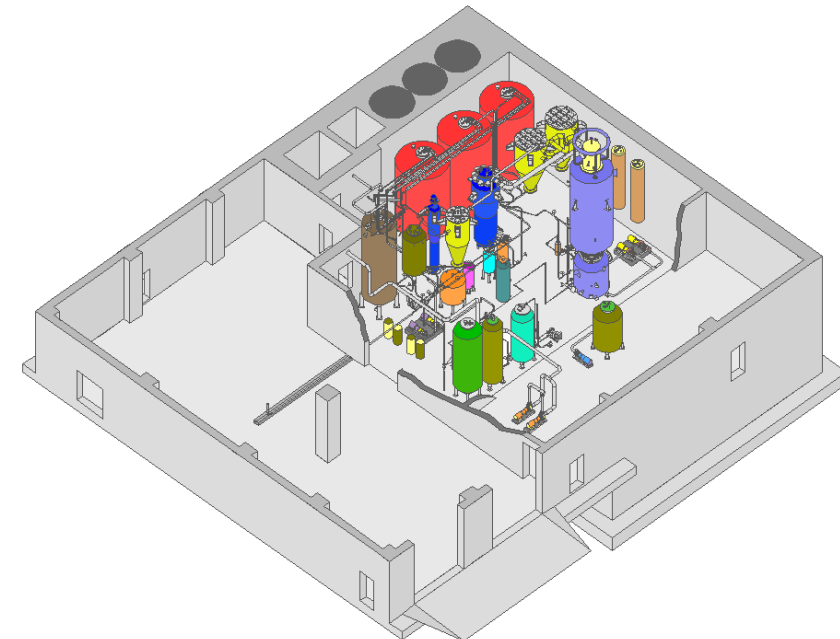


Outline

- THOR – Thermal Organic Reduction
- Technology overview
- Wastes treated
- Solid product characteristics
- Leach resistance
- Optional monolith waste form
- Summary

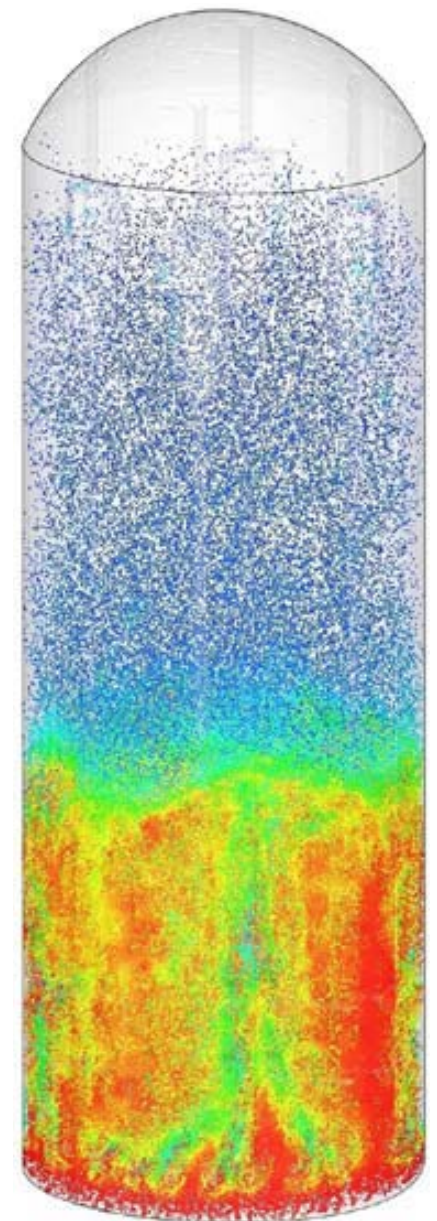
THOR - Thermal Organic Reduction

- Fluidized Bed Steam Reforming process
- Decomposition of Organic Compounds into carbon dioxide (CO₂) and Steam (H₂O)
- Reduction of Nitrates into Steam (H₂O), nitrogen gas (N₂), and (CO₂)
- Non-Incineration
- No dangerous Off-Gases
- No liquid effluents
- Captures 99.99% of radioactivity into the final, solid product
- Customizable final product characteristics
- Low maintenance
- Volume Reduction
- 14+ Years of Continuous, Full-Scale Operations in Erwin, TN



