

**Decommissioning Sodium Dump Tanks – 15547**

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**ABSTRACT**

The Nuclear Decommissioning Authority (NDA) is a non-departmental public body of the UK Government responsible for managing the effective and efficient clean-up of the UK's nuclear legacy. DSRL (Dounreay Site Restoration Limited, a wholly-owned subsidiary of the Cavendish Dounreay Partnership Ltd, a consortium of Cavendish Nuclear, CH2M HILL and URS) is the site licence company operating under contract to the NDA and funded by the NDA for the clean-up and demolition of the Dounreay Site, Britain's former centre of fast reactor research and development, near Thurso, Scotland, including decommissioning the Dounreay Prototype Fast Reactor (PFR). The plutonium metal fuel PFR was the second and last fast reactor to be built in the UK, with construction commencing in 1968. The reactor closed in 1994 and was de-fuelled, but the reactive sodium remaining in the cooling system required decommissioning, and approximately 12 tonnes of low level waste (LLW) sodium remained in the un-heated dump tanks. This paper highlights the approach used for decommissioning the dump tanks and their contents. The sodium was removed as a solid at ambient temperature, packaged, and staged for destruction at a later date. The tanks and pipework were then cleaned, size reduced and packaged for disposal as LLW.

**INTRODUCTION**

This paper highlights the approach used for decommissioning the Nuclear Decommissioning Authority's Dounreay Prototype Fast Reactor (PFR) secondary cooling circuit dirty dump tanks. A team extracted and repackaged approximately 18 tonnes of tritium contaminated sodium from the dump tanks.

**HISTORY OF THE PROTOTYPE FAST REACTOR [1, 2, 3, 4]**

Reconstruction of the United Kingdom (UK) in the aftermath of World War II was hampered by a number of shortages such as indigenous, readily extractable coal, therefore nuclear power was seen as an alternative energy source. Rather than producing power from uranium based upon water-cooled thermal reactors utilising only one per cent of the natural element, the potential use of uranium discharged from thermal reactors provided a strong incentive to develop a type of fast neutron breeder reactor that could utilise a much higher fraction of the available uranium. Although a wide range of reactor types was considered (graphite, beryllium, light and heavy water, were all candidates for moderators), the list of possible coolants was longer. There was a choice between two options; 1) establish the elements of the new technology, select the most promising and progress towards a specific design; or, since the significance of the many problems and their relative importance was not then quantifiable, 2) proceed with an imaginative but flexible design that could be adjusted or adapted as experience and a parallel research programme dictated. The latter was selected and the successful strategy led naturally towards developing the Dounreay Fast Reactor (DFR), a completely new venture. The only other fast reactors then in existence world-wide were of low power output and detailed information about them was unavailable to the UK.

The designers decided to forego small scale experiments and aimed for a plant large enough to be considered as a prototype for a fast reactor power station. The DFR successfully met the original target of 60MW (thermal), but by the time construction was completed a number of electrical power industry developments were suggesting that radical changes would be required for the fast reactor successor. Power stations were becoming much larger and operating temperatures much higher. The role of DFR

changed to testing candidate fuel and construction materials at high temperatures in a fast neutron flux and paved the way for the fuel element development required for the PFR, and the second generation of fast reactors.

The plutonium oxide fuelled PFR was the second and last fast reactor to be built in the UK, with construction (£28.4 million) commencing in 1966. PFR went critical in 1974 and provided power to the national grid and offered unique research and development facilities. Although PFR provided information for future design and operation of large commercial fast reactor stations, by the late 1980s the UK decided there was no immediate need for such development so the reactor closed in 1994, was de-fuelled, and the bulk sodium from the primary and secondary circuits was removed. The world's largest liquid metal destruction plant was built at PFR and destruction of over 1500 tonnes of bulk sodium was completed by 2008. The current decommissioning programme is designed to lower the overall hazard by prioritised removal of hazards including removal of sodium residues. Decommissioning PFR between 2013 and 2022 is expected to cost in the region of £130 million.

