UK Vitrification Plant Throughput & Operational Waste Disposal

Nick Gribble

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Short History of UK Vitrification

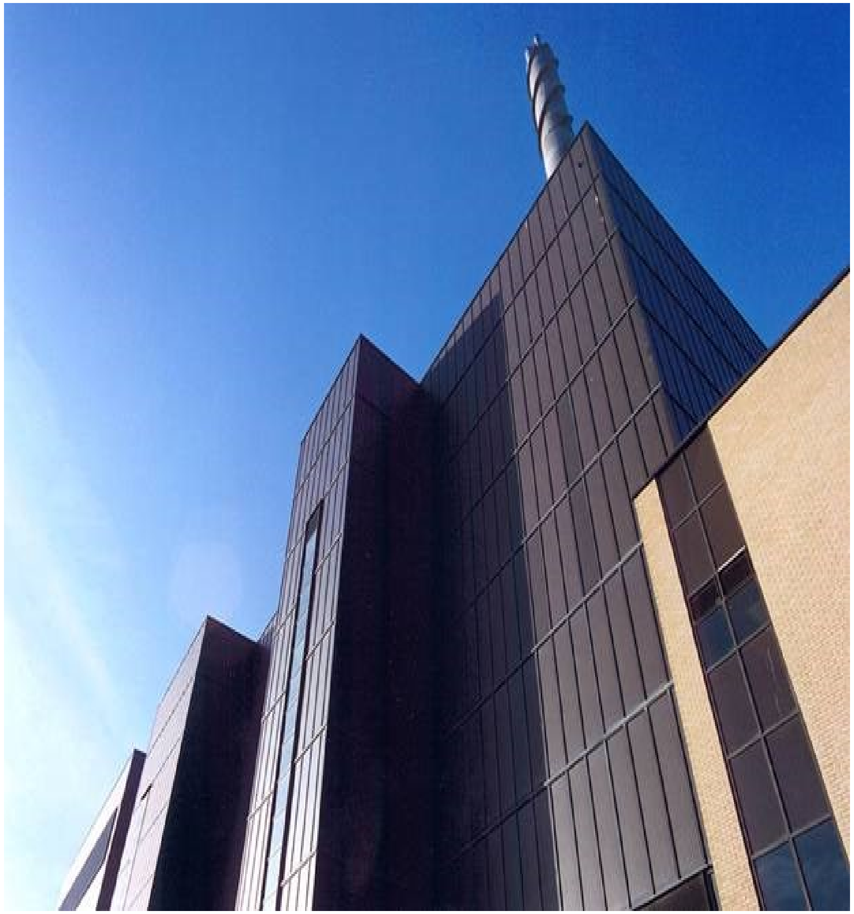
- R&D started in 1950s, range of glass systems investigated, alkali-borosilicate glass system chosen
- 1960s - suitable borosilicate glass formulation developed and tested at pilot scale - FINGAL process
- First generation process, batch production, fully active feeds including some HA liquor from Sellafield
- Mid 1970s, BNFL undertook the development of the Windscale Vitrification Plant – HARVEST
- 1980 - comparison of capability/availability of HARVEST process and French AVM process
- Economics, throughput, volatility issues & time constraints - decision made to build 4 lines of French AVM plant
- Later updated to two lines of AVH plant (second generation, higher throughput plant)
- Line 3 added when it became clear production targets were too optimistic

WVP Operational Capability

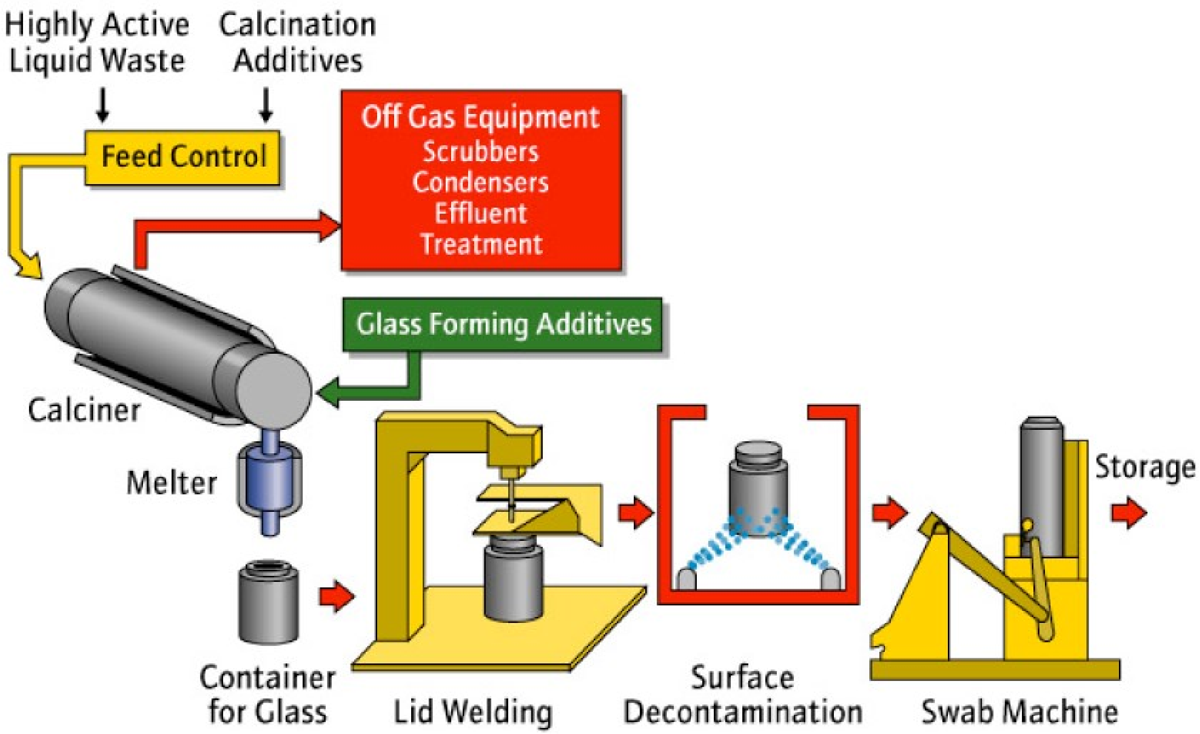
- Waste Vitrification Plant (WVP)

