High Level Waste (Calcine) Disposition Project

Project Overview

for the

National Academy of Sciences

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Project Manager

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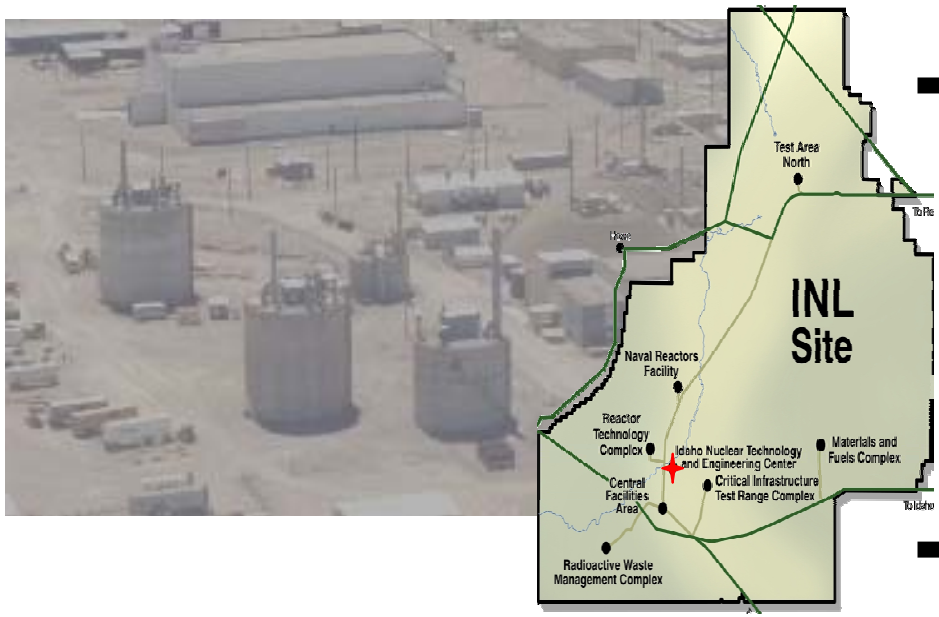
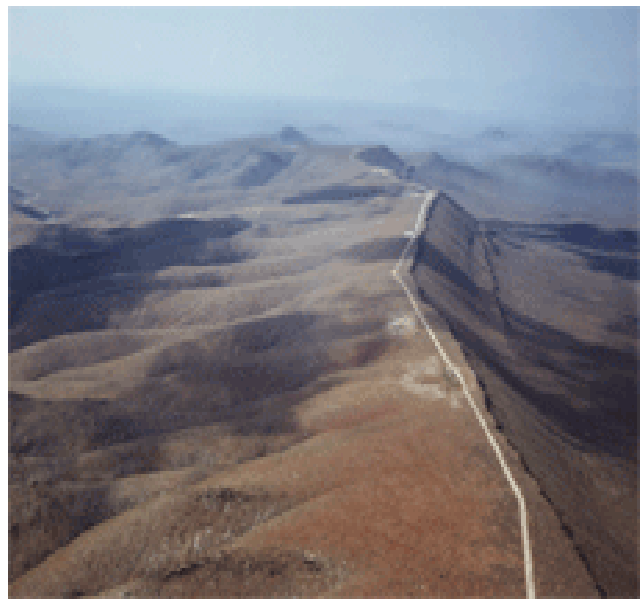
Need for Calcine Disposition Project

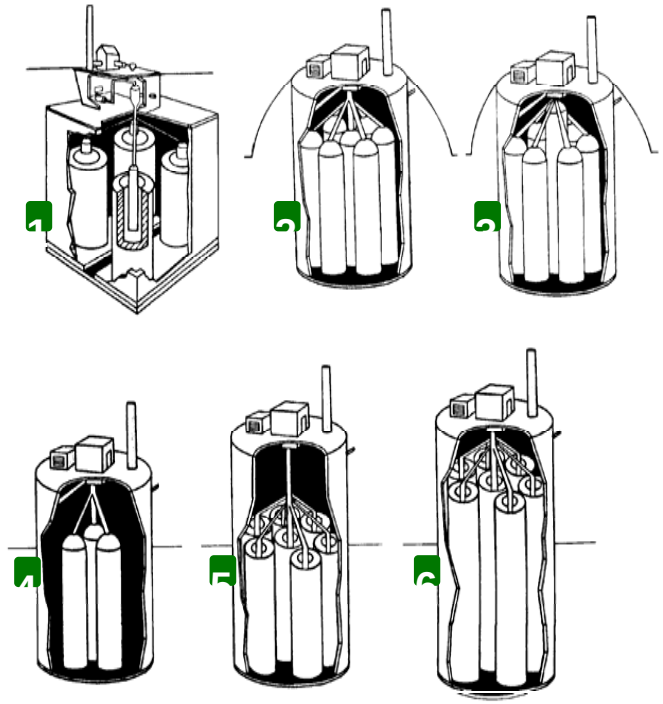
Environmental Management (EM) has identified a need to establish the Calcine Disposition Project to disposition high level waste (HLW) calcine including characterization, retrieval, treatment (if necessary), packaging, and onsite interim storage pending shipment to a geologic repository or offsite interim storage facility.

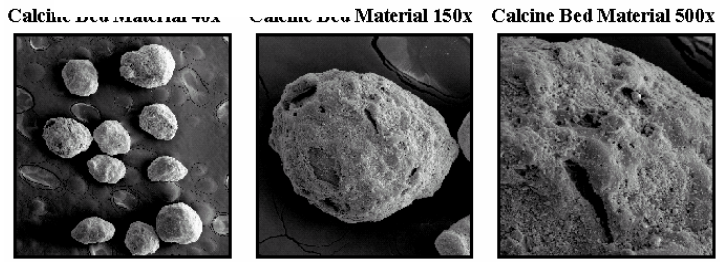




Calcine Particulars

- ***Calcine is HLW by source-based definition***
  - Byproduct of reprocessing (ended in 1992)
  - Also classified as mixed waste regulated under the Resource Conservation and Recovery Act (RCRA)
- ***7 to 1 volume reduction through calcination***
  - 8-9M gallons acidic liquid converted to 4400 cubic meters of solid calcine
  - Contains roughly 44 metric tons heavy metal
  - Stored in 43 shielded bins in 6 binsets with one spare (7th set)
    - *Designed for 500 year service life*
    - *Currently being inspected under permit*
- ***Abrasive, hydroscopic, granular oxides***
  - Ranging from 0.2 to 0.6 mm (~15% "fines")





Calcine Disposition Project Drivers

- ***Meet Idaho Settlement Agreement (SA) milestones***
  - Issue a **Record of Decision (ROD) by December 31, 2009** to identify method to treat calcine (if necessary)
    - *Dual path ROD will also carry forward both a treatment and the direct disposal option*
  - Submit a **RCRA Part B Permit application by December 1, 2012** to the state of Idaho for retrieval and treatment (includes packaging)
  - Have all **calcine ready for transport out of the state of Idaho by a target date of December 31, 2035**

