Hot Isostatic Pressing Technology

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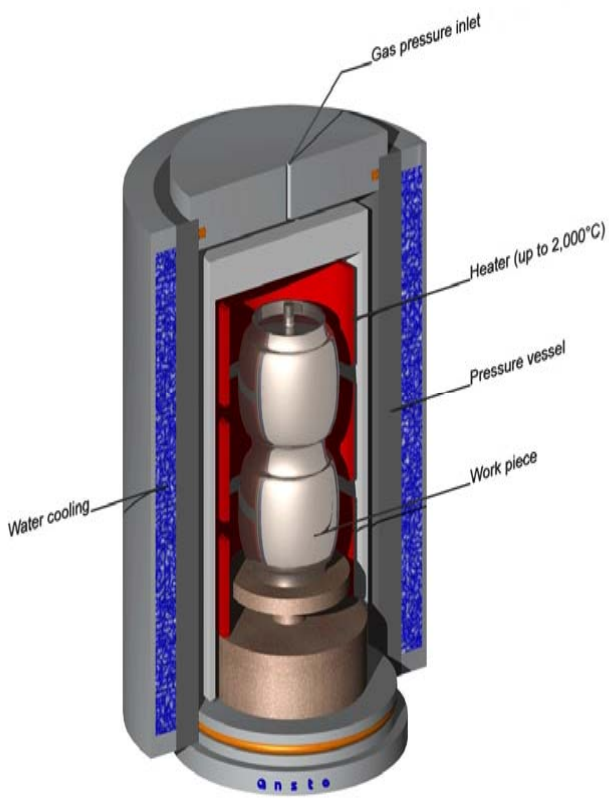
Basic HIP Process

- ***HIP patented in the US by Romp in 1941.***
  - Battelle patented HIP process to diffusion bond nuclear fuel in 1964.
- ***Technology consists of a pressure vessel containing an electrically heated furnace.***
- ***Components are placed in a sealed can inside the furnace and isostatically pressed with argon to maximum density***
- ***Pressure vessels are built to stringent ASME codes, and include active and passive safety systems.***

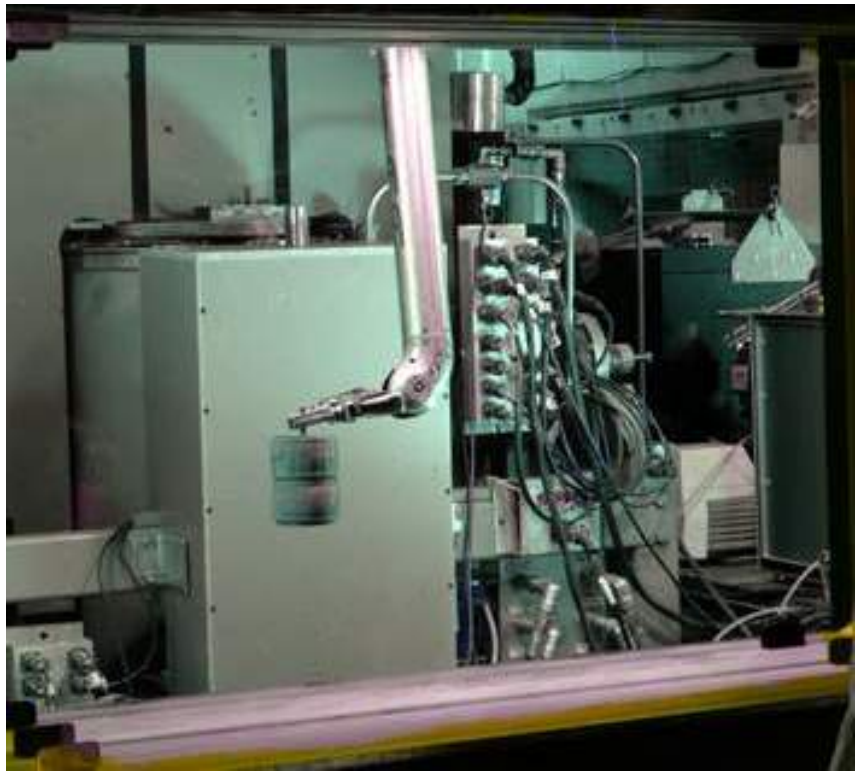


Why Current DOE-ID Interest in Hot Isostatic Pressing

- ***Technology is mature***
  - 50 years world-wide safe operating experience at scale larger than required for calcine
  - Used in the US by BWXT for fuel manufacture
  - HIP unit in HFEF hot-cell at INL.
- ***Higher waste loadings***
  - Not limited by waste form electrical properties or viscosity
- ***Flexible technology capable of producing a range of waste forms***
- ***Maximum volume reduction***
- ***Zero emissions from the high temperature densification process***
  - No need for extensive off-gas system