THOR Technology

- Thermal process
 - Fluidized bed of granular solids
 - Fluidized with steam
 - Operates at 650-850°C
- Waste preparation and inputs
 - Mineralizing additive
 - Waste feed injected into fluidized bed
 - Coal
- Inside the Fluidized Bed Steam Reformer
 - Water evaporates
 - Nitrates reduced to nitrogen gas
 - Inorganic waste constituents converted into insoluble minerals



Simplified CFD model of Fluidized Bed Steam Reformer

THOR – Treated Wastes

- **Nitrate Wastes**

- Main Chemical Component: Sodium Nitrate and other Nitrates and Nitrites
- Other Chemical Components: Organics, Sulfates, Chlorides, Calcium

- **Ion Exchange Resins (IER)**

- Main Chemical Components: Long-chain Organics
- Other Chemical Components: Boron, Sulfur, Iron, Sodium, and Lithium
- Commercial Treatment of IERs for over 14 years in Erwin, TN

- **Dry Active Waste (DAW)**

- Main Waste: Filters
- Other Waste: Clothing, Plastics, Rubber, etc.
- Commercial Treatment of DAW for over 14 years in Erwin, TN

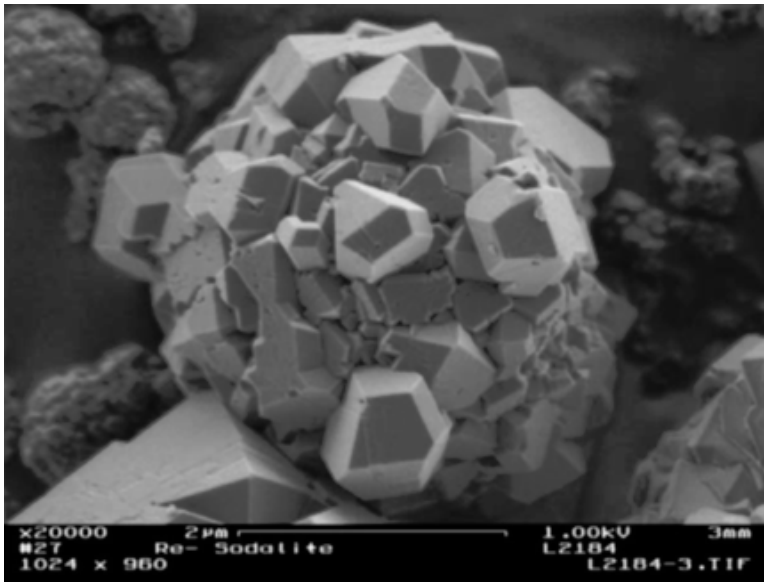
- **Various Wastes Liquids and Sludges**

- Main Wastes: Oils, Sludges, etc.
- Other Wastes: Heavy Metal (Uranium and Magnesium) bearing wastes

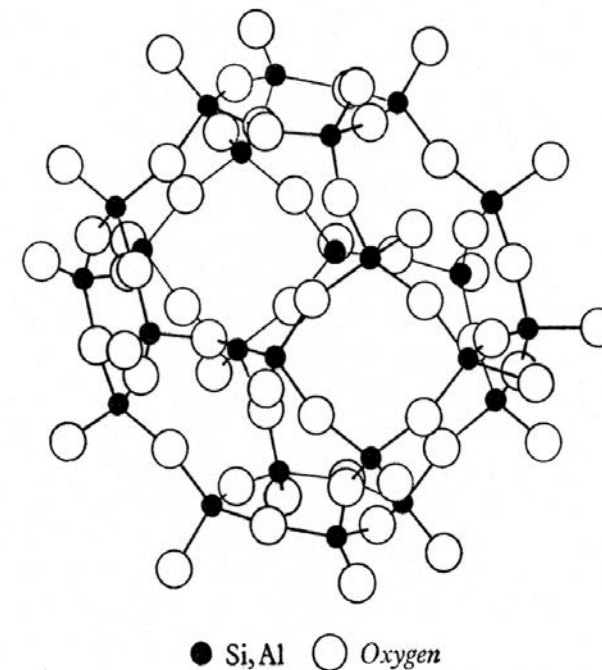
Solid Waste Products

- Small sized particles of ceramic mineral
- Alkali-Alumino-Silicate (feldspathoid) minerals (NAS)
 - Nepheline ($\text{Na}_2\text{O}-\text{Al}_2\text{O}_3-2\text{SiO}_2$)
 - Nosean (6 Nepheline + Na_2SO_4)
 - Sodalite (6 Nepheline + 2NaCl)
 - Leucite ($\text{K}_2\text{O}-\text{Al}_2\text{O}_3-4\text{SiO}_2$)