### DESCRIPTION OF THE PROTOTYPE FAST REACTOR [2, 5, 6, 7]

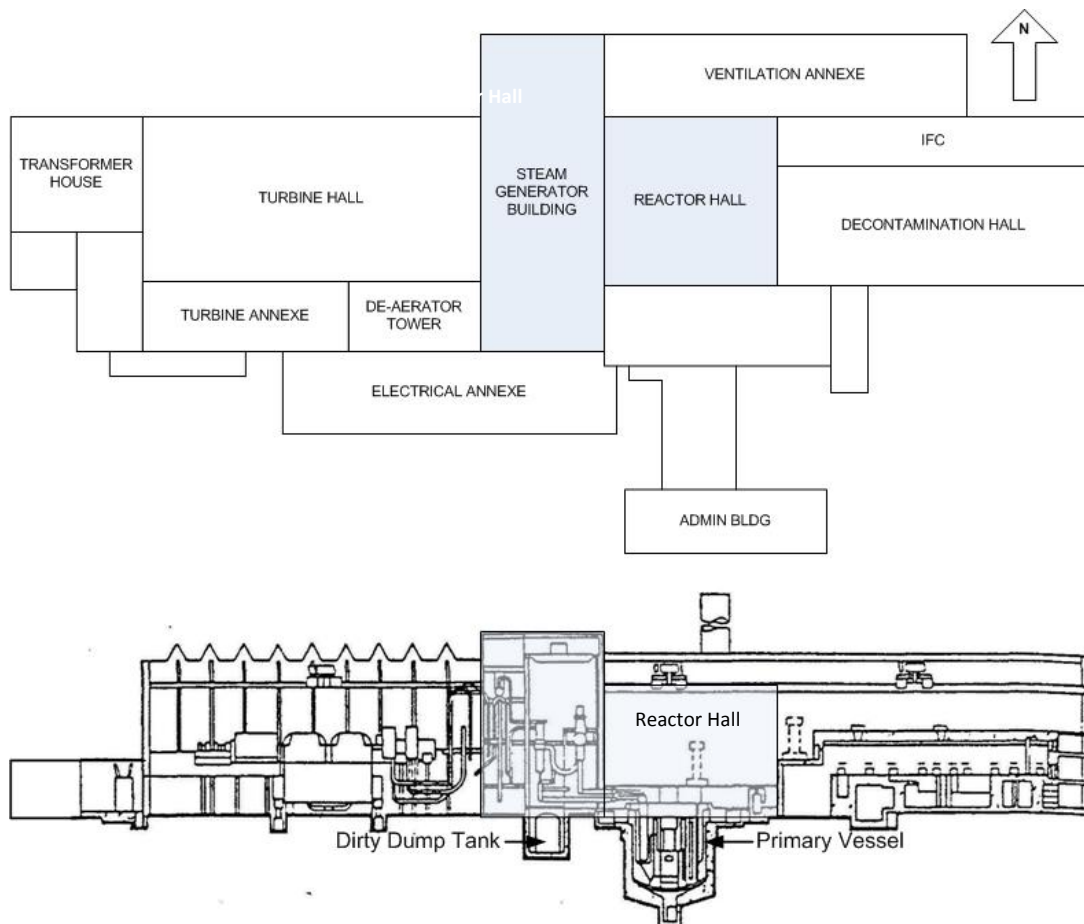


Figure 1: PFR Reactor Hall and Steam Generator Building

PFR was built to validate and provide operational experience of a large pool-type fast reactor (DFR was a loop-type). It had three important inherent safety characteristics:

1. The reactor was not pressurised, so there was no danger of a pressure system failure leading to sudden loss of coolant. Even if there was a primary leak, the leak jacket ensured that the sodium still covered the core.
2. If all power to the coolant pumps failed, the sodium could still remove the decay heat by natural convection.
3. The reactor had a strong negative power coefficient, meaning that as its coolant temperature rose, the power level actually went down. In the event of multiple control systems failure, the reactor would stabilise at about 600°C, well below the boiling point of sodium, and the power level would fall to zero. In effect, the reactor would shut itself down.

PFR was designed to produce 250MW (electrical) from 600MW (thermal) core power and its design incorporated lessons learnt from early DFR operations. Located beneath the reactor hall (Figure 1), the reactor core (only 0.91m high by 1.55m in diameter) and its surrounding breeder blanket were made up from an array of hexagonal sub-assemblies, with 325 fuel pins in each. Control was exercised through five boron carbide absorber rods and a further five similar rods were available to shut down the reactor. A radial breeder blanket surrounded the core and was itself bounded by stainless steel reflector assemblies to improve neutron economy. A graphite shield, outboard of the blanket, essentially eliminated neutron activation of major removable components such as the primary pumps, valves and the intermediate heat exchangers. The reactor was a pool type design, i.e., the full primary circuit with reactor, coolant pumps and intermediate heat exchangers were submerged in the sodium pool in the reactor primary vessel (Figure 2).