- ***Meet Idaho Site Treatment Plan (STP) milestones***
  - Approval of **CD-0 by June 30, 2007**
    - *Approved June 29, 2007 by Deputy Secretary Clay Sell*
  - Approval of **CD-1 by March 31, 2008**
    - *Plan to request 18 month extension*
  - Submit an **enforceable schedule** for disposition of calcine (including design, construction, and start of operations) **by June 30, 2010**

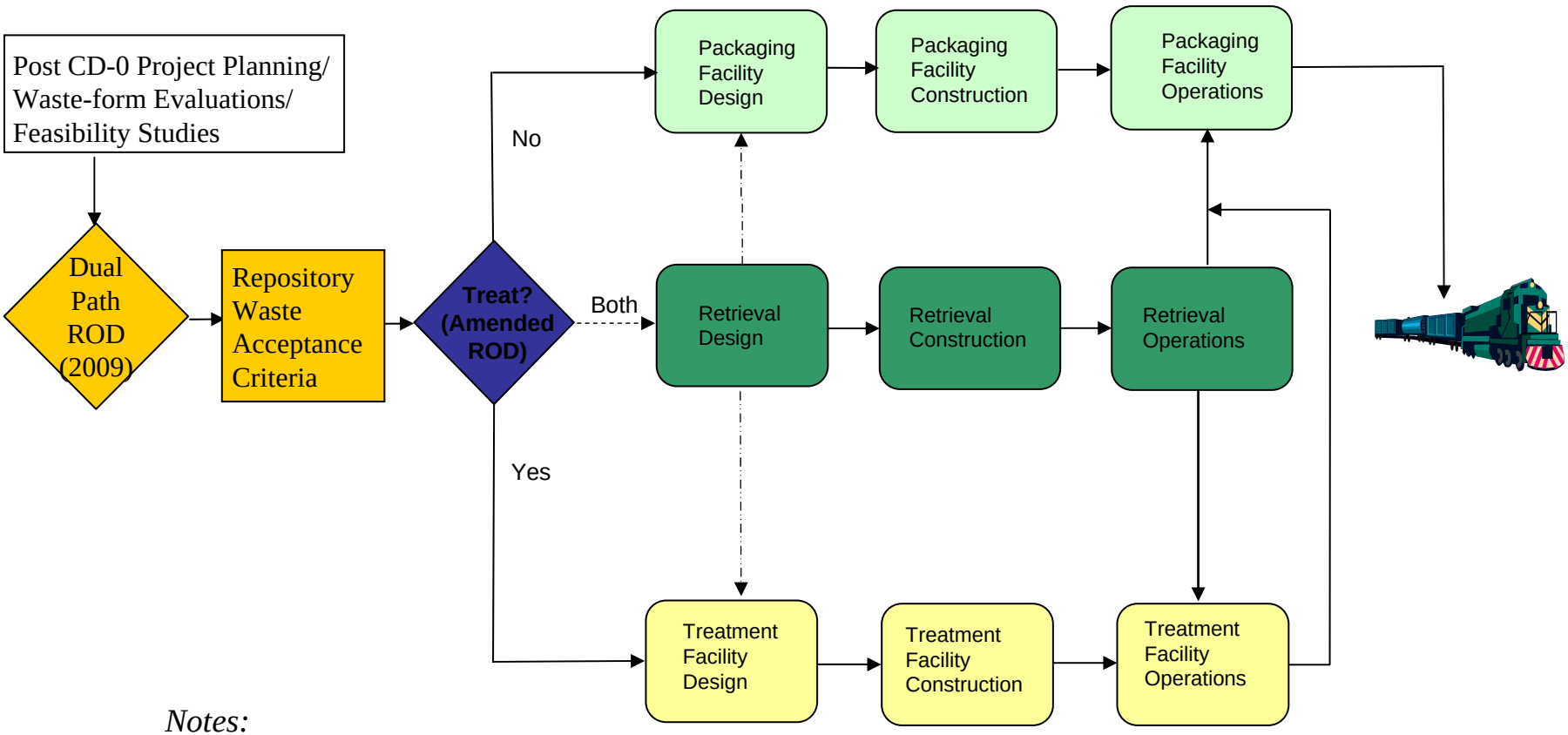
- ***Prepare Calcine for disposal in the Repository as required by the Nuclear Waste Policy Act***

- ***Fulfill commitments in 2005 ROD from the Idaho HLW and Facilities Disposition Environmental Impact Statement (EIS) - DOE/EIS-0287***

Project Status

- ***Demonstrated pneumatic retrieval with cold calcine***
- ***Down-selected to 3 treatment technology options as alternatives to direct disposal***
- ***Canister modeling & selection for direct disposal***
- ***option completed***
- ***Detailed calcine characterization has been completed***
  - Process models, legacy sample analysis, thermodynamic computer modeling
- ***Groundwater modeling and Land Disposal Restriction evaluations***
  - Untreated Calcine disposal at the Repository will meet Total System Performance Assessment (TSPA) for both radioactive and chemical (RCRA) constituents
  - New EPA radiation standard for groundwater has no expected impact on modeling
- ***Obtained 10-year RCRA permit for current storage (November 9, 2006)***
- ***Critical Decision 0 (Approval of Mission Need) issued June 29, 2007***
- ***Closely following repository and regulatory developments***
  - Need to petition EPA for conditional exemption of calcine from regulatory definition of hazardous waste and exemption from prohibitions on land disposal
    - *Update November 2004 draft petition when repository models are frozen*
    - *Engage EPA in preliminary discussions as appropriate*
    - *Submit draft application to DOE-HQ for review (in parallel with finalization)*
    - *Submit petition to EPA following repository license application submittal to NRC*

Calcine Disposition Project Dual Path Approach



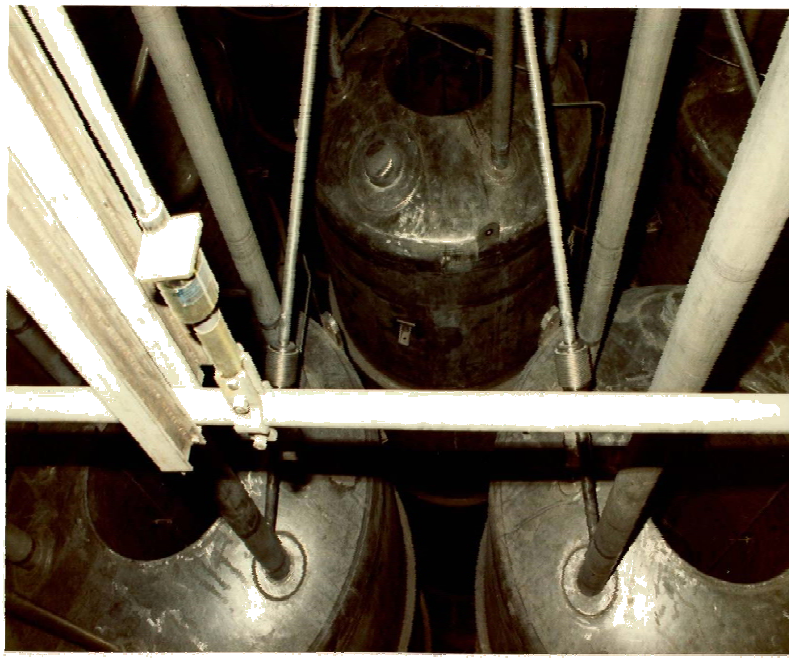
Notes:

(1) Repository Waste Acceptance Criteria factors in RCRA compliance and waste-form performance

(2) Project will re-use the Integrated Waste Treatment Unit to the maximum extent practicable upon completion of the Sodium Bearing Waste Project mission

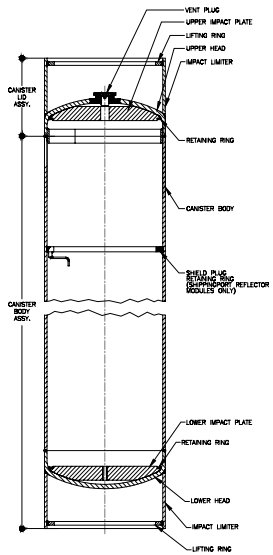
Direct Disposal Option (Retrieve and Package Without Treatment)

- Retained as one of the dual path options (lowest project cost, shortest schedule)
- Meets Repository performance criteria, but EPA petition approval or legislation necessary to meet regulatory requirements
- 6,600 canisters – granular waste form



Top view of CSSF #6 bins

ASME Spent Fuel Canister

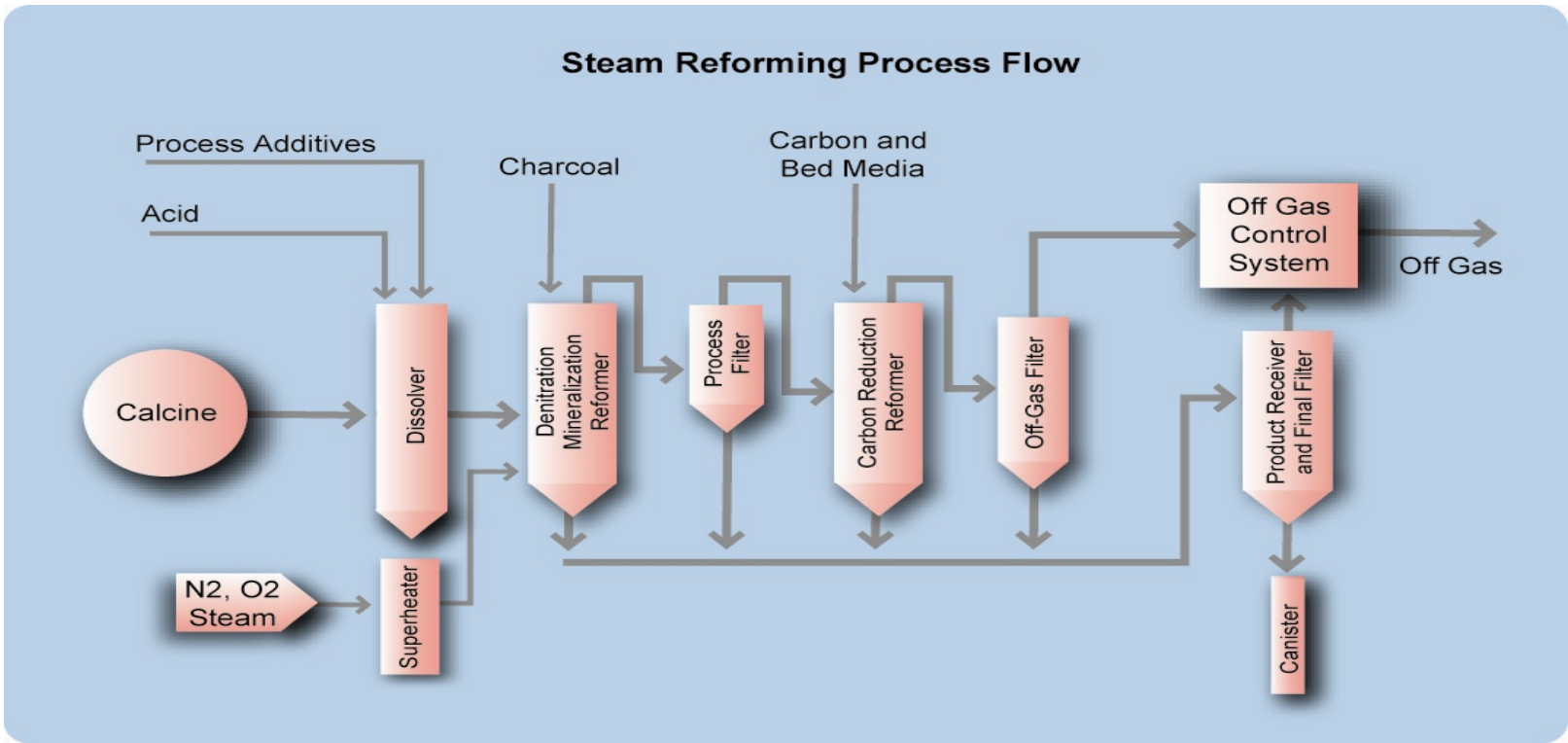


- **ASME B&PV Code, Section III, Division 1, Subsection NB (with Code Case N 595-2)**
- **Constructed of 316L stainless steel**
- **Full penetration closure weld, ultrasonic & liquid penetrant NDE**
- **Sizes**
  - 18 inch diameter, 10 or 15 ft long
  - 24 inch diameter, 10 or 15 ft long
- **Designed for Transport and Storage at a National Repository**

Foster Wheeler Environmental Corporation

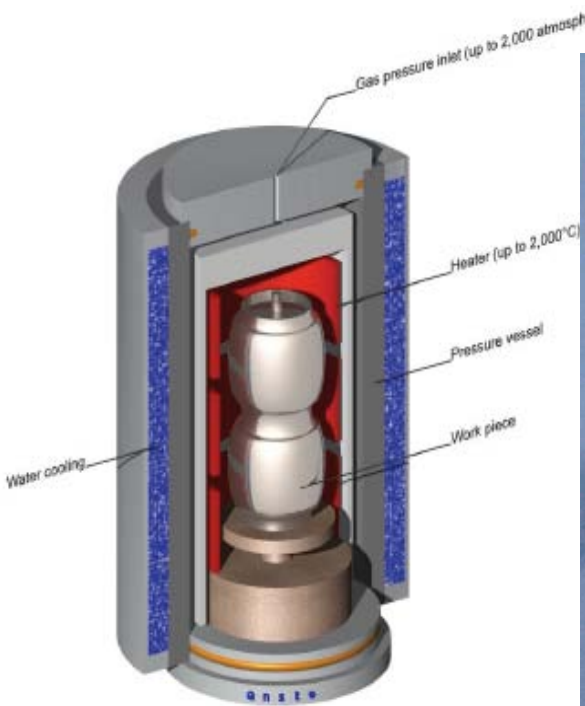
Steam Reforming Treatment Option

- Re-uses major portions of Integrated Waste Treatment Unit
- Requires dissolving calcine in nitric acid
- Moderate to high regulatory risk –granular waste form
- Significant technical challenge –minimum of 6,600 canisters (likely 2 to 3 times more)



