

DESIGN FEATURES TO FACILITATE HOT ISOSTATIC PRESSING IN REMOTE SHIELDED FACILITIES

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The use of Hot Isostatic Pressing (HIP) is gaining favour as a potential method of immobilising legacy radioactive wastes. Legacy wastes are often poorly characterised and chemically heterogeneous making them particularly problematic. HIP, in combination with tailored ceramic and/or glass-ceramic waste forms are well suited to immobilise these challenging wastes.

The HIP process offers a number of advantages, including; process flexibility, minimal final disposal volume and highly durable immobilisation matrices. Waste is conditioned inside sealed containers, eliminating high-temperature off-gas emissions, and the HIP process is largely insensitive to what is inside the container. Consequently waste loadings are maximised, and the process operability window much broader than alternative processes.

A hot-cell HIP deployment option for treatment of high-activity legacy wastes is presented. Key hot-cell design features that allow for the incorporation of a production scale HIP into remotely operated hot-cells for long term waste processing will be reviewed.

1. Introduction

Legacy high-level wastes are typically extremely diverse in terms of their origin, chemical composition and physical form. They are often poorly characterised, and in many instances contain radionuclides that are highly mobile in the environment. Some are volatile, many contain components that are either have low solubility or are difficult to incorporate into borosilicate glass. Together these attributes present unique challenges to implementing a low-risk immobilisation strategy.

No single waste form or process is suitable to economically handle the cleanup of all legacy wastes. For many of these heterogeneous wastes utilising tailored ceramic or composite glass-ceramic waste forms designed to suit the unique waste characteristics offer significant advantages. These include: higher waste loading (fewer disposal canisters), enhanced chemical durability (lower environmental risk), and greater processing flexibility. Together these offer life-cycle cost savings worth billions of dollars.

Hot-isostatic Pressing (HIP) offers significant advantages for the production of these tailored ceramic and/or glass-ceramic waste forms. A HIP consists of a pressure vessel surrounding an insulated resistance-heated furnace as shown in Figure 1. The process of hot isostatic pressing radioactive wastes involves a stainless steel can being filled with the dry feed (with or without treatment additives). The can is evacuated and sealed, then placed into the HIP furnace and the vessel closed, heated and pressurized. The pressure is applied isostatically via argon gas, which at pressure, is also an efficient conductor of heat. The combined effect of heat and pressure consolidates and immobilises the waste into a dense monolithic block sealed within the stainless steel can.

The fact that the waste is processed inside a sealed stainless steel HIP can, offers further advantages. Process flexibility is increased, as there is no need to control viscosity to pour the waste form (very problematic for heterogeneous feeds). The requirement for a high-temperature off-gas system is eliminated as the waste is hermetically sealed inside the can during hot consolidation, which also minimises secondary wastes. Contamination is restricted as there is no direct contact between the waste and the HIP itself. Not only does this minimise subsequent decontamination costs, but makes the HIP process ideally suited to deal with multiple cleanup missions.

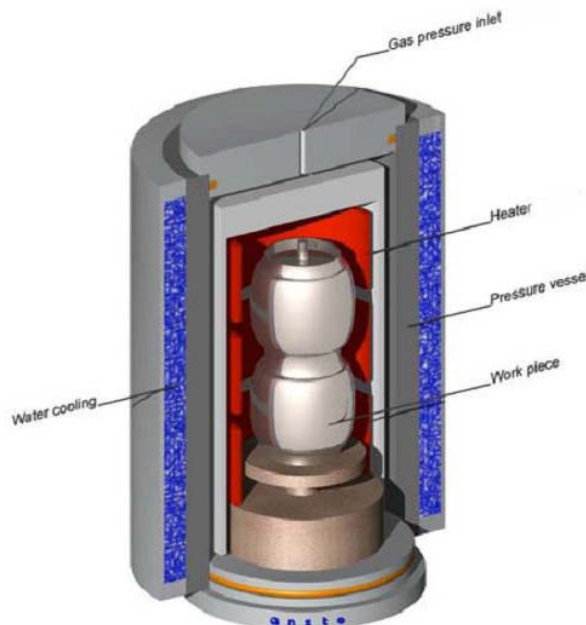


FIGURE 1: Schematic of a Hot-Isostatic Press with a Loaded Sealed HIP Can

ANSTO has demonstrated the risk reduction benefits and life-cycle cost savings HIP tailored waste forms can provide for a wide range of wastes including: plutonium residues (UK), calcined reprocessed waste (US), fuel pond sludges (US and UK), technetium/iodine/cesium, and waste from molybdenum-99 production, among others.