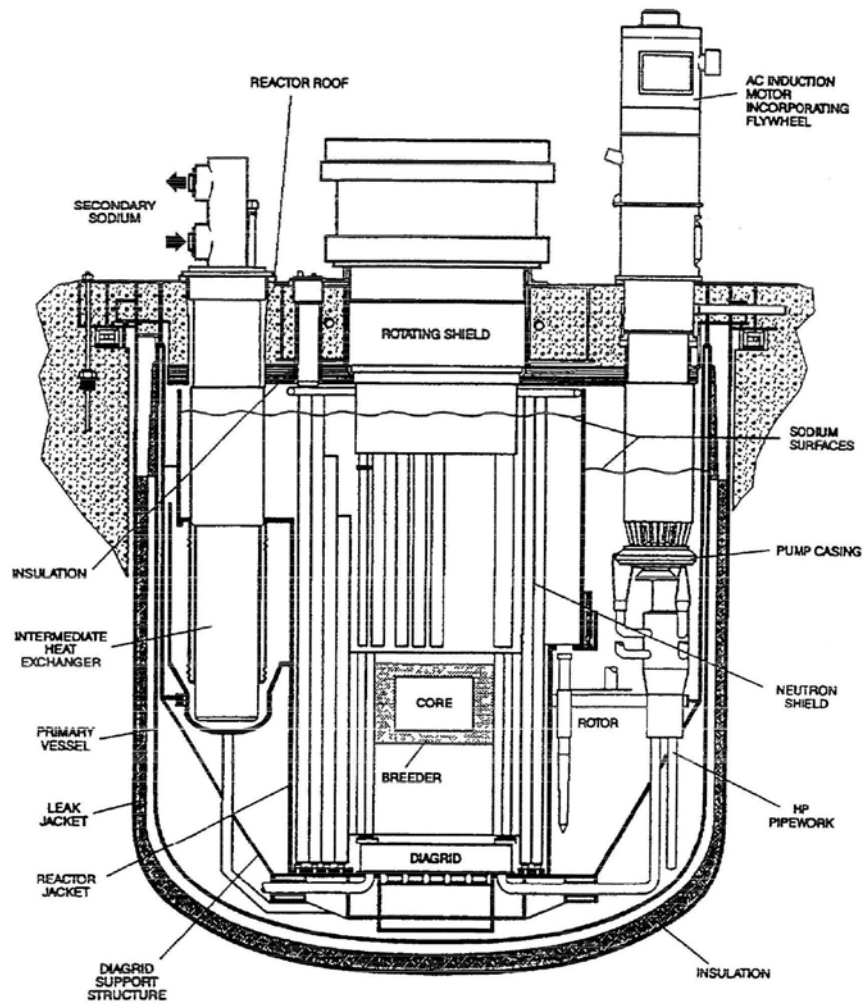


Figure 2: Cross Section of the Primary Vessel

Sodium was selected as the coolant because (compared to the sodium-potassium alloy (NaK) used at DFR) sodium was cheaper, safer and easier to handle. The stainless steel primary vessel (12.2m in diameter and 15.2m deep) contained 900 tonnes of sodium coolant compared to DFR's 57 tonnes of NaK and the primary vessel was encased by a secondary vessel made of carbon steel for containing leaks. Both were located in an underground concrete lined pit which eased containment and shielding issues. Coolant flow was upwards rather than downwards to avoid the gas entrainment problems shown at DFR. Three electrically driven (1MW) mechanical centrifugal pumps (rather than the lower capacity electromagnetic pumps used at DFR) circulated the liquid primary sodium coolant to extract the fission heat from the reactor core. The primary circuit sodium entered the core region at around 400°C and left the core top at around 560°C. Heat from the primary sodium transferred to the secondary circuit sodium as the secondary sodium flowed through the shell side of each of the six intermediate heat exchangers (IHX) located within the primary vessel. The secondary sodium transported the heat to a steam raising plant which fed a steam turbine with an electrical output. These heat transfer arrangements were essential to prevent the core being blocked by sodium/water reaction products following a steam generator tube failure, that no active primary sodium was involved in such a reaction, and that the primary sodium remained in the biological shield and primary containment.

The secondary circuit consisted of three completely independent closed loops that each coupled a pair of

IHX to three sets of steam generators consisting of an evaporator, a superheater and a reheater. The steam generators were an advanced, highly rated tube-in-shell design rather than DFR's low rated, double walled matrix design. The evaporators were of a forced-circulation type, with each of the three loops having a steam drum and a boiler circulating pump. This system generated superheated steam from the three loops and the steam then flowed to a common header to drive the single 300MW turbo-generator and thus produce electricity for the national grid. The main feed was via a 100% duty steam-driven pump with 10% electric and 10% steam-driven pumps for start up and post-trip use. Appropriate water conditions were provided by a full-flow polishing plant and the feed-heating by sets of low pressure direct contact high pressure tube units. The under slung condenser was cooled via the seawater pumphouse, supplying 480 tonnes of water per minute to the main condenser. The maximum rise in the water temperature was ~10°C.

PFR was used as a test bed for the fuel, components, materials and instrumentation needed for an eventual commercial sized station, and was unique in that it used full commercial-sized fuel assemblies, exactly as would be used in commercial fast reactors. The fuel was mixed plutonium-uranium oxide in sealed stainless steel pins (DFR had used vented enriched uranium alloy) to achieve higher burn-up and to keep the contamination of the coolant to a minimum. The original design target for fuel burn-up was 7.5%, however improved design from operating experience eventually led to a world record of 23.2% burn up. PFR also contained a shielded remote handling facility known as the Irradiated Fuel Cave (IFC). Fuel could be transferred from the IFC to a storage rotor within the primary vessel while the reactor was operating. Fuel discharged from the rotor after irradiation was first stored under sodium in the IFC (to cool further) and then transferred to the PFR buffer store (water pond), after removing any sodium residues, to await transfer to the reprocessing fuel plant. The IFC contained ~70 tonnes of liquid sodium in a number of storage tanks.

#### **DESCRIPTION OF THE PFR DUMP SYSTEM [8]**

With the exception of the IHX and a portion of the secondary sodium pipework contained within the reactor hall, the secondary circuit was located in the steam generator building (SGB) located west of the reactor hall (Figure 1 and Figure 3). Each of the three secondary circuit loops typically contained approximately 75 tonnes of sodium circulated by a mechanical pump similar to the primary sodium pumps. In addition, each secondary loop incorporated a secondary cover gas system and an individual dumping system. The sodium dump system was provided to allow each secondary loop to be drained for maintenance and inspection purposes. Contained within independent concrete cells in the SGB (Figure 3), the dump system consisted of drain lines from a number of points in a loop that connected into a dump tank (except for common dumping and cold trapping facilities). The dump system components were located beneath each steam generator and the circuitry was sized to handle the complete quantity of sodium within a loop. Isolating valves in the feed lines and in the return lines would isolate the IHXs from contaminated sodium.

The dumping circuitry was arranged for sodium in the circuit on the reactor hall side of the isolation valves which was referred to as "clean" sodium and for sodium in the circuit on the steam generator side of the isolation valves referred to as the "dirty" sodium. Clean sodium from all loops would dump into a single clean dump tank. Dirty side sodium from each loop was dumped into its own individual dirty dump tank (DDT) enclosed in a cell that also housed ancillary pipework. The cells (Figure 3) provided containment of the circuits and allowed any sodium leakage from one loop to be isolated. Dirty sodium was drained from the loops by gravity into the DDTs. Three 4-in (101.6°mm) bore, three 2-in (50.8°mm) bore, and one 1-in (25.4°mm) bore stainless steel drain connections were provided on the dirty side of each secondary loop, feeding into the main 6-in (152.4°mm) bore drain to a DDT.

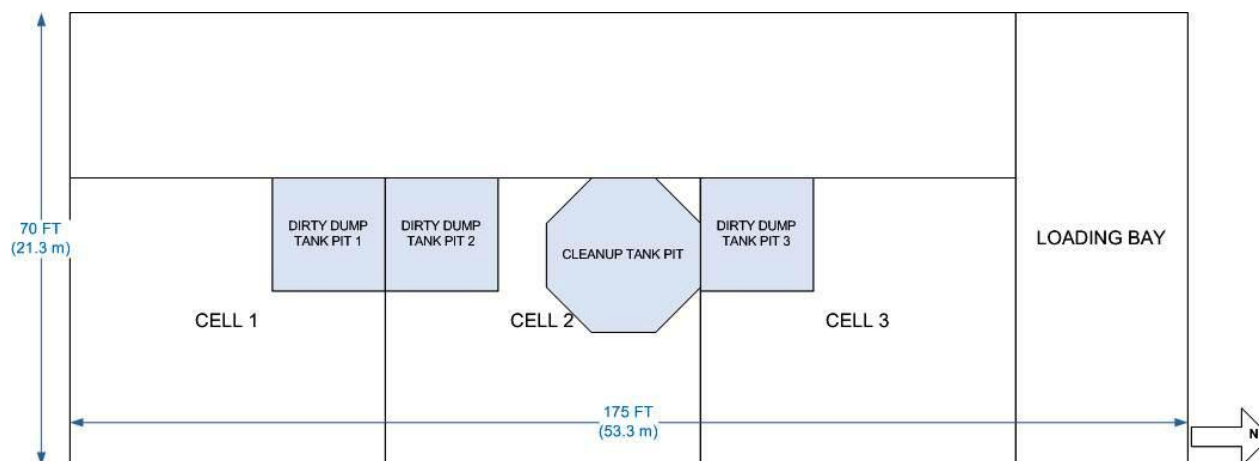


Figure 3: Plan View of the PFR Steam Generator Building (SGB)