Hot Isostatic Pressing (HIP) Treatment Option

- Significant volume reduction resulting in 3,300 - 4,400 canisters
- Moderate regulatory risk, high pressure and temperature – monolithic waste form
- May be most cost effective option on a total life cycle cost (through disposal) basis
- May be able to retrofit IWTU to support this process
- Residual facility could support varied future missions



Direct Vitrification Treatment Option

- Borosilicate glass, - EPA and state of Idaho preferred waste form
- Lowest regulatory risk – ~11,200 canisters – monolithic waste form – highest cost, longest schedule

Defense Waste Processing Facility @ SRS

Filled Canister

Materials:	304L Stainless Steel
Empty Weight:	1150 lbs.
Glass Weight:	3800 lbs.

Independent Life Cycle Cost Estimate Results *

Treatment Technology (project contingency)	Retrieve, Process, Store (1), D&D	Estimate Number of 10' Canisters	Repository Disposal Charge (2)	Shipping Costs (3)	Total Estimated Life-Cycle Cost (4)
Direct Disposal (40%)	$2.319B	6,660	$4.129B	$0.393B	$6.841B
Direct Vitrification (50%)	$16.307B	11,200	$6.944B	$0.661B	$23.912B
Steam Reforming (60%)	$5.679B	6,660 *(could be 2X+)*	$4.129B	$0.393B	$10.201B
Hot Isostatic Pressing (50%)	$13.324B *(ANSTO $4B+)*	3,300 *(up to 4,400)*	$2.046B	$0.195B	$15.565B *(ANSTO $6B+)*

*** 85% confidence level and 2006$s**

Notes:

(1) Cost estimate does not include storage cost beyond reuse of limited IWTU storage
(2) Repository disposal charge (@ $620K per canister)
(3) Shipping cost will not accrue to EM (@$59K per canister)
(4) Total estimated cost impact to DOE (2006 $'s)
(5) Differing professional opinions from ICE Report

Further Evaluation of HIP Option Appears Warranted

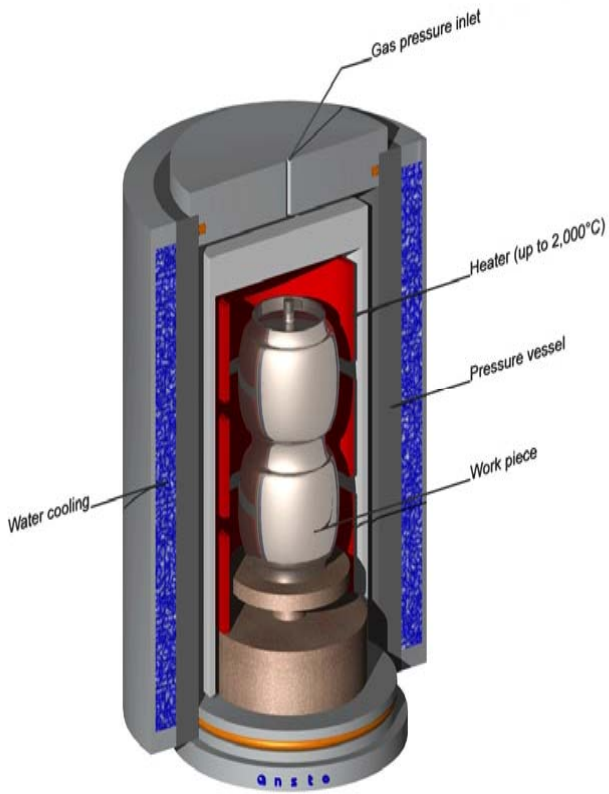
Consolidation:	HIP	Vitrification (JHM)
Matrix:	glass-ceramic	borosilicate glass
Waste loading:	**60-90%**	**20-35%**
Durability (PCT-B):	10-100 x EA glass	10 x EA glass
Final volume: (relative to untreated calcine)	**15-45% reduction**	**100+% increase**
Temp:	2200°F	2100°F
Pressure:	4500 psi	atmospheric
Off-gas:	none	medium-high
Facility		
Future Mission Flexibility:	diverse/flexible	extremely limited/inflexible

Cold calcine in glass-ceramic matrix

Direct SBW compaction (no additives)

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.***

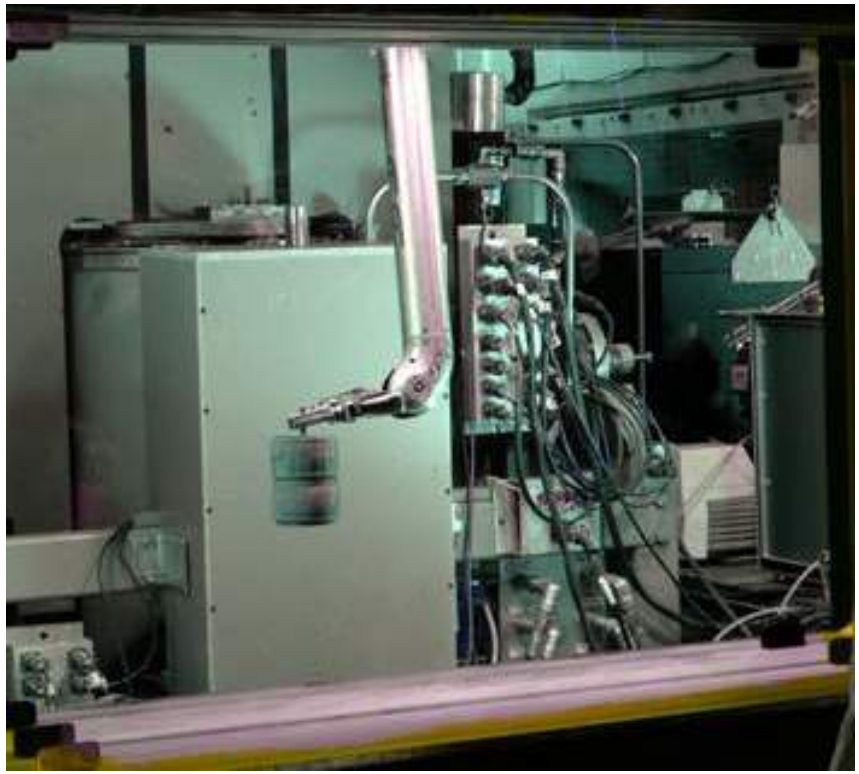


Why Current DOE-ID Interest in Hot Isostatic Pressing

- ***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.
- ***Process promotes higher waste loadings***
  - Minimal constraints on waste form chemistry
  - Not limited by waste form electrical properties or viscosity
- ***Flexible technology capable of producing a range of waste forms***
- ***Maximum volume reduction***
- ***Virtually no 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.