Additional Advantages of HIP

- ***Waste isolated from process equipment.***
- ***Process is readily scalable***
- ***Batch process reduces risk for heterogeneous waste feeds***
- ***Lower decommissioning costs than other treatment alternatives***



HIP unit installed in the HFEF cell at MFC

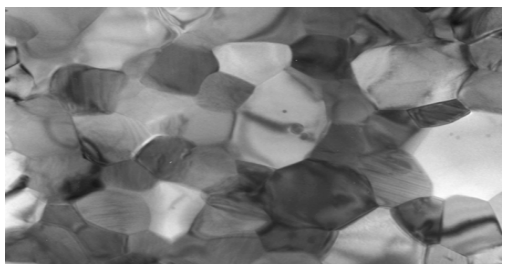
Glass Ceramic Stability

- ***By design, the refractory glass produced in the waste form is highly durable as are the crystalline components.***
- ***The glass-ceramic will be unaffected by temperatures predicted in the repository.***
  - The glass-ceramic does not de-vitrify under raised temperatures in a repository.
- ***The presence of crystalline phases in the glass matrix toughens the waste form, leading to excellent mechanical properties.***
  - Resultant glass-ceramic is much less susceptible to cracking than borosilicate glass.
- ***Radiation and transmutation resistance would be at least equivalent to a borosilicate glass***

Benefits of Complementary Waste Forms

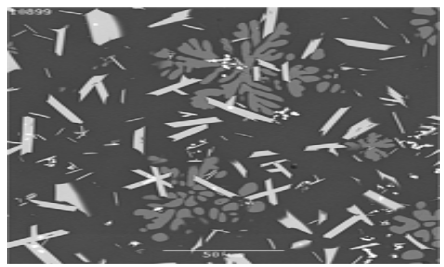
- ***No single waste form or process is suitable to economically handle the total HLW cleanup challenge.***
  - Parallel deployment of complementary tailored ceramic and hybrid glass-ceramic waste forms can overcome the limitations of baseline approach for wastes difficult to vitrify and create opportunities to:
    - *Deliver significant life-cycle cost savings and reduce risk*
    - *Add flexibility and provide defense-in-depth treatment options*
    - *Utilize flexible process technology*
- ***Waste difficult to incorporate into glass can be processed in a common process line*** *(determined by waste characteristics)*

Multiphase Glass-ceramic

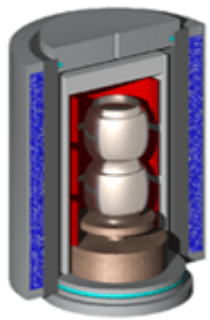


(titanates, zirconates, phosphates, silicates)

Hybrid glass-ceramic

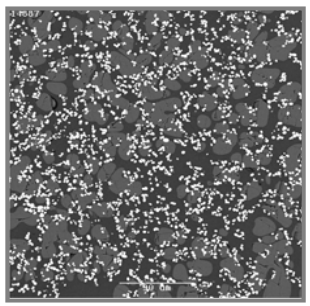


(Durable glass plus ceramic phases)

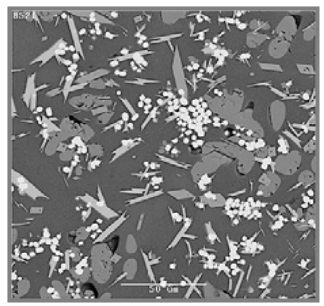


Technology Comparison

Technology:	HIP	CCIM	JHM
Matrix:	glass-ceramic	glass-ceramic	borosilicate glass
Waste loading:	60-90+%	50-60%	20-35%
Durability (PCT-B):	10-100 x EA glass	10-100 x EA glass	10 x EA glass
Final volume:	15-45% reduction	10-15% reduction	100+% increase
(relative to untreated calcine)			
Process temp:	2200°F	2375°F	2100°F
Process pressure:	4500 PSI	Atmospheric	Atmospheric
Off-gas:	very low	medium-high	medium-high