Nitrogen blanketing was provided to all free surfaces within a loop (i.e., steam generator units, expansion tanks, dump tanks and main isolating valves). Drain lines were suitably trace heated (200°C), insulated and finished with protective mild steel galvanised sheeting. Certain cross-over and sodium transfer lines were capable of 350°C. Drainage was controlled by small bore bellows-sealed valves. The valves also assisted in fast dumping of sodium in the reactor hall pipework in the event of a leak in a loop.

To avoid the risk of fires, an automatic protection system would dump the sodium in the event of a sodium-water reaction in any of the steam generating units or a sodium leak. Hydrogen detection loops (gas phase and sodium phase) were fitted to detect a leak at a very early state, because the following exothermic sodium and water chemical reactions would take place at elevated temperatures 200 – 300°C [9]:

- 1)  $2\text{Na} + 2\text{H}_2\text{O} \rightarrow 2\text{NaOH} + \text{H}_2\uparrow$
- 2)  $2\text{Na} + \text{H}_2\text{O} \rightarrow \text{Na}_2\text{O} + \text{H}_2\uparrow$
- 3)  $4\text{Na} + \text{H}_2\text{O} \rightarrow \text{Na}_2\text{O} + 2\text{NaH}$
- 4)  $\text{Na}_2\text{O} + \text{H}_2 \rightarrow \text{NaOH} + \text{NaH}$
- 5)  $2\text{NaH} + 2\text{H}_2\text{O} \rightarrow 2\text{NaOH} + 2\text{H}_2\uparrow$

The high pressure and temperatures produced by the reactions would give rise to a pressure chock which would break a vent rupture disc after about 10 milliseconds and the sodium would enter the pressure suppression line on its way to the loop's dump tank. The water side would also be dumped. In February 1987 a superheater tube failed due to fretting caused by flow-induced vibrations, but the large safety margins enabled the plant to survive with no other damage than to tubes. As a result of these dumping events and years of batch cold-trapping operations, it was believed that sodium hydride (NaH), sodium oxide (Na<sub>2</sub>O) and significant quantities of other materials such as steel corrosion/erosion products would be contained in the residual sodium that was to be removed. [10]

The total quantity of sodium on the clean side of a secondary loop was calculated as 30°tons (30.5°tonnes), with 49°tons (49.8°tonnes) on the dirty side. As two IHX containing 11.5°tons (11.7°tonnes) could not be drained of sodium, the clean dump tank was of sufficient capacity to accommodate the clean side sodium for all three loops. Each DDT was unable to fully accommodate the theoretical quantity of dirty sodium for each loop. However, because of sodium leakage through the main 14-in (356°mm) isolating valves when closed, a more even sodium split was achieved as sodium tended to flow from the dirty to the clean side of the secondary circuit. It was estimated that a complete circuit dump of approximately 67°tonnes would take about 30 minutes.

**DESCRIPTION OF THE PFR DIRTY DUMP TANKS (DDTs) [8]**

DDTs, one per cell, were located underground within concrete dirty dump tank pits (Figure 3). The DDTs were 10°ft 6°in (3.2°m) diameter and 24°ft (7.32°m) long with hemispherical ends, with a sodium capacity of 45°tons (45.7°tonnes). The construction material was carbon steel to British Standard (BS) 1501-151-28A with a shell thickness of 1 in (2.54°mm) to a height of 9°ft 9°in (2.97°m) above the bottom, and 0.5°in (1.27°mm) above that, apart from the upper hemispherical head which was 1°in (2.54°mm) thick, at minimum. For emergency dumping of sodium from a loop there was a 2-ft (0.61°m) diameter centre dump tube (Figure 10) extending from the top dome to near the bottom of the tank where a deflection cone structure was affixed to the base dome. The emergency dump outlet (for displacement of the gas within the tank during an emergency dump) was a short 3-ft (0.91°m) pipe offset from the centre dump tube.

A filtration facility was provided in Cell 2 to clean up dumped sodium, if necessary, before it was returned to the secondary circuit. Stainless steel lines (2-in (50.8 mm) bore) interconnected each DDT via filters to the cleanup tank (CUT). Located in the cleanup tank pit in Cell 2, the CUT was larger than the DDTs (15°ft (4.57°m) inside diameter by 24°ft (7.32°m) with hemispherical ends) and had a sodium capacity of 90°tons (91.4°tonnes). The construction material was also carbon steel to BS1501-161-28A with a minimum shell thickness of 11/16°in (17.5°mm). The CUT was trace heated with 370°kW to provide a tank surface temperature of 350°C. This amount of electrical heating together with permanent connections from the CUT to the secondary cold trap loop provided an operationally flexible cold trap system for secondary circuits.

The DDTs and CUT were vertically oriented and stood on integrated, fully welded skirts bolted (on the insides of the skirts) to studs embedded in the pit floors (Figure 4) and could be accessed from an overhead 50-tonne crane (Babcocks & Wilcox 8069 manufactured around 1960) near the ceiling of the SGB. Reservoirs of approximately 2.03 tonnes of sodium had been kept permanently in the DDTs to minimise the effect of thermal shock in the event of a hot dump.

Two types of lagging (calcium silicate and Rocksil) were used in the original construction to insulate the secondary pipework and dump system. Pipes in the reactor hall under the 14-ft level (4.27°m) false floor were lagged in calcium silicate. Secondary pipes in the SGB cells were insulated with Rocksil°90 (a mineral rock wool material with fibres parallel to the main axis of the insulation sheet and backed by chicken wire mesh) whereas hot secondary pipes to reheaters and superheaters were insulated with lagging of a composite nature; an inner layer of Rocksil°90 plus an outer layer of Lamella (a mineral rock wool material with fibres at right angles to the main axis of the sheet). However at some point during reactor operations, asbestos containing material (ACM) was used in the SGB, therefore very low concentrations of asbestos fibres were occasionally detectable in dust and debris samples in the cells.