THOR Product Solids



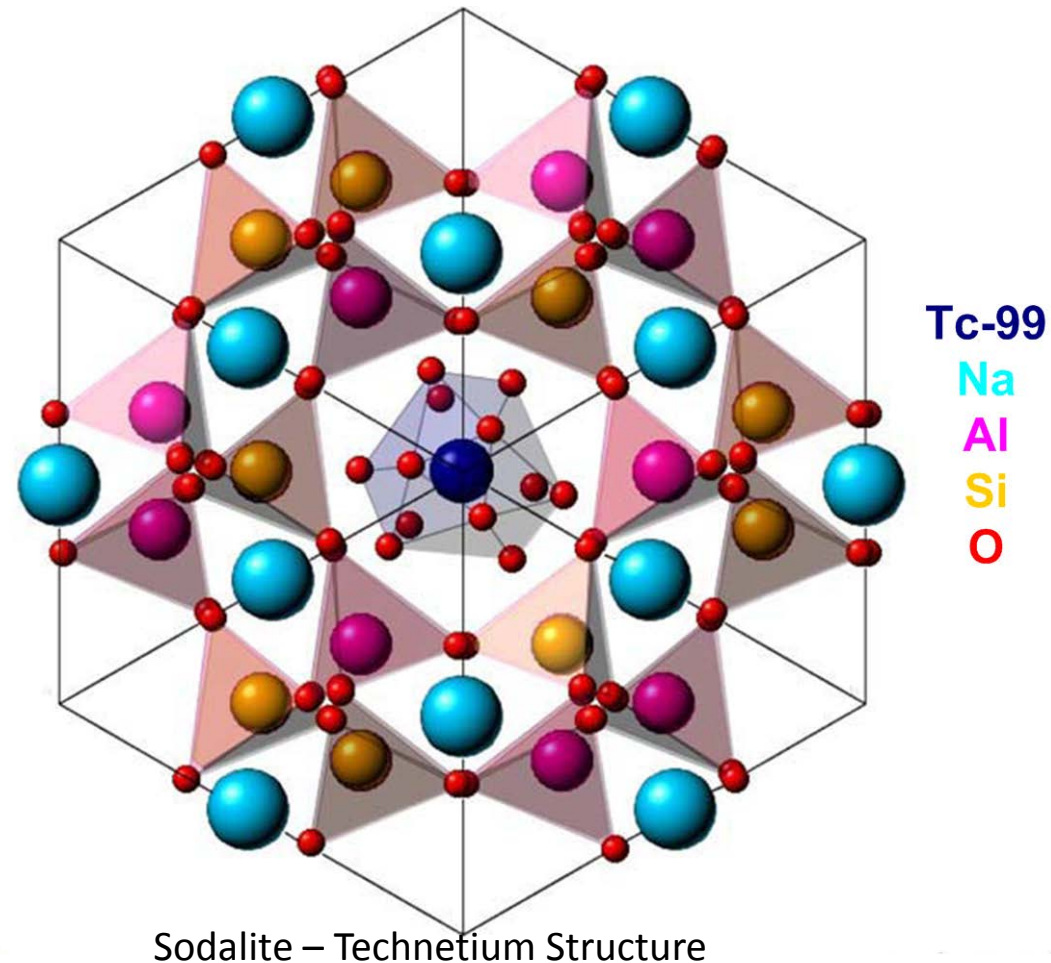
Scanning Electron Microscope Image of Sodalite mineral