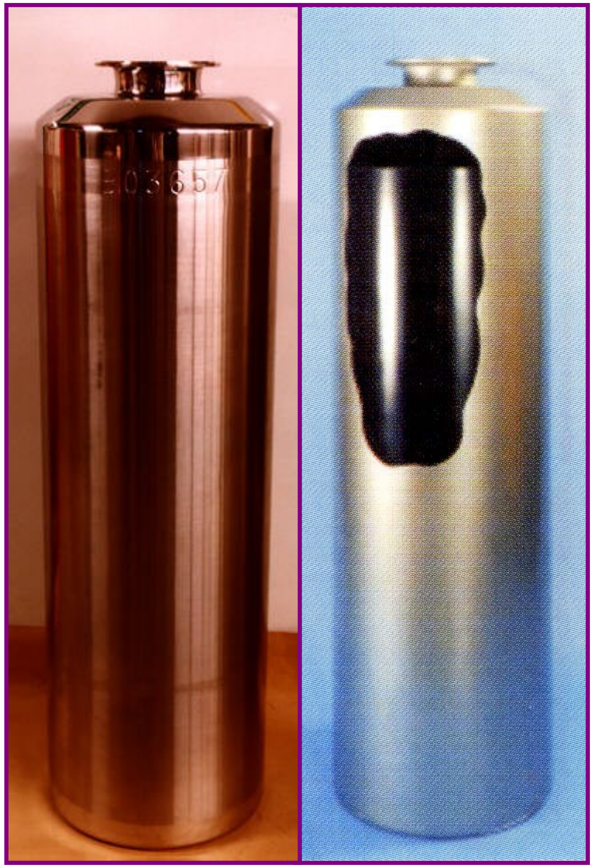
- Basis of Design
  - 25kg/h per line
  - 25wt% waste incorporation
  - 2 pours per container
  - 1.5 containers/day

- Function: safely immobilise stored and future HLW derived from reprocessing nuclear fuel