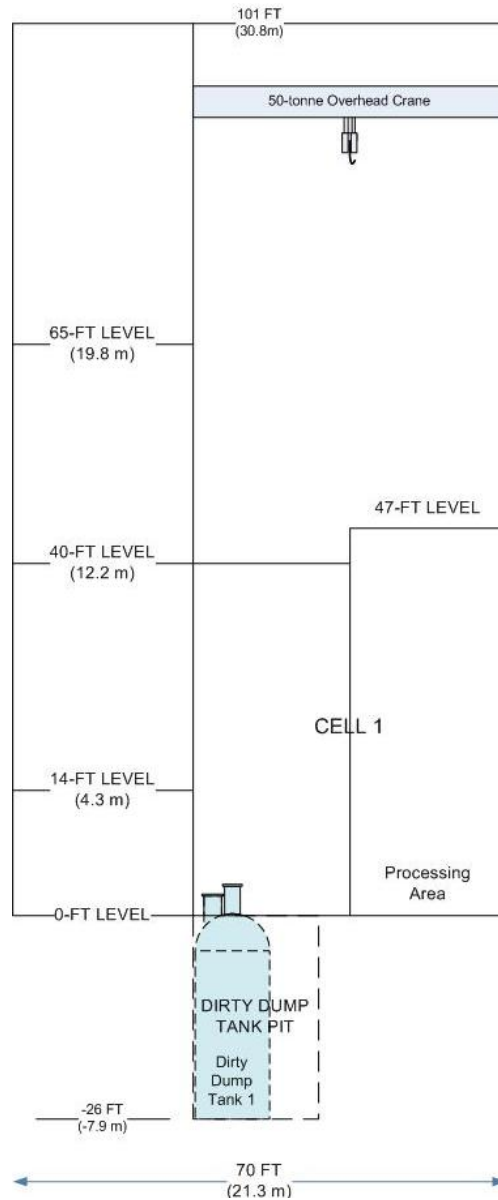


Figure 4: Cutaway View of the SGB at Cell 1 at the South End, facing North

Cell No.	Tank	Ht (m)	Dia (m)	Wt (tonnes)	Material	Na Capacity (tonnes)	Approximate Na Residue (tonnes)	Qty of Drums Packaged
1	DDT1	7.3	3.2	35.8	Carbon Steel	45.7	3.4	76
2	DDT2	7.3	3.2	35.8	Carbon Steel	45.7	11.3	195
2	CUT	7.3	4.6	52.4	Carbon Steel	91.4	0.13	3
3	DDT3	7.3	3.2	35.8	Carbon Steel	45.7	3.6	78

Figure 5: Summary of Tanks and Waste Sodium



### PREPARATIONS FOR DECOMMISSIONING THE DIRTY DUMP TANKS

At the start of the decommissioning of the DDTs and CUT, it was estimated that ~13 tonnes of low level waste (LLW) secondary sodium remained in them. The final amount was estimated to be ~18 tonnes (Figure 5). These figures are 90% of the weight of the drums' contents in order to allow for the mass of secondary waste (e.g., salt). The secondary sodium contained tritium transferred across from the primary sodium. The majority of tritium was produced by means of ternary fission resulting in fission products and a tritium nucleus. This occurred in a small but significant proportion of fissions. Tritium was also produced from neutron reactions with boron (mainly in control rods, but also an impurity of the sodium) and lithium (which is a substantial impurity in most sodium). Given the temperatures during power operations (especially at the IHX), diffusion through the system was facile, therefore tritium dispersed widely over much of the whole system, including the DDTs, CUT and secondary loops. Based upon prior sampling campaigns, the sodium tritium content was assessed to be 1000 megabecquerels per kilogram (MBq/kg).

Various methods [11] were considered for removing and treating the sodium in the tanks, including:

- Carbonation of the sodium followed by removal
- Melting and pumping out the sodium followed by treatment in the DSRL Sodium Disposal Plant
- In-situ treatment and removal via the DSRL Water Vapour Nitrogen (WVN) process
- In-situ treatment and removal via the Creative Engineers Superheated Steam process

Whilst all good methods, each would have required significant modifications to the existing plant or to the PFR decommissioning safety case (due to the process, elevated temperatures and/or elevated pressures). For example, there was no longer any convenient method to heat the tanks (for melting or Superheated Steam methods), and no convenient method to demonstrate that the tanks were acceptable pressure vessels (for carbonation or WVN). In addition, the quantities of sodium were too large for economical application of WVN. The most sensible strategy was to separate removal from treatment; i.e., remove the sodium at ambient temperature and pressure and package it for future disposal. From a safety perspective, this was a practicable strategy and would require little modification to the safety case. It was also considered to be the least complicated and the most rapid. Although mechanically extracting 18 tonnes of sodium seems daunting to anyone who has observed the fire and explosion that accompanies dropping a small piece of metallic sodium in a beaker of water, the method was selected based upon:

- Lower tritium release because the work would be performed at ambient conditions
- Sodium's smooth reaction in the presence of low humidity
- The ability to limit the sodium surface area being exposed at length to ambient conditions
- Availability of on-site alkali metals specialists who were expert in the physical and chemical properties of sodium metal
- The speed of removal compared to the other methods

Having selected the mechanical removal method, the work was broadly categorised into ten sections with the first seven being preparatory work prior to decommissioning the tanks:

- 1) Hazard recognition and hazard control planning
- 2) Procurement and contracting with the supply chain
- 3) Specific Training
- 4) Ventilation control and monitoring
- 5) Hazard control
- 6) Structural steel removal
- 7) Ancillary pipework removal
- 8) Tank transfer/relocation
- 9) Sodium removal and packaging
- 10) Size reduction of the vessels