Typical Feldspathoid Structure

Solid Waste Products

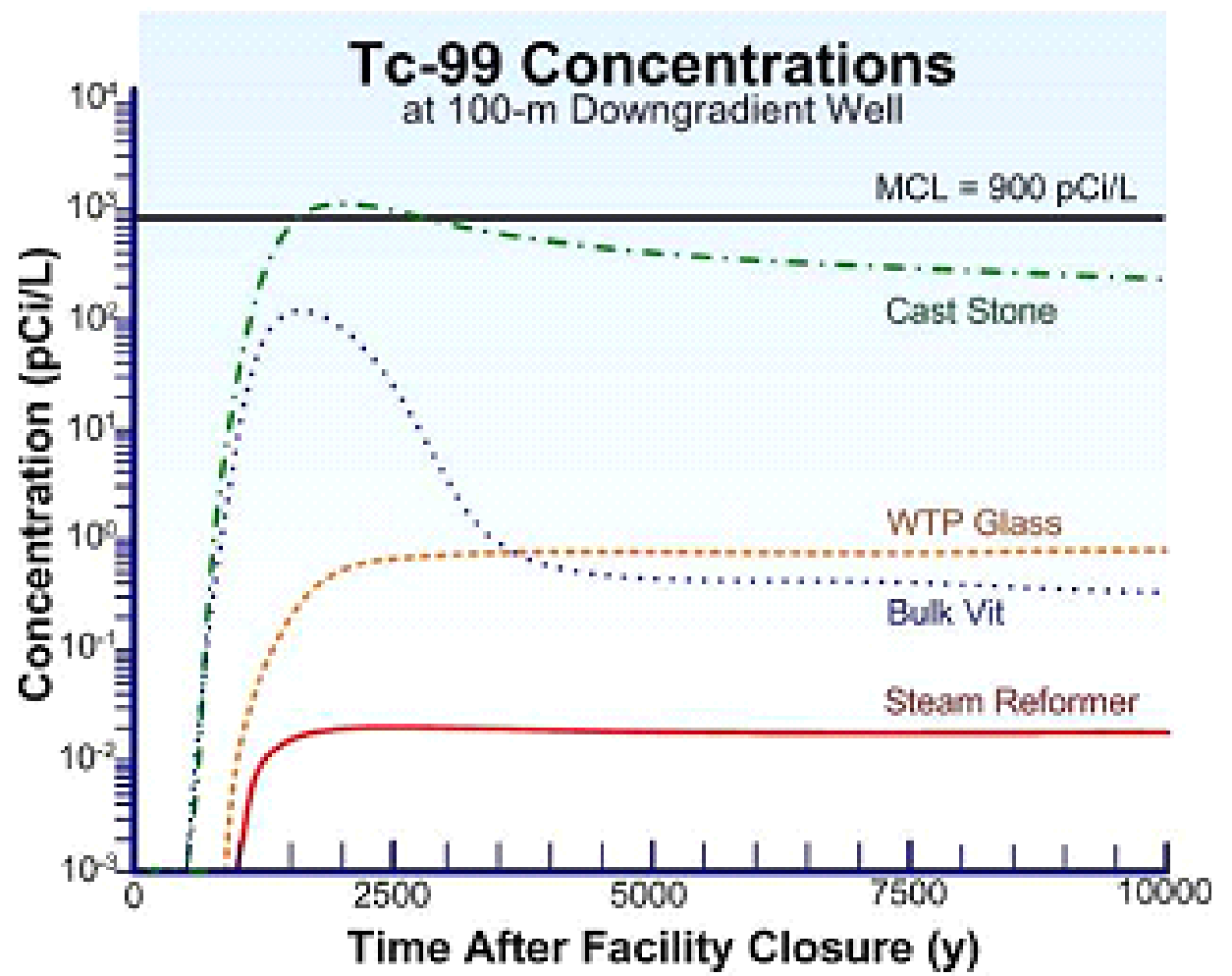
- Process operating temperature is sufficiently low to not vaporize radionuclides
- Ceramic waste form contains cavities/sites that incorporate:
 - Radionuclides (Tc, Cs, most I)
 - Alkali Metals
 - Sulphur
 - Chlorides
 - Fluorides
- Spinel minerals form that contain various metals
 - Cr, Ni, Fe, Pb, etc.



Leach Resistance Performance of THOR Product

- Leach resistance performance is better than vitrified glass
 - >99.99% retention of Cs, Tc and other radionuclides
 - Can accommodate Cl, F, SO₄, Mo, Re, Tc, etc.