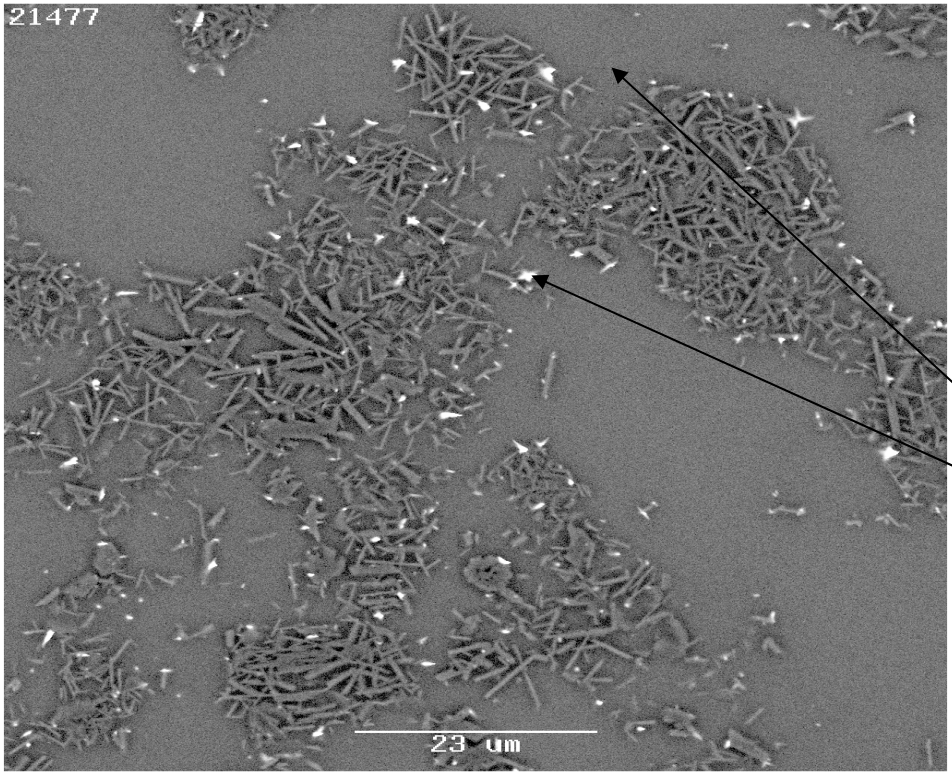


HIP Glass Ceramic



Cold Crucible Glass Ceramic

Alumina-rich INL Calcine (Bin Set #1)