### **Hazard Recognition and Hazard Control Planning**

Hazard recognition was performed in accordance with UK legislation and DSRL integrated safety management system standards. Option studies were used in hazard control planning to select safe and practicable methods for performing the work with particular consideration to any impacts to other decommissioning activities in nearby work areas. Minimising waste and impacts to the environment were weighted as important selection criteria. Samples of the sodium in the DDTs and CUT were taken to analyse their tritium content in order to prepare an estimate of the quantity of tritium that might be released during the work to assess the impacts on personnel and the PFR tritium discharge limits. It was believed that the highest levels of tritium would be in the sodium at the bottoms of the tanks, but sampling would need to be performed under confined space controls at the bottoms of the pits. To avoid this risk, it was decided to base the planning on the tritium content of more accessible waste sodium (1000 MBq/kg), and confirm this basis later by sampling the tank sodium after the tanks had been removed from the pits.

### **Procurement and Contracting with the Supply Chain**

Without prior work of this magnitude at Dounreay, DSRL decided that the best value and risk strategy was to form an alliance with the supply chain that would result in the best combination of experience and control to attain a successful outcome. DSRL entered into the Alkali Metals Residues Removal Alliance (AMRR Alliance) with Babcock Nuclear Services Ltd., Jacobs Engineering and JGC Engineering & Technical Services Ltd and contracted for the work on a target cost plus incentive basis using a New Engineering Contract (NEC).

### **Specific Training**

Workers received instruction in hazards, hazards control and emergency response as part of the basic facility and decommissioning training package. In addition, a Ph.D. alkali metals specialist provided a shorter project specific digest of the normal one and a half day classroom and laboratory alkali metal training course to project workers, supervisors and other personnel directly involved with the work. Curriculum topics included alkali metal behaviour, hazards, safe handling, disposal methods, engineering controls, personal protective equipment (PPE), emergency response, and incident analysis.

### **Ventilation Control and Monitoring**

The SGB is not continuously ventilated with an exhaust system, therefore it was considered that the sodium repackaging and steel size reduction activities in the cells might result in the release of constituents to the environment via non-monitored points. To remedy this, a local exhaust system was designed and installed to move the air from the cells directly into an adjacent operation's ducts that are HEPA-filtered and monitored, including for tritium. In addition, a bunded area was constructed in Cell 1 and a temporary processing tent was erected above it, using scaffolding and fire-retardant plastic (PVC) for the walls and retractable ceiling.

### **Hazard Control**

Initial and follow-up dust & debris cleanings were performed by specialist asbestos abatement contractors. Non-asbestos insulation removal was controlled by using containments, wet removal methods and local, filtered extract ventilation.

The hazards were most acute during the sodium removal and packaging phase and were broadly grouped into chemical, radiological and industrial categories. Fire prevention and control topped the list given sodium's reactive nature, therefore the DDTs and CUT were normally under a low pressure, low volume nitrogen blanket. Prior to moving the tanks the nitrogen source line was removed and the inlet and exhaust valves closed and isolated so that the tank interiors remained blanketed with nitrogen. As nitrogen

was used as an inert gas wherever practicable, oxygen monitors were deployed to provide warnings of potential asphyxiation. Additional fire detection devices were installed in the work areas along with more firefighting equipment and the Dounreay fire brigade was on special alert.

To estimate the quantity of hydrogen to be released during the mechanical extraction of the sodium from a DDT, data collected from and modelled in DSRL's Water Vapour Nitrogen (WVN) process was used to estimate that atmospheric water vapour (relative humidity greater than 95% at 20°C) would penetrate the sodium surface at a rate of 0.05 mm per hour. [12] Applying this rate to the exposed sodium surface area during mechanical extraction, it was estimated that the sodium and water vapour would react ( $2\text{Na} + 2\text{H}_2\text{O} \rightarrow 2\text{NaOH} + \text{H}_2\uparrow$ ) at a rate of 0.13 grams per second [8], releasing hydrogen at a rate of 5.7E-03 g/s, therefore the small quantity of hydrogen generated could be managed through adequate ventilation. However, flammable gas monitors calibrated to hydrogen, were used during sodium handling operations. Tritium release was considered proportional to the tritium concentration in the sodium, the speed of the water vapour and sodium reaction, the amount of sodium surface area exposed, and the duration of sodium handling. It was estimated that ~150 GBq of tritium would be released whilst processing a DDT. [12] The estimate was approximately 20% greater than the value measured during the work. Control measures to limit the tritium release included developing techniques to remove larger pieces of sodium as quickly as practicable. Additional ventilation was installed in the processing area, therefore the quantity of tritium available for inhalation was reduced. Workers took part in a tritium bioassay monitoring program and no significant exposure was observed.

Provisions were made to prevent burns, slips and drops from the generation of caustic and slippery sodium hydroxide. The tank steel was consigned as LLW therefore the swarf and metal fines from scoring and size reduction was collected and packaged as LLW. Electrical and mechanical systems in the area were physically isolated if they were assessed to be a hazard. Work at the bottom of the tank pits was controlled as a confined space. Scaffolding was used to control work at height. Fatigue from strenuous work in PPE was reduced by using numerous crews with strict working time limits.

### **Structural Steel Removal**

In order to lift the tanks and move them from their pits into other areas of the cells for processing, tonnes of structural steel (Figure 6) had to be removed to provide vertical and lateral clearance for the tanks. Structural and safety engineers assessed and determined the sequence and methods of removal to take into account hazards such as collapses, drops, working-at-height, etc.

### **Ancillary Pipework Removal [13]**

Secondary circuit pipework that was attached to the tanks had to be removed. A DSRL WVN process was applied to the majority of pipe interiors because they were contaminated with sodium. The amount of sodium residues in each loop was estimated to be up to 200 kg. Each circuit was cut and capped to isolate the intermediate heat exchangers before the WVN gas was introduced at multiple positions near the low points of the system. The WVN was delivered in stages until no hydrogen was detected. The circuit was then filled with water and the resultant weak hydroxide liquor was extracted, circulated through a neutralization system and put back into the circuit. After suitable recirculation and neutralization, the liquor was removed and treated in Dounreay's effluent treatment plant. All three secondary sodium loops were cleaned, dismantled, size reduced and packaged as LLW in Half-Height ISO (HHISO) Containers. Some secondary circuit pipework that was not treated via WVN had to be removed and temporarily packaged and staged so the tanks could be moved. This pipework was eventually cleaned and packaged for disposal (see Pipe Handling & Packaging section, below).