The following paper briefly reviews the industrial maturity and key safety features of HIP systems, prior to outlining design features to facilitate incorporation of a production system in a remotely operated hot-cell environment.

2 Hot Isostatic Pressing

2.1 Maturity: Industrial and Nuclear

The basis of HIP technology was first patented in the US in 1941. Subsequent patents by Battelle were made in 1961 to apply HIP technology to diffusion bond nuclear fuel. Today HIP technology is an industrially mature, safe, technology used globally in support of the automotive, mining, medical, aerospace, defense and nuclear industries. Components are routinely processed at tonnage scales.

There are a number of large HIP processing facilities around the world. The Sandvik Powdermet facility in Sweden for example processes components and valves that can weigh several tons and are produced at temperatures in excess of 1200°C. In the US, many production scale industrial HIP facilities have been operating for over 30 years. Table 1 shows a summary of US industrial HIP units that are in excess of 0.60 meters (24 inches) in diameter. Many of these HIP systems are over 1.5 meters (60 inches) in diameter and operate at 100 MPa (15,000 psi) and 1200°C, in 24 hour 7 day per week production environments. Work pieces between 4500 kg (10,000 lbs) and 8100 kg (18,000 lbs) are

routinely processed. The uptime availability of these large-scale production HIP units is between 80 and 95%.

Company	HIP Units diameter > 0.6 m	Operating Temperature >1150°C	Operating Pressure >50 MPa	Service life >12 years	Oldest HIP in use (years)
Bodycote (USA)	13	12	12	8	>20
Bodycote (international)	12	12	12	6	>20
Alcoa	5	5	5	3	>30
Crucible Materials	2	2	2	1	>30
KittyHawk Products	3	3	3	3	>25

HIP technology has also been used within the US nuclear industry for ~ 30 years. Babcox & Wilcox, installed one of the largest HIP units of its day in 1979 for use in diffusion bonding nuclear fuel rods for the U.S. Navy. This unit has operated successfully for over 25 years, and current plans have it operating well into the future. Small-scale HIP facilities have been operated in hot cells in the US (Idaho National Laboratory, Oak Ridge, Argonne) and UK (AWRE).

2.2 HIP System Safety

2.2.1 Coded Pressure Vessel Design

Safety is of the utmost importance within the HIP industry and is the principal driver throughout the design, construction, testing and operation of HIP systems. Typically in the US pressure vessels are designed, built and tested in accordance with demanding specifications of the American Society of Mechanical Engineers (ASME) Pressure Vessel and Boiler Code, Section VIII, Division 2 and 3.

ASME vessels can be designed for high cyclic life of 10,000-100,000 cycles at the maximum operating pressure which translates to 20 - 100 years of operation. These values are the ASME calculated safe life based on a presumed flaw in a pressure vessel. This presumed flaw is set by the minimum capability of the flaw detection equipment and incorporates additional safety margins to provide the basis for operational safety. For example division 2 coded vessels have a burst pressure more than 2.5 times the operating pressure and inbuilt safety systems initiate well before those pressures are reached.

By increasing the level of conservatism built into the pressure vessel design, the subsequent major inspection interval for the vessel can be greatly extended. In many instances, it is possible to design a hot-cell HIP that could complete the cleanup mission/campaign well before the first major vessel inspection is required under the code.

During construction, pressure vessel forgings are examined ultrasonically and by magnetic particle inspection to ensure freedom from material defects. A hydrostatic test is performed on the finished vessel at between 110% and 125% (depending on the code used for certification) of the operating pressure. An authorized independent pressure vessel inspector witnesses this test and verify compliance to the code prior to signing the Certificate of Inspection, and stamping the vessel with an assigned serial number registered with the National Board of Boiler and Pressure Vessel Inspectors.

2.2.2 Active and Passive Safety Systems

HIP systems are further protected from over-pressure or over-temperature via multiple independent sensors and active and passive safety systems. Active systems include process controls that continuously monitor the vessel pressure and temperature and vent excess gas if the alarm set point is exceeded, or isolate power from the furnace to prevent overheating. Passive safety systems include multiple mechanical pressure relief valves or burst discs that release pressure at a controlled rate if the maximum rated operating pressure is exceeded. The rate of pressure release can be controlled to avoid challenging the capacity of the cell ventilation system.