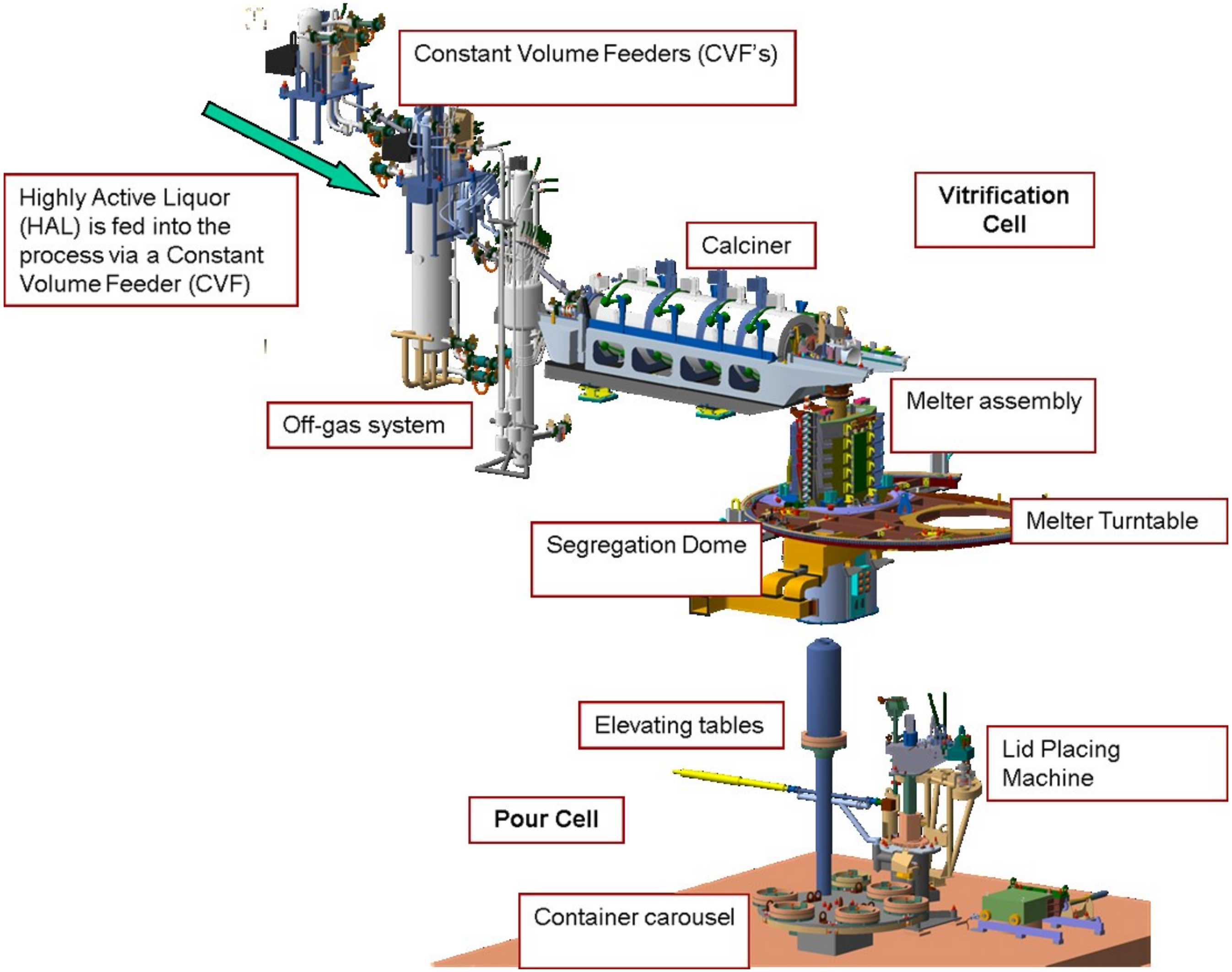


Schematic of the WVP Vitrification Process

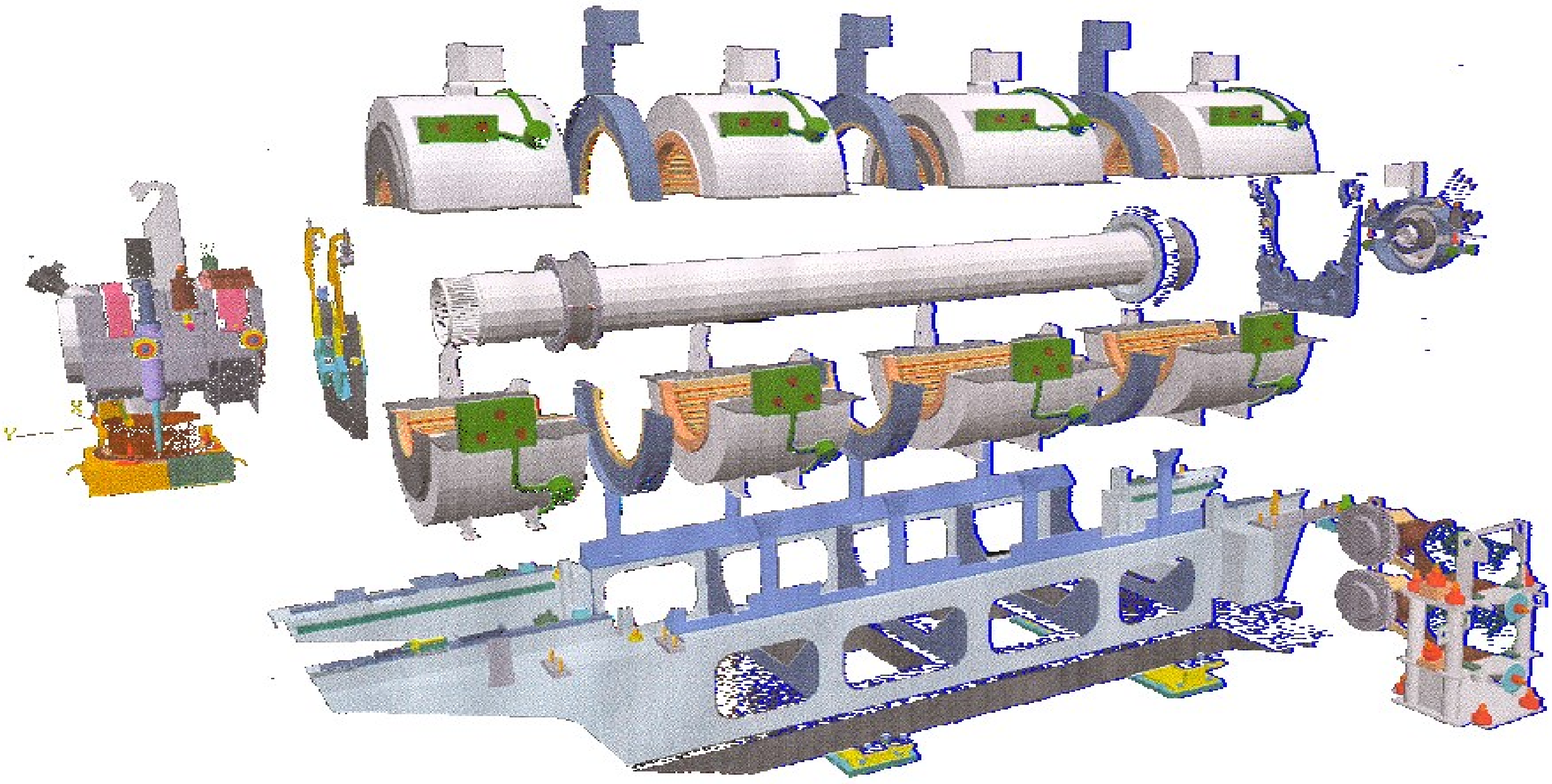




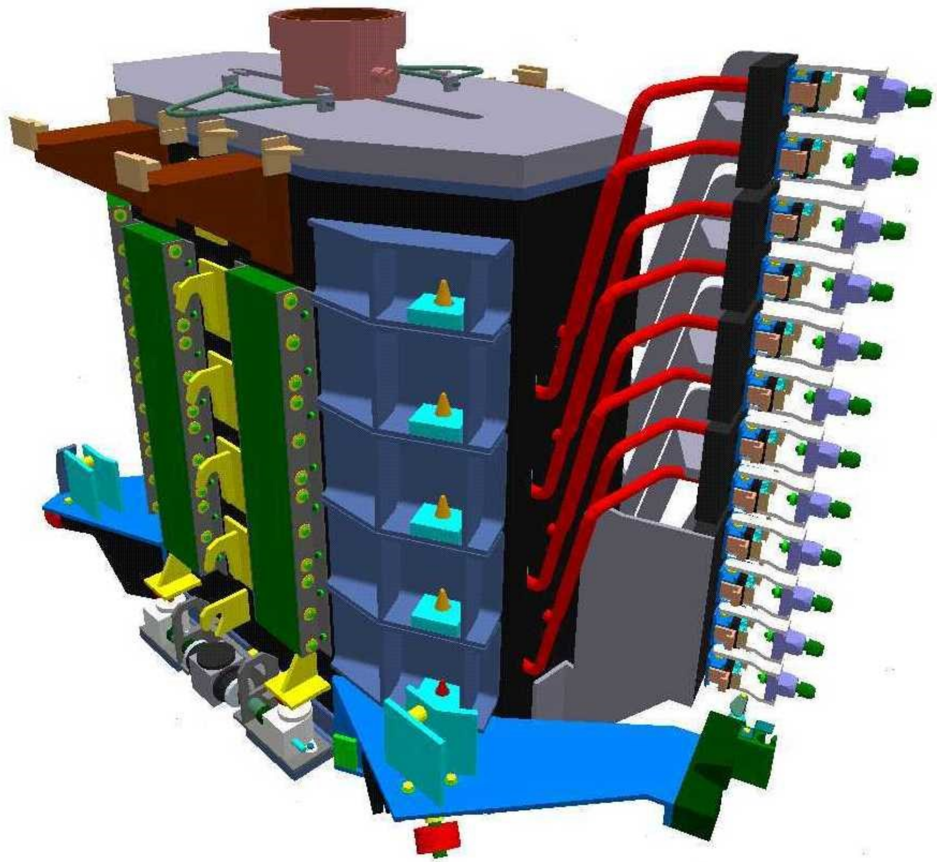
WVP Plant Layout



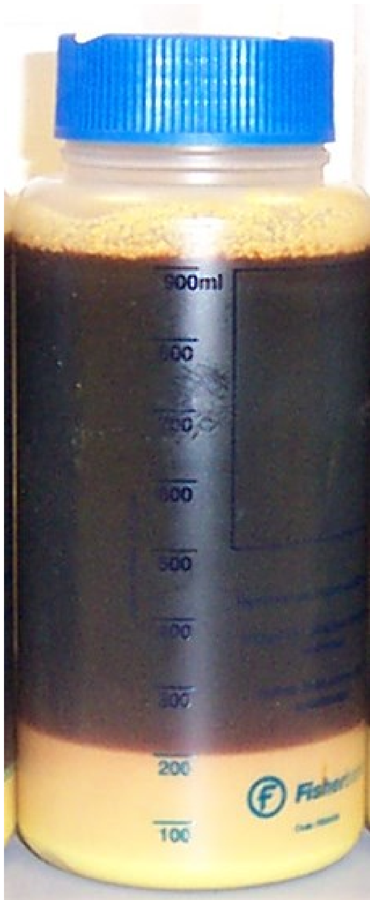
Calciner



Melter



What Does HAL Look Like?



- 99% of dissolved fission products from fuel reprocessing
- Insoluble fission products (IFPs)
- Impurities from cladding materials
- Corrosion products
- Traces of unseparated U and Pu
- Most transuranic elements

HAL supernate 80% HWO

Settled HAL solids 20% HWO

Line 1 & 2 Start Up

- 28/07/1990 – active commissioning Line 1
- 22/08/1990 – first active glass, 7 containers of 1% HAL in simulant then 6 x 10% HAL
- 23/10/1990 – 100% HAL operation
- 10/02/1991 – Line 2 started operating (100% HAL)
- 15/08/1991 – Regulator gave Consent to Operate

Operating Experience

- Blockages
  - Dust scrubber airlifts & recycle & off-gas line
  - Calciner tube & off-gas pipe
  - Melter neck & pour nozzle
- Equipment failures
  - CVF motors, glass feed system, sugar pumps
  - Calciner half shells, drive motor, bearings, thermocouples, seals & rabble bar
  - Melter split, leaking tombac seals, thermocouples & plugs
  - Container load cells, elevating tables, vitrification & pour cell crane availability, swabbing robot
- Efficiency
  - Crane decontamination
  - Container cleaning
- Long recovery times to change design and Safety Case
- Original design - 2 line plant with some shared facilities

Line 3

- By 1995 it was recognised that a Line 3 was required
- Line 3 designed with benefit of operating experience
- Existing melter induction system was obsolete so 50Hz system was developed

Line 3 Improvements

- Bracket Cranes in Pour & Breakdown Cells
- Improvement to the Pour Extract system
- Addition of filter crusher in Filter Cell
- Revised MA waste & waste filter export route
- Wider Cells with MSM's on both sides
- New ram design of Elevating Tables
- RFD's used for sampling rather than VOSL's
- Several design simplifications
- Provision of Wash Cells (4000 bar water jetting)
- Two Polar Cranes in Vitrification / Breakdown Cell
- Vessel Vent condenser situated in separate room
- MSM decontamination tanks, ultrasonic and heated air sparges
- Melter Turntable incorporating duty & standby Inductor Stack and Crucible
- Six container carousel & larger Pour Cell with more storage positions
- Addition of Disc Saw and Reciprocating Saw in the Breakdown Cell
- Improved Dust Scrubber
- Distributive Control System
- Through-wall drives
- Higher lighting levels in cell
- Larger shielded windows
- Through-wall cameras