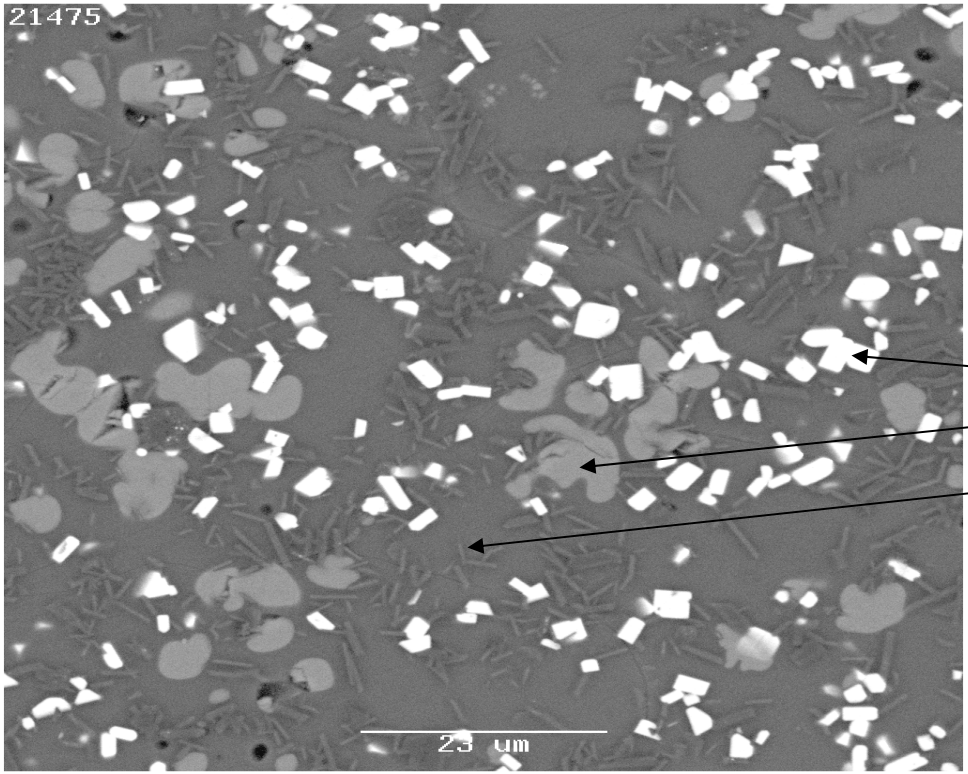


Waste Loading: 50%

Density:2.8 g/cm3

<u>Crystalline phases:</u>
corundum (major)
zirconia (trace)

“Mixed” INL Calcine (Bin Set #2)



Waste Loading: 80%
Density:3.0 g/cm3

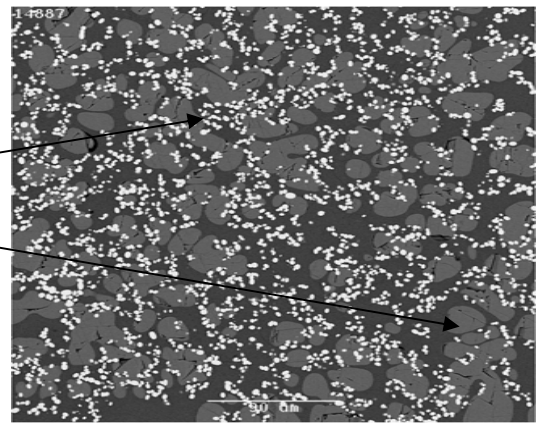
<u>Crystalline phases:</u>
zirconia (major)
fluorite (major)
corundum (major)

Zr-rich INL Calcine (BS#4)

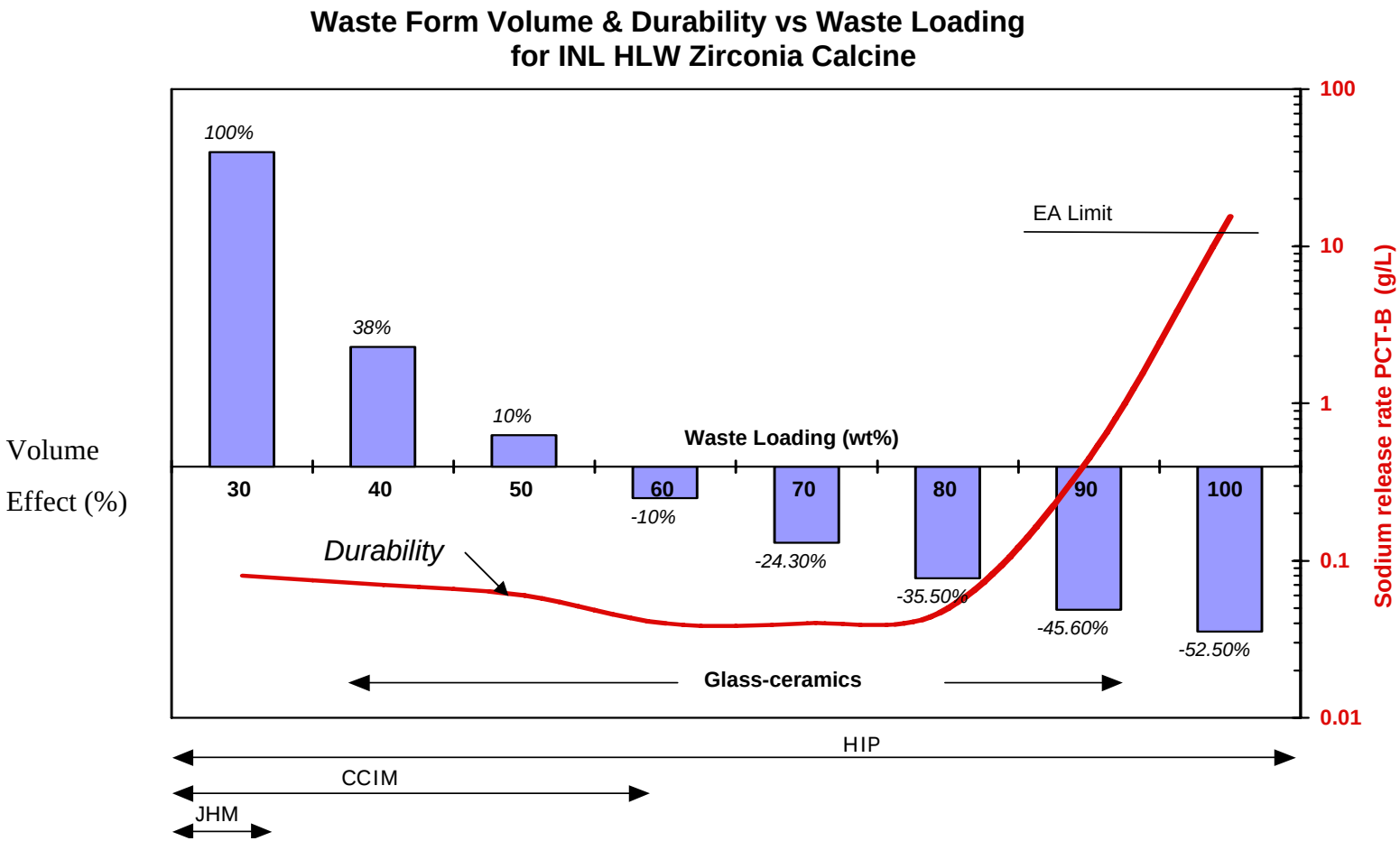
Consolidation:	HIP
Scale:	65 lbs
Diameter	8 inch
Waste loading:	**80%**
Durability:	100 x EA Glass
Density:	3.10 g/cm3
Final Volume:	35% reduction