3 Hot Cell Considerations for Remote HIP Operations

3.1 Location - in cell versus out of cell components

As a mechanical process with few moving parts the HIP is well suited for remote operations. In cell components of a HIP system can be limited to the pressure vessel, with electrically heated furnace, and a can loading/unloading system. All principal support systems such as gas, cooling, electronics and power supplies, can be externally located to the cell. This not only simplifies maintenance requirements, but also provides the option of redundancy and back up for support systems to service more than one HIP. This configuration is commonly used in large-scale industrial HIP facilities.

3.2 Contamination Control

Contamination control is an integral part of the HIP process layout. Once the HIP can has been filled it will be subject to complete surface decontamination. Once clean it will be placed in a proprietary Active Containment Overpack (ACOP) that serves as a secondary containment system. The HIP can remains inside the ACOP throughout the process until the can has been successfully HIPed. This process will serve to minimise if not eliminate downstream contamination.

The ventilation system for the HIP cell represents the “high-point” of a cascade style scheme, where air flows from clean to contaminated areas. Because heat removal from the HIP is handled by the vessel cooling system, air flow rates and operating temperatures within the cell will not be required to operate outside the “normal” operating range for a “typical” hot cell. Confinement doors are used to isolate the HIP cell from the adjoining cells to prevent the spread of contamination in the event of a loss of ventilation.

In the unlikely event a HIP can failure were to occur due to some manufacturing defect, the high temperature and pressure environments within the HIP would serve to constrain the material within the product container. The ACOP provides an additional measure of protection against the spread of contamination by ensuring that any material escaping the HIP can will be retained fully by the ACOP. The ability to decontaminate the ACOP and HIP can, would be provided in-cell.

All vent gas from the HIP (from active and passive control systems) is passed through in-cell HEPA filters prior to being exhaust either into the cell ventilation system or reclaimed for re-cycle, as appropriate.

3.3 In Cell Maintenance

The general maintenance philosophy for a HIP cell is run the equipment to failure and replace. As mentioned above, whenever possible, components such as valves, pumps, instrumentation, etc. are located outside the cell where they can be easily diagnosed and replaced or repaired. In cell components that are expected to require replacement over the design life of the facility (seals, switches, sensors and furnace) are modular by design, and

well suited for remote “plug-and-play” replacement. As a mechanical process with relatively few moving parts, overall maintenance requirements are not onerous.

The ability to isolate the HIP and the hot cell in which it resides from radioactive contamination opens up the potential for manned entry. Eliminating the need to design the in-cell equipment entirely for remote maintenance, represents a large potential cost savings.

To accommodate a manned entry maintenance strategy it is essential for the cell designer to provide the ability to recover the cell by removing source terms (HIP containers) or isolating them using temporary shielding in the event of an equipment failure that cannot be addressed remotely.

3.4 Additional Design Considerations

With the ability to make manned entries into the HIP cell to perform major maintenance, the provisions to incorporate a HIP into a remote work environment are minimised. The primary considerations are:

- It is necessary to coordinate between the size of the cell, the ventilation system capacity, and the potential volume and flow rate of inert gas from the HIP in the event of a breached rupture disk on the vessel. Because heat is removed from the pressure vessel boundary by an independent cooling system, no special cooling loads are imposed upon the cell ventilation system.
- The design of the HIP and its support structure must be coordinated with the remote handling requirements required for operation of the cell, vessel feed through locations, and support criteria driven by the design basis.

Additional considerations unique to a specific application may be determined during the preparation of the safety design basis, but the expectation is that this would be the result of the overall process being performed rather than the use of the HIP. The balance of the cell design remains typical to standard hot cell design practice.

4. SUMMARY

HIP tailored waste form technology provides an opportunity to lower the risk and significantly reduce the life-cycle cost to disposition problematic legacy wastes difficult to incorporate in glass. Contamination control features afforded by HIP process make it well suited for use in addressing multiple cleanup missions. HIP systems are readily scalable, allowing the size and cost of the unit to be appropriate to the waste feed stream(s).

Large-scale production HIPs have operated reliably in commercial applications for decades. They have run through tens of thousands of cycles, producing work pieces weighing several tons, and have been in use in the nuclear industry for approximately 30 years.

Safety is a primary consideration in the design of the equipment. Similarly, system design features can be tailored to address specific operator preferences or safety basis driven criteria.

Elaborate, complicated, or costly remote maintenance schemes are not required for HIPs installed in Hot Cells. HIP systems can be customized to reflect the user's preferences between low cost manned entries and the ability to maintain the equipment remotely. No major technical design challenges exist to installing a production HIP in a hot-cell.