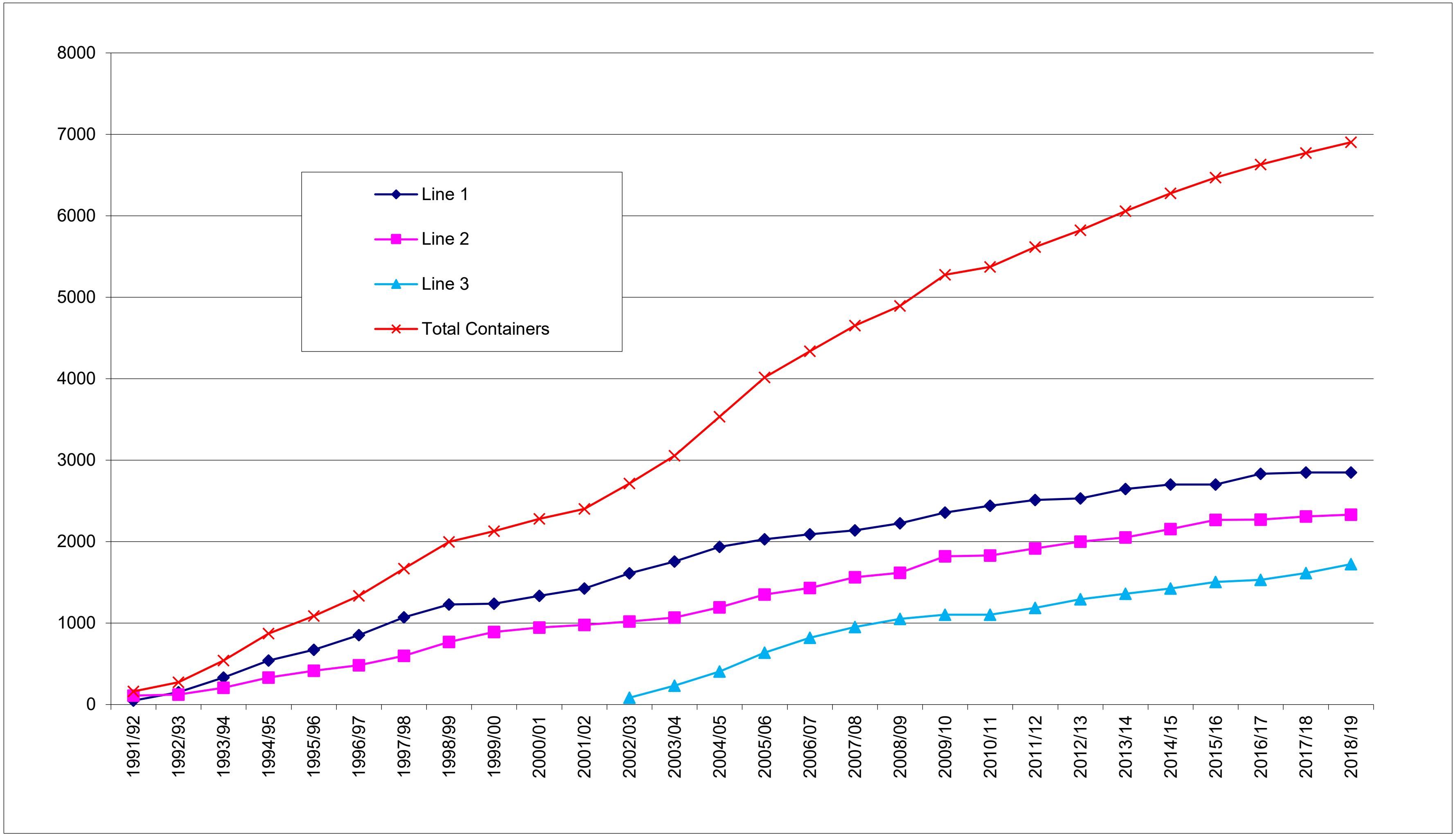
Other Improvements

- Cranes
  - Cable and reeling drum, modules, recovery procedure, contamination protection, improved decontamination methods, new plugs & limit switches, better access for maintenance
- In-cell maintenance
  - Lighting, tools, camera (fixed & mobile) cutting equipment
- MSMs
  - Robust jaws & drives, better counterbalance, ultrasonic decontamination bath, larger maintenance facility, failure mode analysis, spares policy
- Pour cell, decontamination and control cell
  - Weld inspection turntable, 2nd weighing machine, modular swabbing robot, radiation hardening of components, duty / standby decontamination tank pumps, replaceable valves, container cleaning - “Boris”, dry bead blasting

Other Improvements (continued)

- Waste disposal
  - Resources, shears, power hacksaw, strategy, ownership
- Spares policy
  - Stock levels, UK suppliers helped to reach required standard, collaborative work to improve equipment, avoid taking from other line if at all possible
- Documentation
  - Modern Fully Developed Safety Case, self-audits, instructions review, document wallet error identification and resolution

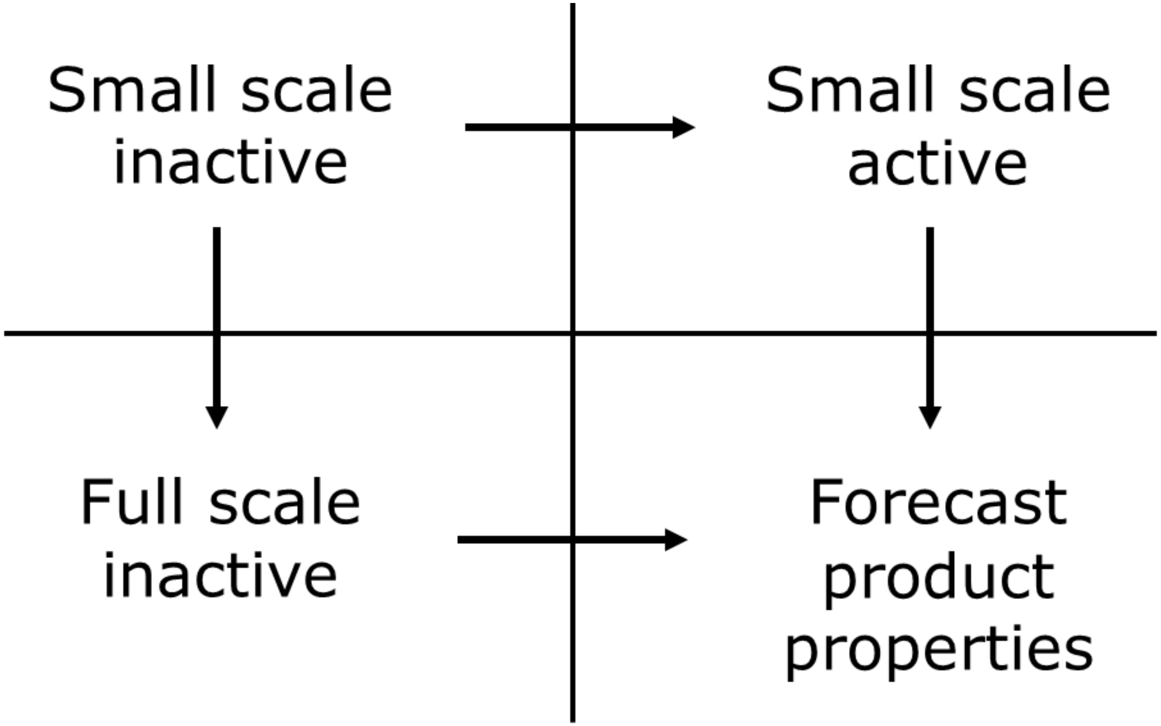
WVP Cumulative Production



Product Quality Philosophy

- The highly radioactive WVP Product Glass is not sampled
- Vitrification process is qualified and maintained within the limits of proven product quality
- Product quality is assured by:
  - Pre-qualification of process parameters through non-active lab and full-scale (VTR) R&D using simulated HLW
  - Control of WVP process parameters through continuous monitoring by trained personnel
  - Maintaining records of the process parameters for each container of HLW glass product

Structure of Development Programme



Approach to Product Quality

- Characterise the waste
- Develop representative simulants
- Define the limits of product acceptability
  - Wide range of studies at small scale
- Establish the process envelope at full scale
- Develop the case for product quality
- Demonstrate process envelope on active plant during commissioning
- Operate the plant within the defined envelope
- Conduct further full scale trials as required to extend the process envelope