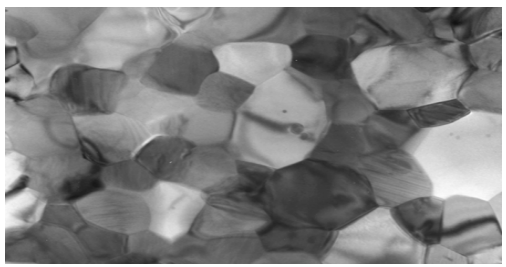
- ***The presence of crystalline phases in the glass matrix toughens the waste form, leading to excellent mechanical properties.***
  - Resultant glass-ceramic is much less susceptible to cracking than borosilicate glass.

- ***Radiation and transmutation resistance would be at least equivalent to a borosilicate glass***

Benefits of Complementary Waste Forms

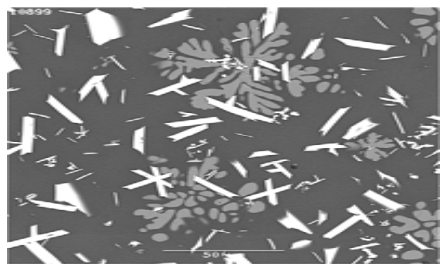
- ***No single waste form or process is suitable to economically handle the total HLW cleanup challenge.***
  - Parallel deployment of complementary tailored ceramic and hybrid glass-ceramic waste forms can overcome the limitations of baseline approach for wastes difficult to vitrify and create opportunities 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

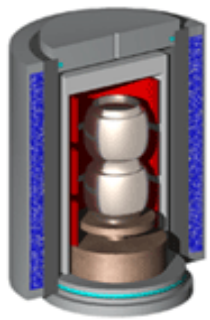


(titanates, zirconates, phosphates, silicates)

Hybrid glass-ceramic

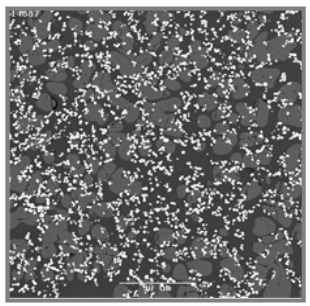


(Durable glass plus ceramic phases)

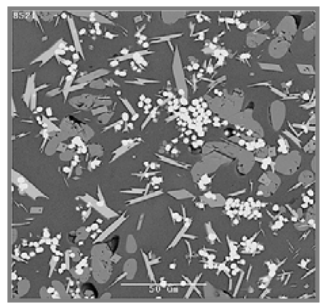


Technology Comparison

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***	***high***

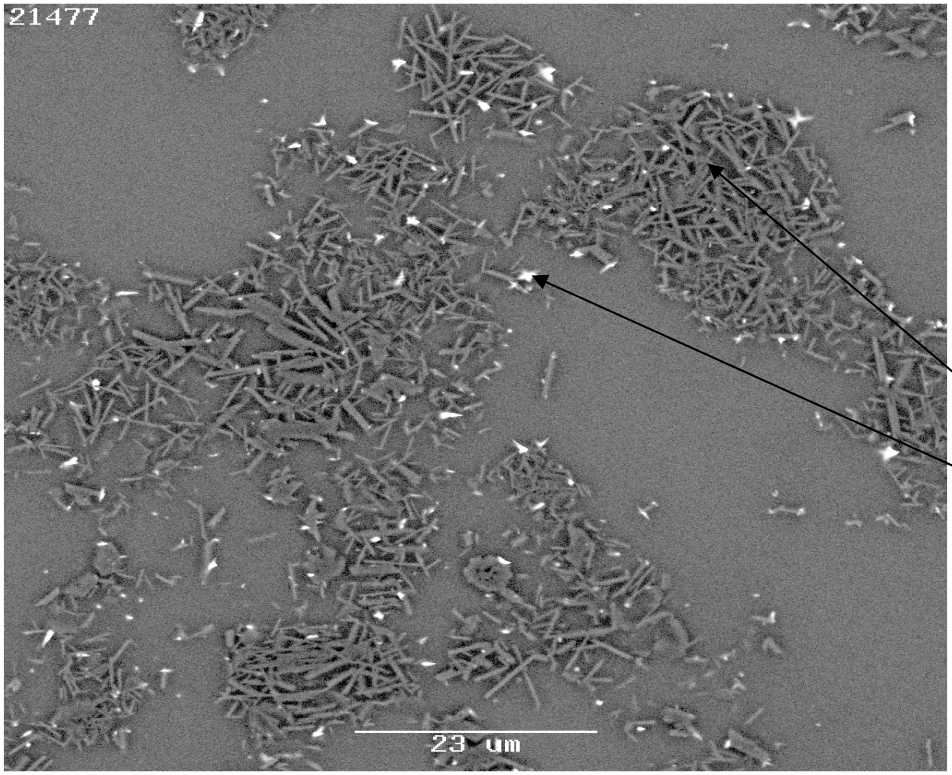


HIP Glass Ceramic



Cold Crucible Glass Ceramic

Alumina-rich INL Calcine (Bin Set #1)