### **TANK TRANSFER/RELOCATION**

Processing areas were set up in Cells 1 and 3 (sodium removal & packaging, and tank size reduction,

respectively) therefore the tanks had to be lifted from their pits and moved to those processing areas.



Figure 6: Example of a Layer of Structural Steel Requiring Removal to Access a Tank



Figure 7: Entry into a DDT Pit to Prepare for Lifting

Thereafter the tank components would be transferred between the processing areas and to/from staging areas at other levels of the SGB. The 50-tonne overhead crane was used to lift the DDTs. The lift plans were prepared and the lifting equipment collected, including manufacturing a bespoke spreader beam. Civil and structural assessments were performed, including magnetic particle inspection to identify any issues associated with tank or lifting hook integrity. Lifting points were welded onto a tank, as required. Attaching the rigging and unbolting the tank from the floor required entry to the pits under confined space controls (Figure 7). Jacking DDT1 was required to free it from the pit floor.

A DDT was raised two inches and held for 0.5 hours before lowering it and repeating magnetic particle inspection to detect any stress cracking on the trunnions. Although large quantities of overhead steel had been removed, there were still space constraints (e.g., approximately four inches of clearance midway up Cell 1 and five inches clearance at the 47-ft level). It took approximately six hours to raise DDT1 from the pit through the Cell 1 roof at the 40-ft level and lower it through the Cell 1 roof at the 47-ft level into the processing area (Figure 4). Subsequent DDT relocations from their pits were faster due to fewer overhead interferences and experience. Once a DDT was positioned in the Cell 1 processing area, access to the bottom of the tank could be made via the manway in the skirt. The bottom was tapped in several positions and sodium samples were collected at a few depths. The tritium content of these samples was below the 1000 MBq/kg value used during planning therefore the work was authorised to proceed as planned.

Sample	1	2	3	4	5
Activity Measured (MBq/kg)	820	430	81	66	16

Figure 8: DDT1 Sodium Sampling Results for Tritium

The plan was to segment a DDT into four pieces: the bottom dome (containing the residual solidified sodium); the top dome; and two middle segments (referred to as rings). First, the skirt was burned off at the bottom of a DDT, just slightly below the bottom dome (the lowest cut line in Figure 10), to reduce the DDT height whilst allowing it to remain free standing. An added benefit was that the bottom dome section was then at a lower elevation, making it easier for workers to access it during the sodium removal work. With the crane attached to the centre dump tube, workers cut the top dome so that the sodium covered centre dump tube could be lifted out of the tank. As it was being lifted, it was sheathed in plastic so that it could be nitrogen blanketed whilst it waited processing. With a DDT attached to the crane, hold-downs were welded



Figure 9: DDT Lifted from Pit

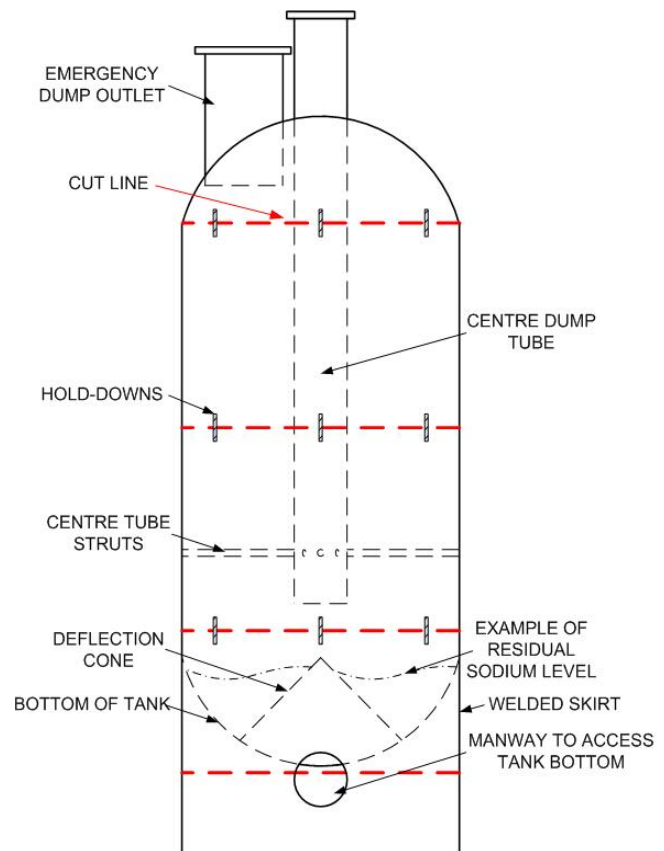


Figure 10: DDT Showing Planned Cut Lines

to the surface so as to straddle the lowest elevation cut line (i.e., just above the residual sodium surface) to keep the segments in place after a breakthrough cut had been made. Wall thickness at the cut line was reduced by scoring it with depth limited saws to allow the eventual breakthrough cut to be made faster, with less loss of nitrogen from the tank interior. After a breakthrough cut was made, two large pieces of plastic were slipped through the cut and sealed to the bottom dome piece and the upper section of the tank in order to maintain the nitrogen blanket in each piece. The hold-downs were released, and the upper section of the tank was lifted away by the crane (Figure 11) and moved to a staging area.

Whilst the removal & packaging crew was working on the bottom dome in Cell 1, another crew prepared the upper section (located in the staging area) for future processing. Scaffolding was erected around the upper section so that additional hold-downs could be welded onto the tank at the remaining planned cut lines. As before, the remaining cut lines were scored in preparation for the breakthrough cuts.