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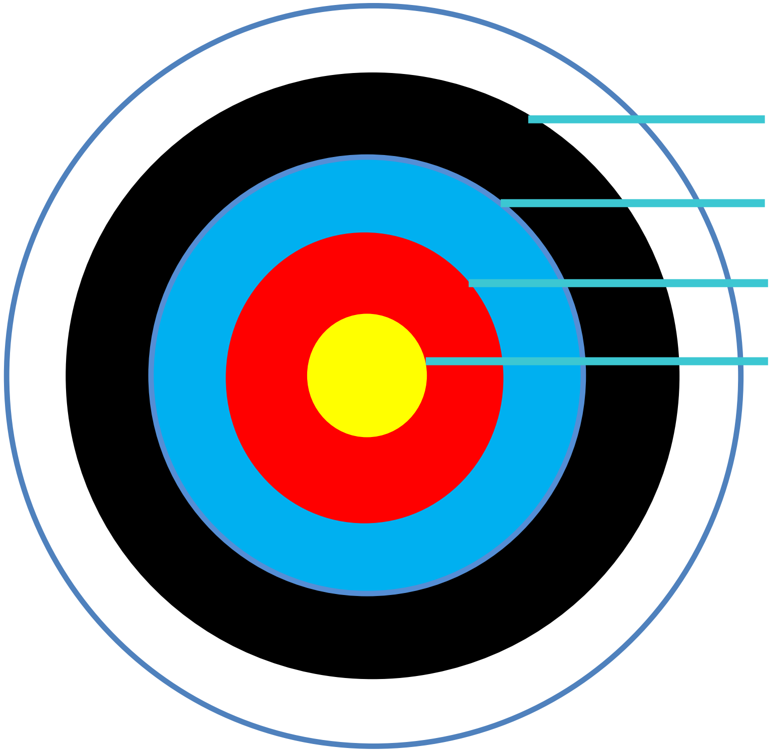
VTR Purpose

- Full scale non-active support facility for the Sellafield Waste Vitrification Plant (WVP)
- Aims
  - Improve waste incorporation rate (waste loading)
  - Increase plant throughput
  - Increase plant availability
  - Broaden WVP process envelope
  - Develop flowsheets for alternative waste compositions
  - Increased understanding of process, equipment and limitations
- VTR provides the underpinning PQ & operability data to allow implementation of changes on WVP

Defining the Limits of Product Quality



Boundary for acceptable waste

Limit of process operation

Process envelope

Process flowsheet

Vitrified Residue Specification (VRS)

- The document:
  - Defines how quality will be managed on WVP
  - Specifies the parameters guaranteed to the customers
  - Provides supplementary information and typical data
- Guaranteed Parameters:
  - Matrix composition (base glass) %w/w WO, FP & actinides and addition products
  - Container material
  - Package weight
  - Surface contamination levels
  - Activity content (overall and certain specific isotopes)
  - Dose & heat rate
  - Package identification

Process Specification

- Provides plant management (WVP & REF) with an envelope of conditions within which the plant must be operated in order that the plant operates satisfactorily and that the product meets customer requirements (100% certain to meet VRS)

- Provides instruction regarding acceptable limits within which key plant parameters must be operated

- Defines Product Quality Related (PQR) instrumentation which forms part of the Plant Maintenance Schedule (PMS)

Line Rules (Control Rules)

- Specifies actual set points for parameters that may need to be varied during operation with different feeds

- Each line has its own set of rules as the feeds, equipment and conditions on each line are specific to that line

- Plant items covered:
  - Feed Systems (HAL, recycle, sugar, glass)
  - Dust Scrubber
  - Calciner
  - Melter

Process Specification: PQ or Operability?

- Several of the parameters were introduced to ensure operability rather than product quality
- Limits were set based on extent of variation explored in development programme not on actual envelope limits
- Process Specification became a constraint to operation and product returns
  - Halt to operations if parameters were outside limits
  - Containers quarantined if made out of specification
  - Containers not returnable to customers – resulting in a smaller pool
  - Long technical review process to demonstrate PQ acceptable

Process Specification Parameters

- Intended to control:
  - Feed homogeneity
  - Product composition and consistency
  - Calcine residual nitrate, granulometry & impacts on reaction rate in melter & dust loss to the off-gas system plus ruthenium volatility
  - Dust scrubber solids equilibrium
  - Product quality of the poured glass
  - Quality of the closure weld on the container lid
  - External container contamination to export requirements
- Comply with the guaranteed parameters in the Vitrified Residue Specification
- Residue Export Facility parameters added later

Parameter Limits Widened by Development Work

- HAL mixing and resuspension requirements
- Waste Incorporation Rate (25 %w/w ⇨ 35 %w/w)
- Sugar removed but a ratio to [NO_3] in feed is maintained
- Dust scrubber recycle rate & acceptable range increased
- Calciner expansion minimised then removed
- Calciner rotational speed reduced
- Melter minimum temperature reduced (new glass)
- Melter sparge gas flowrate increased
- Container preheater removed
- Surface contamination limit increased for UK waste