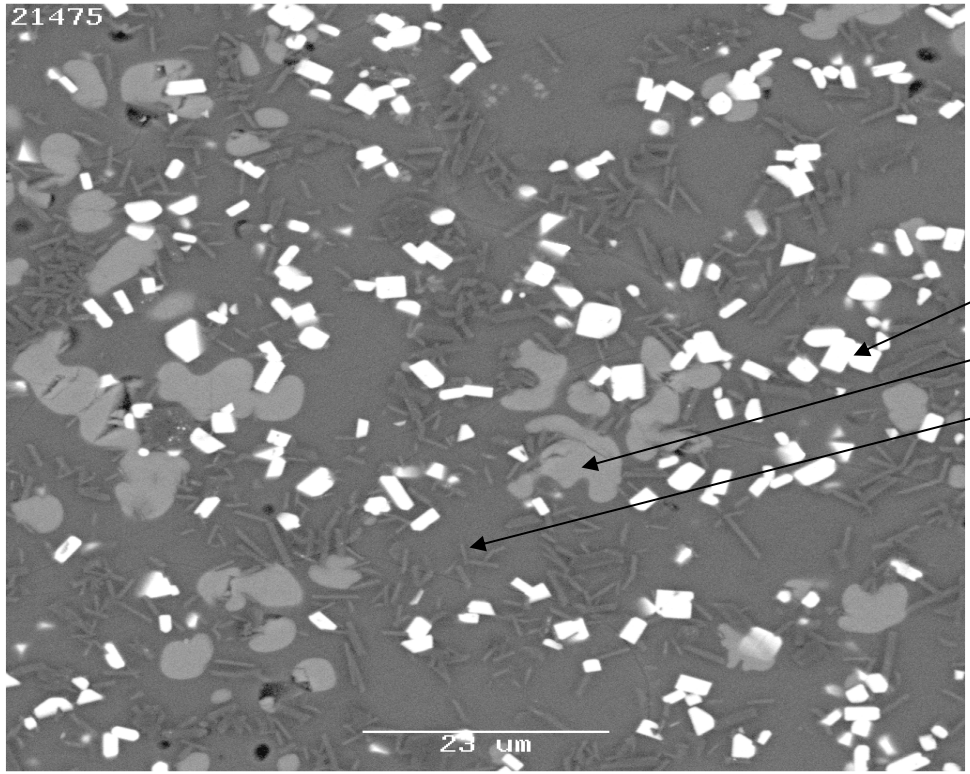


Waste Loading: 50%

Density:2.8 g/cm3

Crystalline phases:
corundum (major)
zirconia (trace)

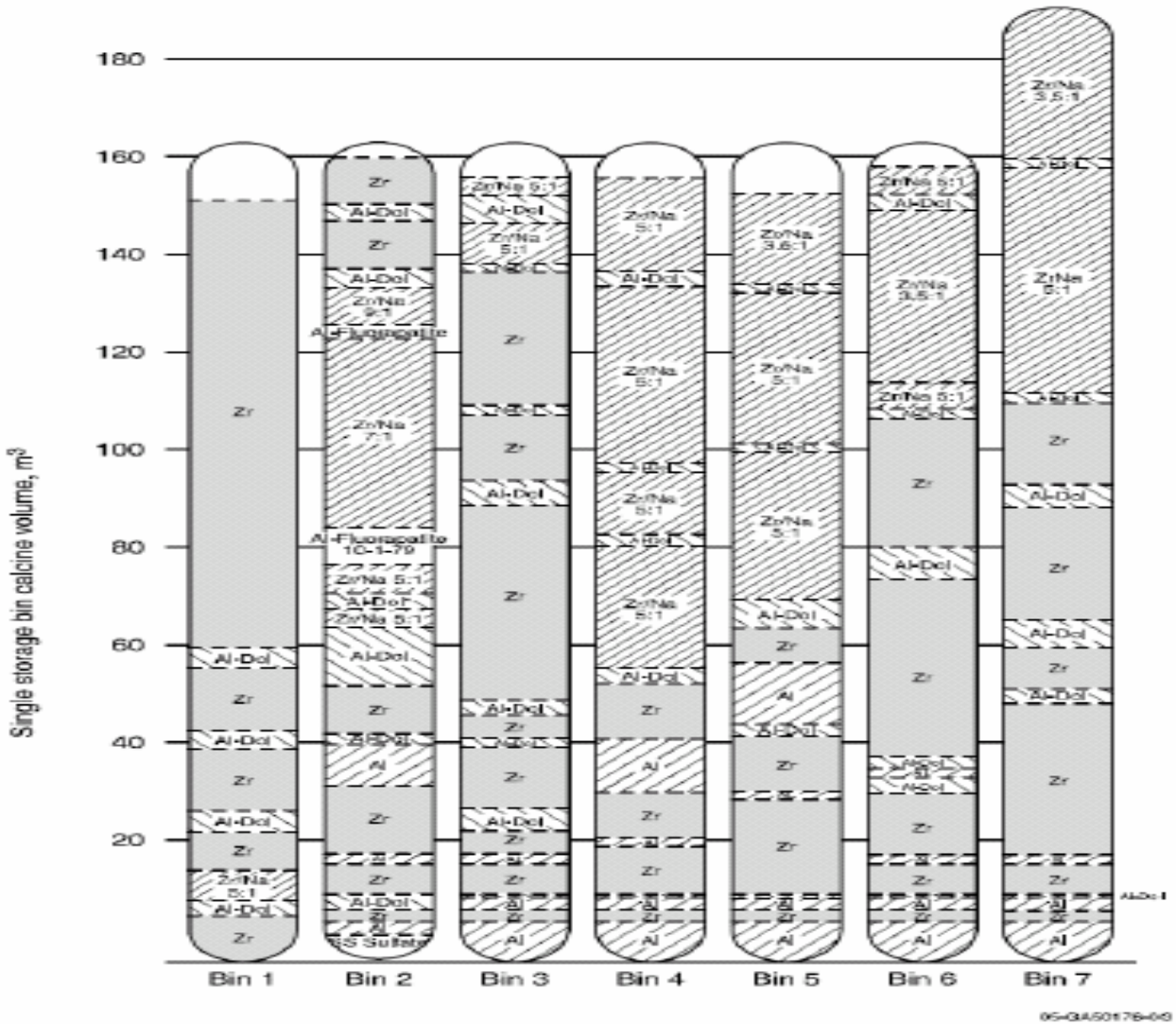
“Mixed” INL Calcine (Bin Set #2)



Waste Loading: 80%
Density:3.0 g/cm3

Crystalline phases:
zirconia (major)
fluorite (major)
corundum (major)

Layering of Calcine (BS#3)

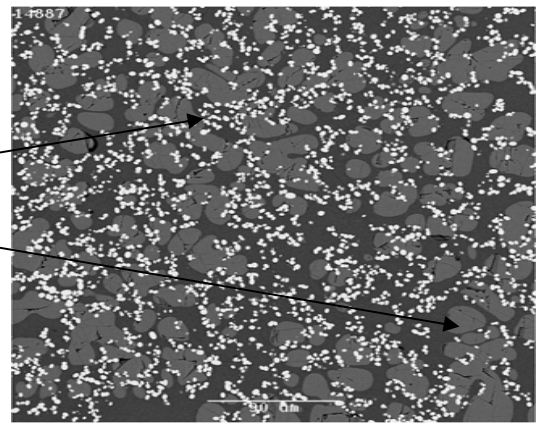


Zr-rich INL Calcine (BS#4)