(relative to untreated calcine)

<u>Crystalline phases:</u>
zirconia (major)
fluorite (major)



Zr-rich INL Calcine (BS#4)



Waste Loading and Volumes

Assume product needs to exceed EA glass durability by a factor of 10

Bin Set	Calcine Volume (m3)	Calcine Density	Vol % of total calcines	Achievable Waste Loading (conservative)	Waste Form Density	Waste Form Volume (m3)	% Volume Reduction
1	*	1.1	*	50%	2.8	*	21%
2	*	1.4	*	80%	3.0	*	42%
3	*	1.6	*	78%	3.1	*	34%
4	*	1.6	*	80%	3.1	*	35%
5	*	1.6	*	80%	3.1	*	35%
6	*	1.4	*	70%	2.8	*	29%
Total	4288		100%			2807	~35%

Overall % *reduction* in waste volume: 35% (1480 m3)

Note: Much greater volume reductions are achievable if direct HIPing of calcine meets regulatory requirements

Provides Flexible Waste Form Options

- ***Overcomes inherent limitations of baseline vitrification for problematic wastes by including hybrid glass-ceramic and multiphase ceramic waste forms***
- ***Delivers cost savings via increased waste loadings (volume reduction) with no loss in chemical durability for these problematic wastes***
  - Results in maximum repository allocation and disposal cost savings
- ***Glass-ceramics are well suited to compositionally diverse, heterogeneous waste streams that contain components with low compatibility with glass***
- ***Reduce technical risk and increase cleanup efficiency by extending portfolio of waste form options***
  - Provides “defense-in-depth” waste form alternatives to the cleanup campaign
  - Provides solid return on investment
- ***Process not limited by waste form chemistry; insensitive to electrical properties, melt characteristics and viscosity of the material***
  - Maximizes waste loadings, process reliability, and throughput
  - Very low off-gas emissions lowers environmental risks