Groundwater Concentrations from Product
(25% of ILAW Inventory per Waste Form)



Leach resistance of Tc-99 compared to other waste forms – analysis performed by Pacific Northwest National Lab

Optional Monolith Final Waste Form

- Granular mineral products are mixed with geopolymer binder to make monolithic final waste form
 - Geopolymers are amorphous to semi-crystalline, three-dimensional silico-aluminate minerals; mineral polymers resulting from mixing clay with sodium silicate and/or NaOH
 - Density of 1.78g/cc
 - Compressive strength of 159 bar at 33 days cure time



Mineral Product



THOR Monolith

Summary – THOR Steam Reforming

Accommodates widely varying inputs

- Treats solids, liquids, or sludges with high or low pH
- High organic destruction
- Does not volatilize Cs, Tc (and others)
- Mineralizes Cl, F, P, and SO₄, and radionuclides in leach resistant solid

Non-Incineration

- Operates below flammability limits
- Modular design can be provided

Leach resistant wasteform from processing

- Qualifications to date validate highly leach resistant
- Leach tests done on real waste and simulant
- Granular and monolith waste forms

THOR is Proven

- 14+ year history of commercial operations treating ion-exchange resins

Studsвик

Supplemental Slides/Data

THOR Product: 7-Day PCT Results for Granular Product made from simulant and actual Radioactive Waste

***PCT requirement for treated LAW waste: <2.0 g/m²

Normalized Elemental Release	ESTD P-1B Granular		BSR Module B Simulant Granular		BSR Module B Radioactive Granular	
	(g/m ²)	Std. Dev.	(g/m ²)	Std. Dev.	(g/m ²)	Std. Dev.
Al	2.12E-03	2.01E-06	2.34E-03	7.09E-05	3.97E-03	1.33E-04
S	3.42E-01	2.17E-03	4.34E-02	1.59E-03	7.72E-02	1.47E-03
¹³³ Cs	9.31E-03	8.78E-05	1.09E-02	2.36E-04		
¹³⁷ Cs					2.29E-03	1.71E-04
Re	4.10E-03	4.07E-04	8.83E-03	3.45E-04	1.13E-02	1.22E-03
⁹⁹ Tc					2.42E-02	5.86E-03
Na	2.15E-02	2.40E-04	1.14E-02	4.73E-04	1.24E-02	3.96E-04
Si	7.82E-04	2.50E-05	9.86E-04	4.71E-05	6.17E-04	4.83E-05
¹²⁷ I	1.51E-02	4.13E-04	9.82E-04	1.06E-03	1.69E-03	8.04E-05
¹²⁹ I					<3.61E-03	N/A
pH	11.63 (Blend)		11.4		11.25	

N/A = Not Applicable

THOR Product: 7-Day PCT Results for Monoliths and Granules of Simulant FBSR Mineral Products

***PCT requirement for treated LAW waste: <2.0 g/m²

Normalized Elemental Release (g/m ²)	Non-Radioactive				Radioactive	
	Fly Ash ESTD P-1B* GEO-7 Monolith (68% FBSR loading)	Fly Ash BSR Mod B GEO-7 Monolith (68% FBSR loading)	ESTD P-1B Granular	BSR Mod B Granular	BSR Mod B Clay Monolith (65% FBSR loading)	BSR Mod B Granular
Al	4.30E-05	4.47E-04	2.12E-03	2.34E-03	2.60E-04	3.97E-03
S	4.78E-02	1.02E-01	1.41E-01	4.34E-02	3.20E-02	7.72E-02
Cs-133	2.01E-03	4.60E-03	9.31E-03	1.09E-02		
Cs-137					7.00E-05	2.29E-03
Re	1.05E-02	1.99E-02	1.87E-02	8.83E-03	3.96E-03	1.13E-02
Tc-99					<8.35E-03	2.42E-02
Na	2.15E-02	7.30E-02	1.74E-02	1.14E-02	1.81E-02	1.24E-02
Si	2.70E-03	7.02E-03	7.82E-04	9.86E-04	2.40E-04	6.17E-04
I-127	5.27E-03	3.61E-03	1.51E-02	9.82E-04	5.00E-04	1.69E-03
I-129					<2.66E-03	<3.61E-03
pH	12.39	12.56	11.63	11.40	10.33	11.25