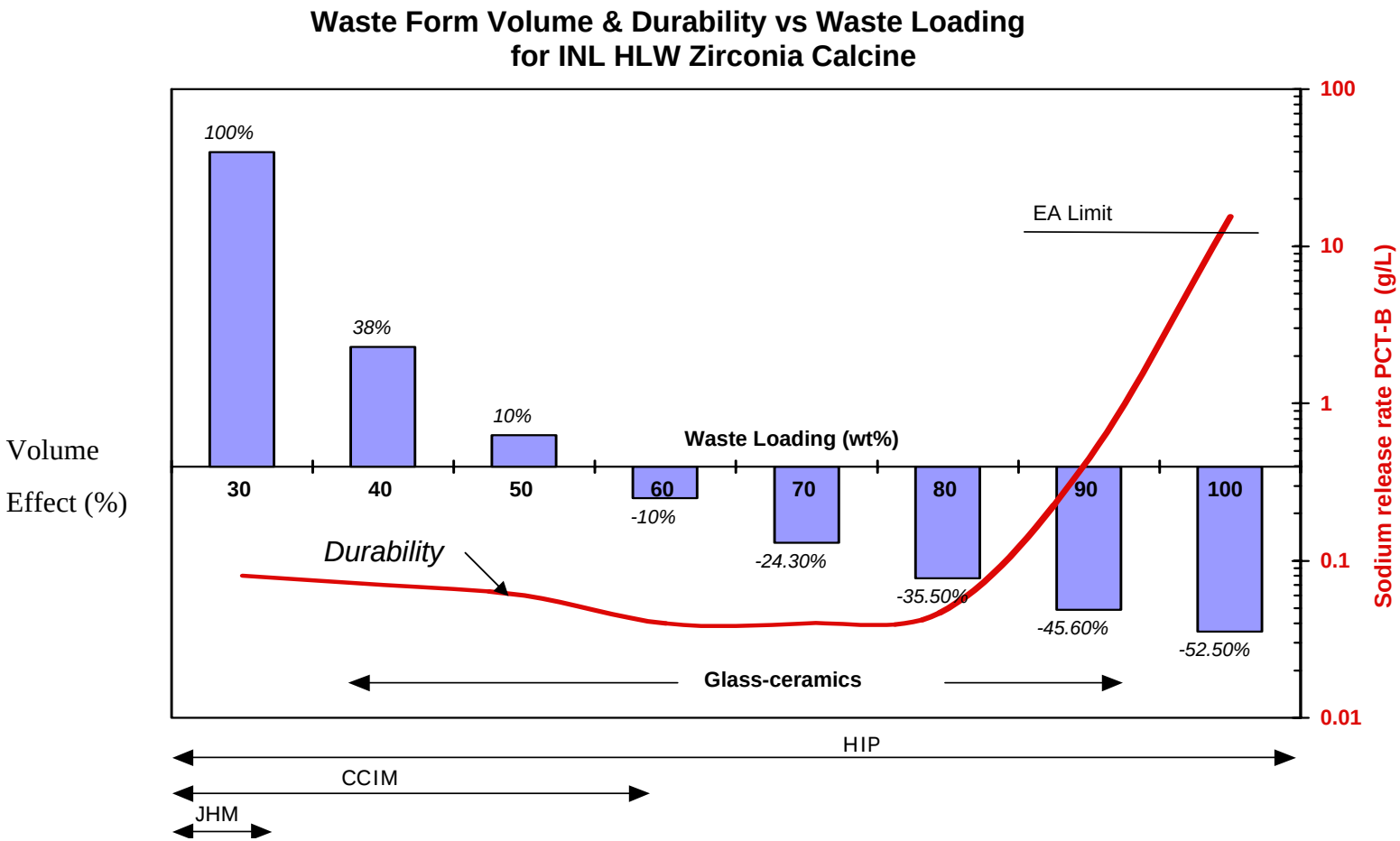
Consolidation: HIP
Scale: 65 lbs
Diameter 8 inch
Waste loading: **80%**
Durability: 100 x EA Glass
Density: 3.10 g/cm3
Final Volume: 35% reduction

(relative to untreated calcine)

Crystalline phases:
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 increase 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

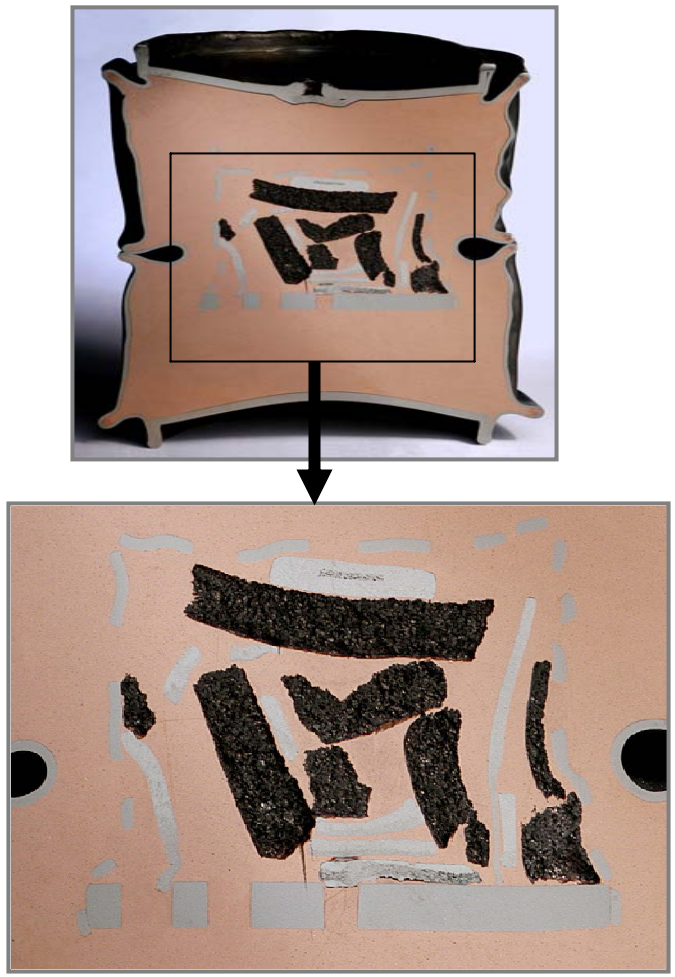
HIP Process Flexibility Includes…

- ***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 the 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