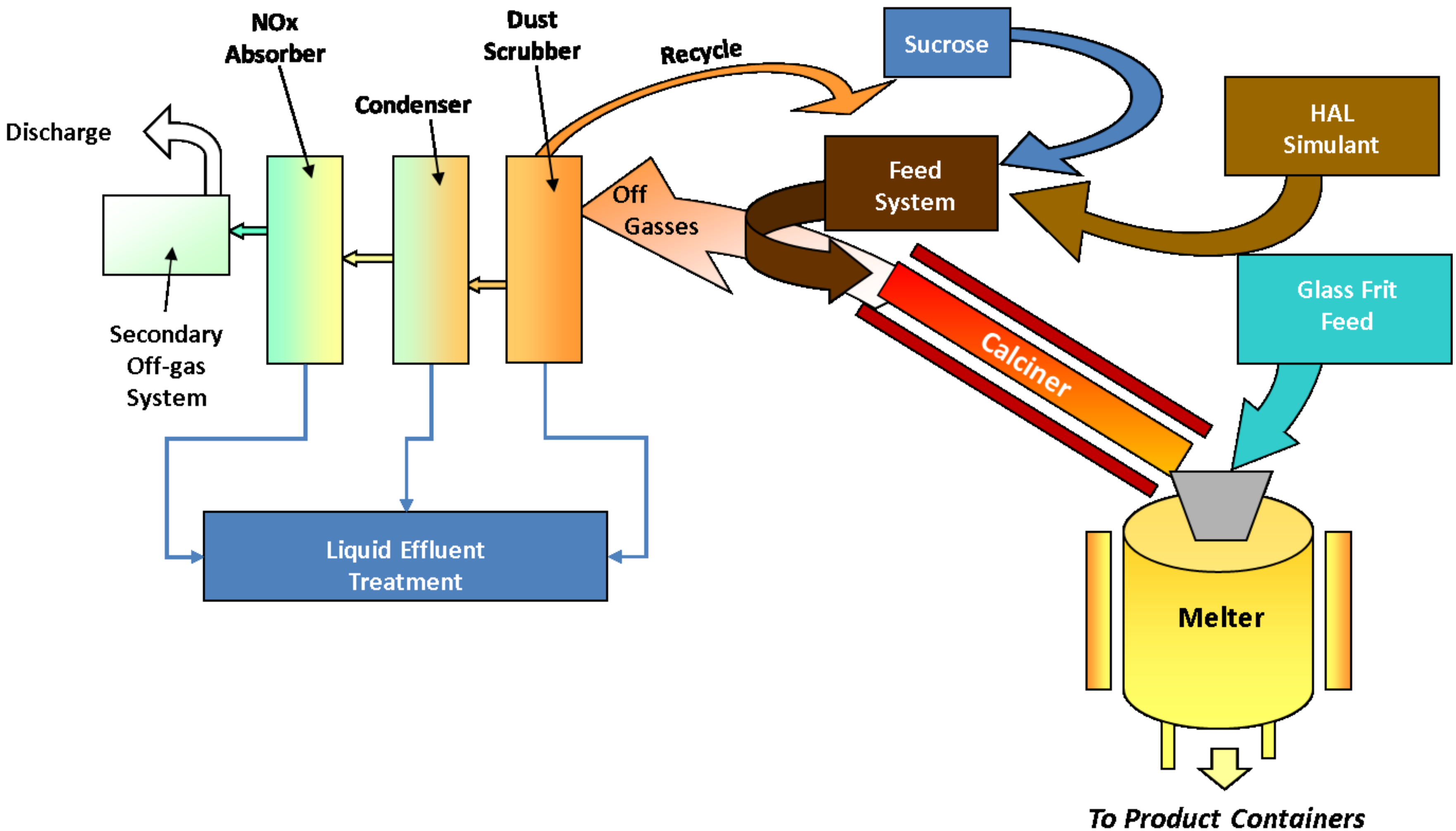
Summary Regarding Process Specification

- Parameters defined in the Process Specification were originally for guidance
- They became obligatory limits
- The acceptable ranges were too tight, optimistic plant control assumed
- Many containers were produced outside the limits
- The work has been done to broaden ranges or delete parameters with agreement of Regulators and customers
- Non-conforming containers now exceptionally rare

Vitrification Test Rig (VTR)

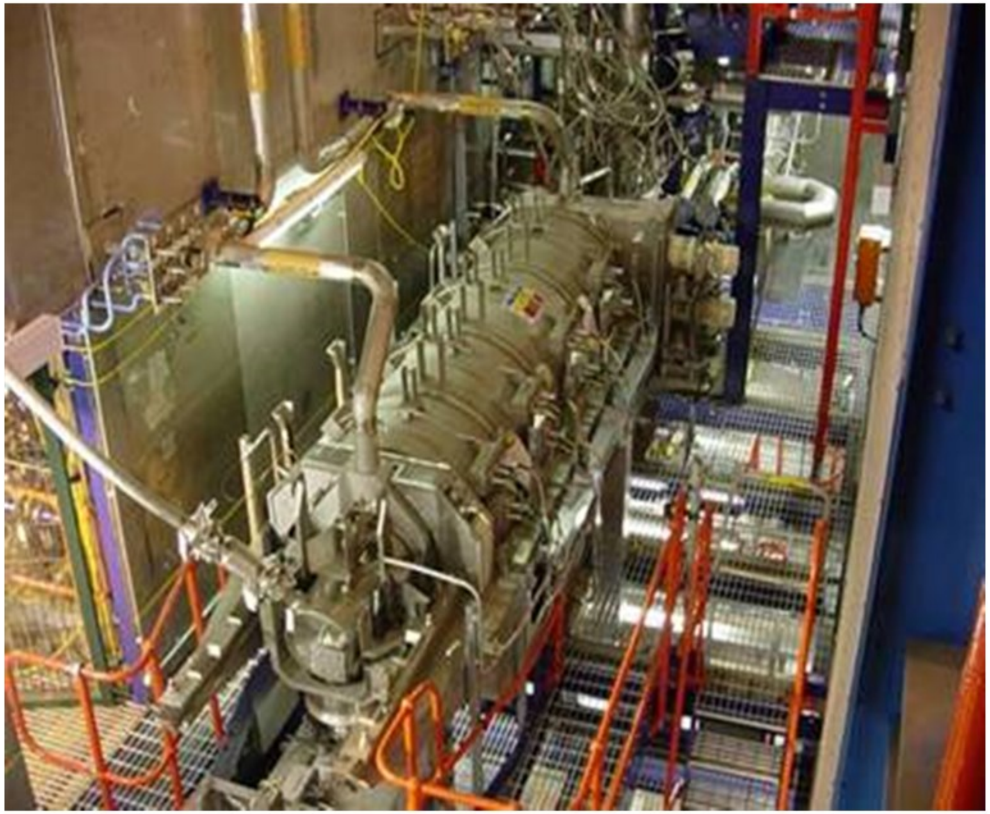
- Full scale replica of Line 2
- Operational since 2004
- Increased liquid throughput demonstrated – >90 L/h
- Higher glass production 35 kg/h
- Higher incorporation rate 38 %w/w underpinned
- All non-conforming containers provided with PQ
- Process envelope widened significantly
- Investigated future post operational clean out wastes, new high Mo glass formulation developed
- Training of operators & supply of operators to WVP

Vitrification Test Rig (VTR)



VTR Calciner and Melter

Full scale non-active support facility for the Sellafield Waste Vitrification Plant (WVP)



WVP glass products not sampled, product quality for flowsheet and operational changes proven at full scale prior to implementation

Vitrification Assistance Programme

- France had continued substantial development work to solve similar problems at La Hague
- UK bought improved technology and training, some changes (green) were more necessary than others (amber & red):
  - Calciner tube bird cage, grit blasted, 2 piece fabrication
  - Calciner lower end fitting seal shape & material, sweep air, brush ring, LEF bellows, rodding point
  - Melter crucible 4 sparges, insulation, spare thermocouples, belt with fins, shape modification, cloche, argon, sparge ID & OD, shoulder purges, same material that UK developed independently
  - RCVF inner bowl, rotational direction, separation of rotor from cover, replaceable dip legs Line 3 design adequate
  - Welding torch replaceable tip