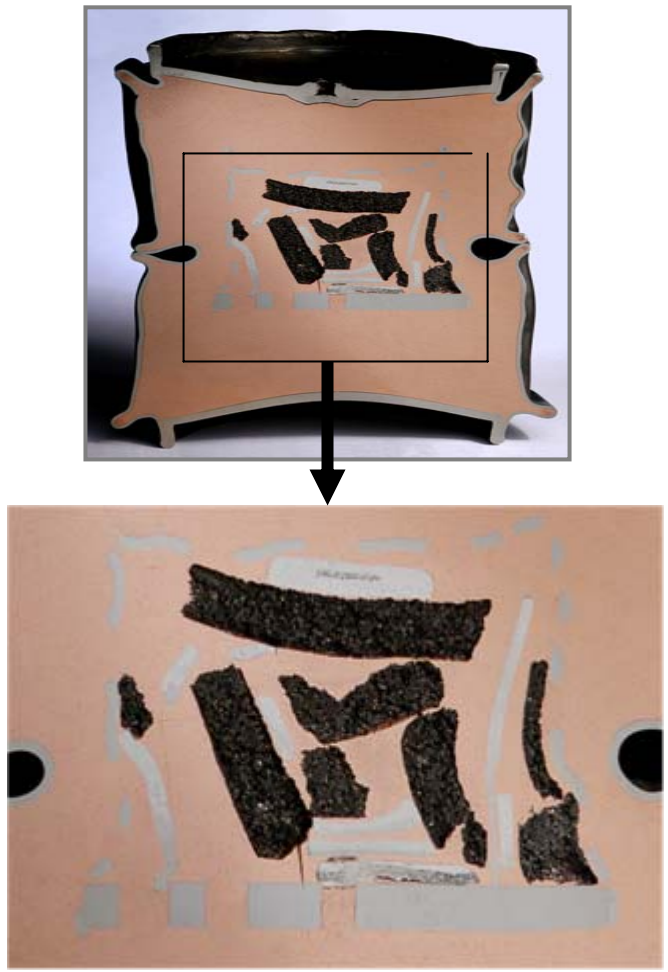
HIP Process Flexibility Includes…

- ***Steam reformed SBW***
  - Uncertainty over disposition path for granular steam-reformed SBW
  - If required, a HIP process could be used to convert the steam reformed powder into a monolithic waste form
    - *Associated volume reduction would be ~ 40%*
    - *Additives could be used if required.*

Mineralized steam reformed SBW product provided by Studsvik and HIPed without additives

HIP Process Flexibility Includes ...

- ***Metal encapsulation of uneconomic feeds***
  - The flexible HIP process also offers metal encapsulation as a means of immobilizing waste streams uneconomic to handle separately including:
    - *Broken fuel pins, fuel hulls, etc.*
    - *This can be done on same process line.*
  - Copper is the basis of the Swedish SNF immobilization strategy



Interest in Maximizing ROI by Diversifying DOE's Technology Platform

- ***DOE-ID currently has a HIP unit installed in HFEF hot-cell at INL***
- ***Opportunity to maximize ROI, and reduce technical risk, by using this HIP unit to perform trials on glass-ceramic and multiphase ceramics with inactive materials in the following areas:***
  - Glass-ceramic waste forms for INL calcines
  - Direct HIPing of INL calcines
  - Direct HIPing of SBW
  - Encapsulation of corroded fuel cladding, hulls, pins etc
  - Immobilization of other waste difficult to vitrify in conjunction with ceramic or glass-ceramic matrices including:
    - *Technetium, U-233, impure Plutonium, Cesium, Iodine, …*
  - GNEP related waste streams
- ***Further demonstration requirements:***
  - In line heater technology
  - HIP can filling at the rate required
  - HIP can cycle time at scale
    - *Current HIP technology allows cooling from 2200F to 750F in one hour*

HIP Quality Assurance

- ***Product quality by input characterization is possible***
- ***HIP can dimensions can be readily measured to verify successful consolidation***
- ***Able to sample feed composition before loading into HIP can***
- ***Process is amenable to existing product quality assurance protocols developed for borosilicate glass***

Worker Radiation and Industrial Safety

- ***HIP is currently installed in the HFEF hot-cell at INL having met DOE safety requirements***
  - Process is remotely operated
  - High maintenance items are located outside hot cell
- ***No direct contact between waste and HIP processing equipment***
- ***Modular furnace design that can be remotely maintained***
- ***Vessel safety features:***
  - Code vessel ASME Section VIII division 2 & 3.
  - Leak before break designs
  - High cyclic life, 100,000+.
  - Additional safety shield.
  - Active and passive overpressure protection systems
- ***HIP can failure rates are < 0.5%, with all welds inspected and helium leak tested prior to filling***
  - Welds are designed to be kept in compression

Summary

- ***HIP glass ceramic process offers significant advantages for calcine treatment***
  - Offers high waste loadings, large volume reductions and high chemical durability
  - Low complexity and low technical risk
- ***HIP technology is industrially mature at the scale required, and is currently used at production scale in US nuclear industry***
  - Safe industrial and radiological working environment
  - Flexibility maximizes DOE's waste treatment technology platform
- ***Same process can HIP calcine directly if legally permitted and deliver 50% volume reduction***
- ***Extremely wide process windows***
- ***Very modest off-gas requirements with minimal secondary waste***