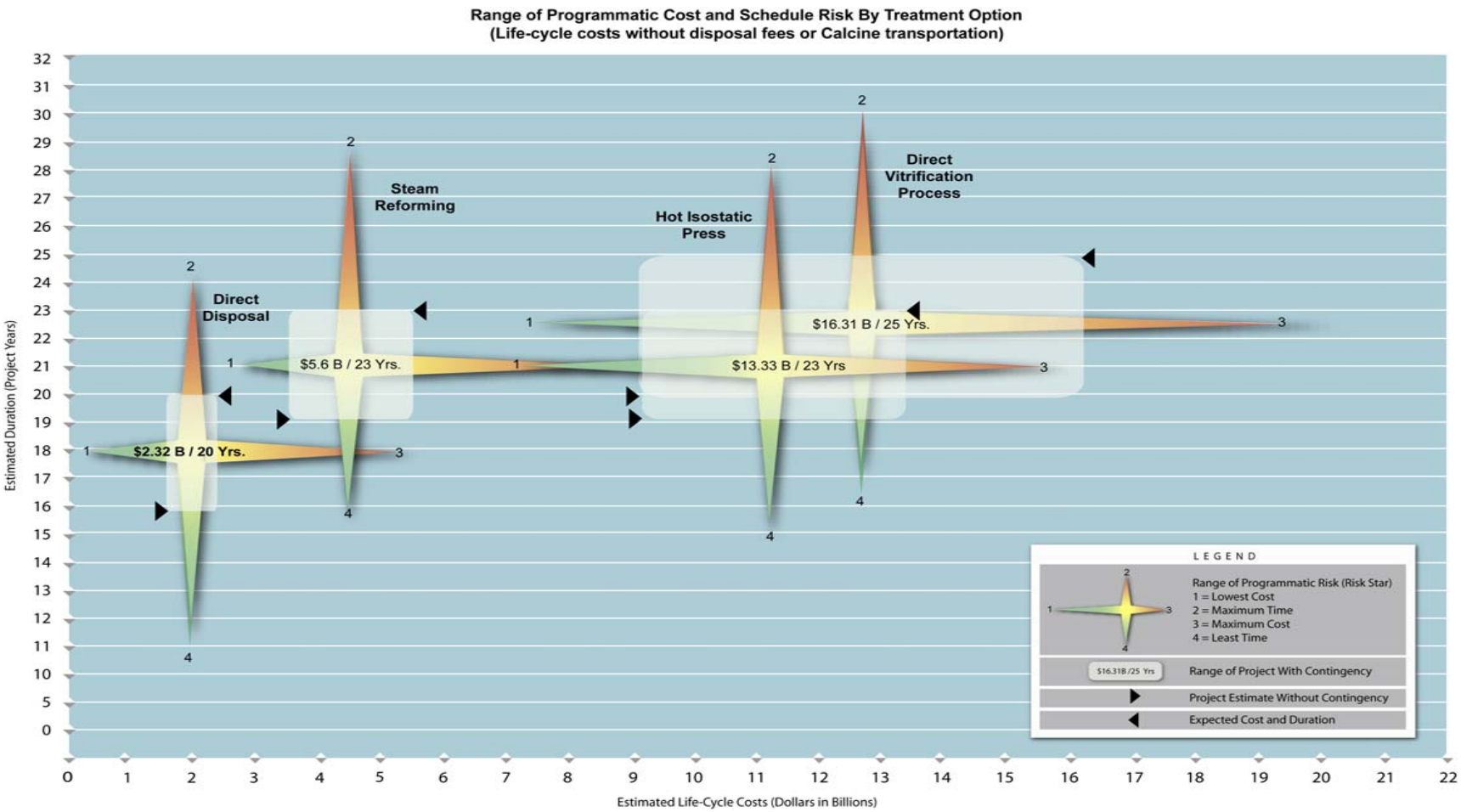
- ***Product quality by input characterization is possible***
- ***HIP can dimensions can be readily measured to verify successful consolidation***
- ***Able to sample feed composition before loading into HIP can***
- ***Process is amenable to existing product quality assurance protocols developed for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

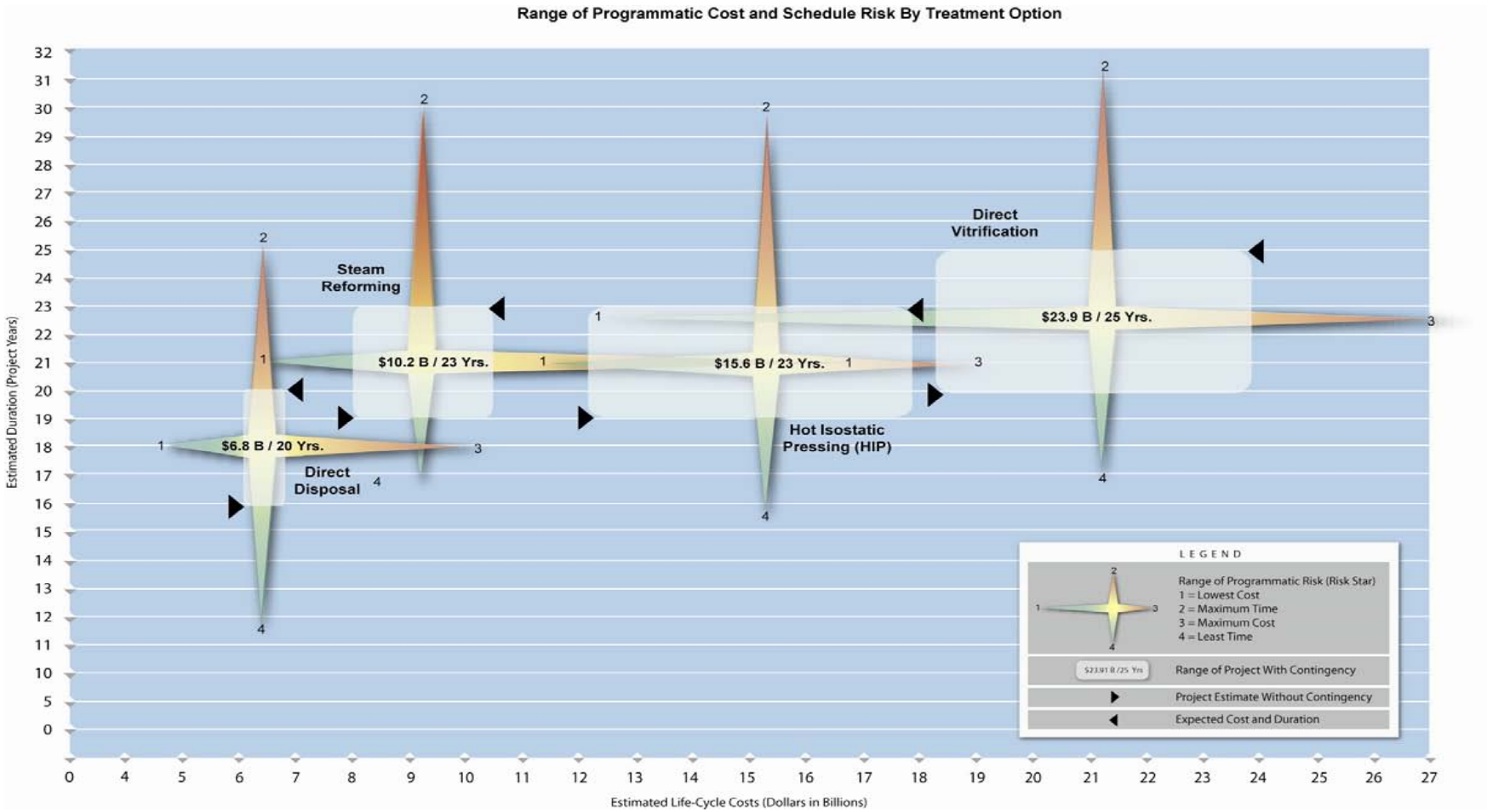
Backup Information

Independent Cost Estimate (Calcine Disposition Project Only)



Cost/Schedule Risk Profiles for Four Approaches (CDP only)

Independent Life Cycle Cost Estimate (Through Disposal)



Cost/Schedule Risk Profiles for Four Approaches (through disposal)