Following sodium removal, the bottom dome was moved to the size reduction area in Cell<sup>3</sup>. The upper section was then moved to Cell<sup>1</sup>, the lowest section was cut away and the remaining upper section re-staged. These movements were repeated until a tank was complete. The most difficult movement was the top dome because it had to be inverted before being cradled and staged. Size reduction of the cleaned segments in Cell<sup>3</sup> was performed with a combination of hot and cold cutting methods. This LLW steel was then lifted into HHISO Containers and carefully packaged to reduce voids.

An alternative removal method for the CUT had to be developed because it weighed over 50 tonnes and thus couldn't be lifted by the overhead crane. For air emissions it was assumed that the tritium concentration in the 150<sup>o</sup>kg of sodium remaining in the CUT would be no more than in the DDT sodium.

A four-column frame was erected around the CUT so it could be jacked up, but not tilt. The segmentation process was essentially the inverse of the DDT process. The 50-tonne crane was rigged to the top dome. When the CUT had been jacked up so that the top dome was sufficiently above the ground level of Pit 2, then the top dome was cut away, lifted, and moved for processing. The top of the remaining lower section was sealed with plastic and the interior of the lower section remained under a low volume, low pressure nitrogen purge until it was jacked up further so that the next section could be cut and moved for processing.



Figure 11: Residual Sodium in the Bottom of a DDT is Exposed after Cutting and Lifting Away the Tank Top



Figure 12: Workers Removing the Sodium from the Bottom Dome in the Temporary Processing Tent

### Sodium Removal and Packaging

The sodium was removed as a solid at ambient temperature and pressure and packaged for destruction as LLW sodium. The majority of the residual sodium was in a tank's bottom dome segment and was also beneath the deflection cones (see lower part of Figure 11). After the upper segment of a tank was lifted away, the final preparatory work in the Cell<sup>1</sup> temporary processing tent was completed. Two access/egress stairways were installed to the working platform surrounding the bottom dome. The tent top and remaining sides were installed. A PPE donning/doffing chamber was established at the tent entrance. Dehumidifiers were installed to maintain a low relative humidity in the tent interior. Materials and supplies were positioned for easy access. When sodium removal commenced, crews worked round-the-clock in two 12-hour shifts until all was removed and packaged. There were ten workers per shift: one supervisor; one safety watcher; six removal operators; and two support operators. The supervisor and safety watcher would monitor other workers via viewing windows in the tent. A crew of two removal operators would scrape, dig, pry or chisel the sodium out of the bottom dome (Figure 12) and place it into plastic bags. A support operator would place the plastic bags into 210 litre steel drums and support the removal operators. As drums were filled, they would be passed out of the tent to be blanketed with nitrogen, sealed, and observed for 24 hours. Observation included monitoring with a remote heat sensor to detect any continuing sodium reactions. Due to the arduous working in PPE, the two removal operators would work for 30 minutes before being replaced with a rested crew of two. During the initial removal they would try to place no more than 25°kgs of sodium in a plastic bag. This was later reduced to 10°kgs in order to provide flexibility in the event incineration was selected as the disposal method because it would require smaller packages. The initial sodium removal rate was only around 10°kgs per hour but increased to over 50°kgs per hour as workers became more efficient with the electric demolition breaker. If the chisel angle was too low then only a small piece of sodium would split

off. If the angle was too steep then the chisel would often become stuck within the sodium and it would take some time to extract it. The production rate also increased once the deflection cone was completely exposed and could be removed in order to access the sodium beneath it.

Metallic sodium reacts exothermically with water to produce caustic sodium hydroxide and flammable hydrogen. Although the exhaust fans created a negative pressure inside the tent and kept tritium and hydrogen at very low levels (hydrogen monitors were used inside and outside the tent) this also meant that humid make-up air was being pulled into the tent. Although dehumidifiers were essential to maintaining low relative humidity inside the tent, a lot of sodium surface was exposed during the removal work therefore the sodium was continuously reacting with water in the air. This resulted in three main problems: 1) fires; 2) caustic burns; and 3) slippery sodium hydroxide liquids. Small flame-ups would occasionally erupt but were easily extinguished by covering them with salt. The PPE was selected for protection from contact with the sodium hydroxide. Liquids were wiped up and handled as a caustic waste.



Figure 13: Scraping and Wiping a Top Dome



Figure 14: Cleaned DDT Top and Bottom Domes

When the bulk of the sodium had been removed, the dome or ring was left dormant for the residue on the steel surface to continue its conversion to sodium hydroxide. From time to time the workers would scrape the surface and wipe up the liquid (Figure 13). The alkali metals specialist would periodically inspect the area and, when satisfied that the correct conditions were attained, would authorise the workers to wipe down the steel surfaces with dilute acetic acid to neutralise the sodium hydroxide. When he was satisfied that the removal action was complete, he would then authorise the steel to be size reduced (Figure 14).

### Pipe Handling and Packaging

There were numerous pipes contaminated with sodium, ranging from small diameter to the size of the centre dump tube. Small pipes were removed using cold cutting methods and then placed into a glovebox-type apparatus blanketed with nitrogen. Workers would cut and split the pipes to expose the sodium so it could be scraped away and packaged for disposal. Large diameter pipes were handled in the process area in Cell 1. For example, as a centre dump tube was being lifted from a DDT, it was sheathed in plastic so that it could be nitrogen blanketed whilst it was staged and awaiting processing. Thereafter it was transferred to the process area using the overhead crane (Figure 15). After a centre dump tube had been positioned, the plastic sheathing was removed and workers removed the sodium from the interior

and exterior surfaces using short and long handle scrapers (Figure 16). Like the bulk sodium, the scrapings were placed into plastic bags which in turn were placed into 210 litre steel drums blanketed with nitrogen. Following scraping, the steel surfaces were wiped with dilute acetic acid. When the alkali metals specialist was satisfied that the removal action was complete, he would authorise the pipe to be size reduced and placed into a HHISO container (see the back of Figure 14).



Figure 15: Lowering Centre Dump Tube into Processing Area



Figure 16: Removing Sodium from Centre Dump Tube

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