Current Production Limitations

- Examples of things that affect annual throughput:
  - Feed batch analysis certification
  - Feed concentration
  - Number of lines available & planned maintenance
  - Breakdown cell space, cranes & MSM availability
  - Lines sealed sufficiently to operate (inleakage / inductor CCCW)
  - Equipment condition
  - Plant trips and recovery
  - Safety system proof checks
  - Breakdowns & spares
  - Container decontamination / swabbing

The Future

- New Evaporator “Delta” is now operating
- Current HAL stocks are relatively dilute
- THORP reprocessing finished December 2018
- Magnox reprocessing finishes 2020
- Reprocessing & HAL Storage Post Operational Clean Out
- Phased closure of WVP lines planned
- Line availability ~50% and productivity ~50%
- Significant MA & HA waste to dispose of whilst glass production continues

Future Challenges

- Dilute Feeds
  - Originally 180-200 g/L WO
  - Currently 90-100 g/L WO
  - Future 50-60 g/L WO
  - Requires higher feed rate to calciner – 92 L/h
- Post Operational Clean Out (POCO) Wastes
  - CPM / ZMH
  - High ammonium nitrate content in feed
  - New feed streams composition
  - New glass formulation using same melter system

Options for Calciner Operation at Higher TEL

- Upgrade calciner zones 1 & 2 – increased power
  - Cost, design, schedule, down time to implement
- Operate zones 1 & 2 near full power at high temperature – evaporative front maintained at zone 2/3 interface
  - Risks; rabble bar damage, stability in water feed/pressurisation, standby/operation differences
- Set evaporative front within zone 3, shorter denitration zone
  - Damp calcine, bubbly glass, lower dust loss to off-gas system
- Optimum is a compromise

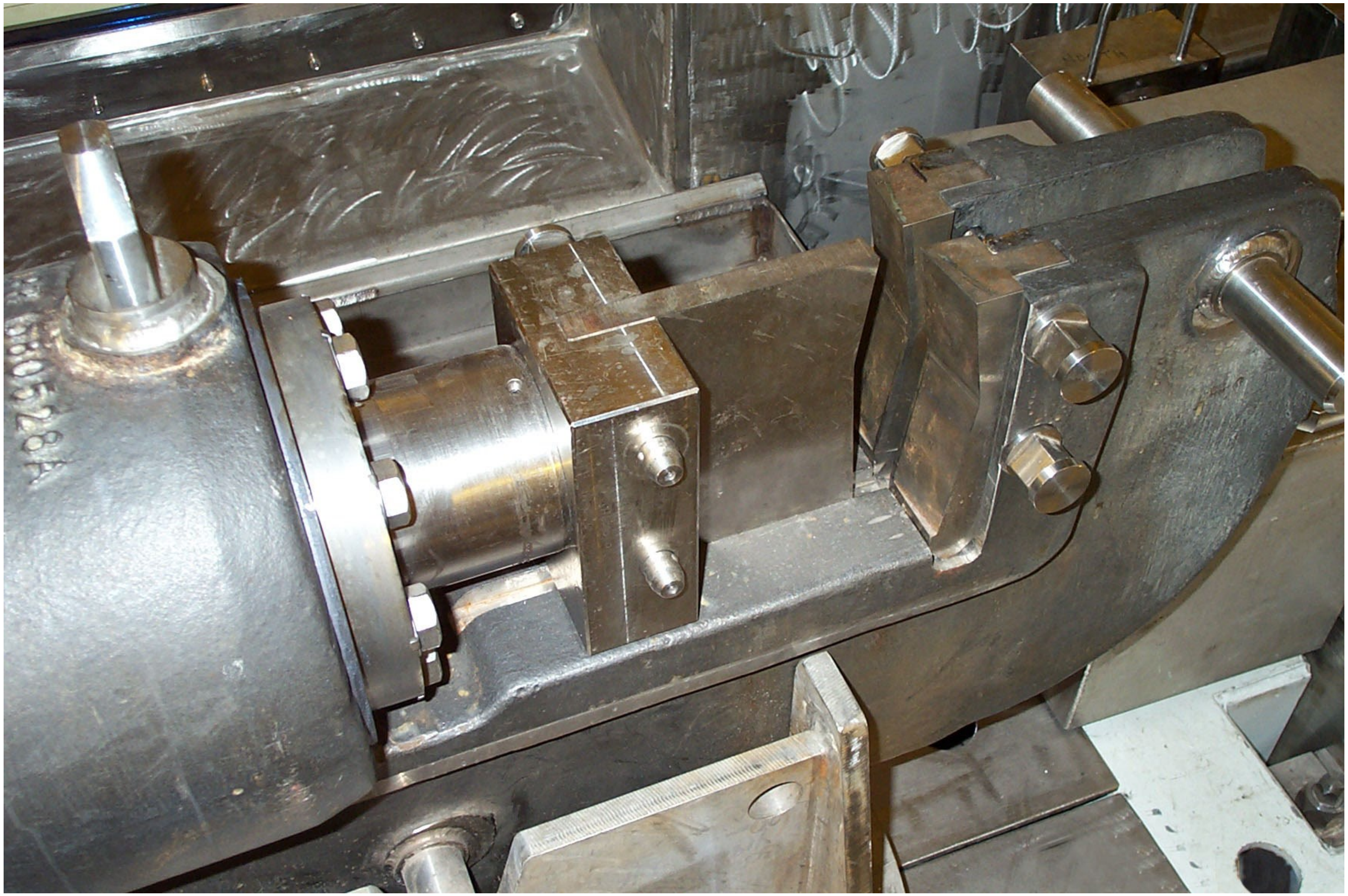
Summary of Improvement Work

- Calcine and glass production rate, waste oxide incorporation and liquor feed rate have all been increased significantly in research work on the VTR
- Implementation on WVP has been occurring in stages but there is more to do
- WVP plans this year to increase the HAL feed rate on the vitrification lines
- Waste oxide incorporation rate will be optimised to minimise container numbers whilst maintaining the heat load within containers to an acceptable level

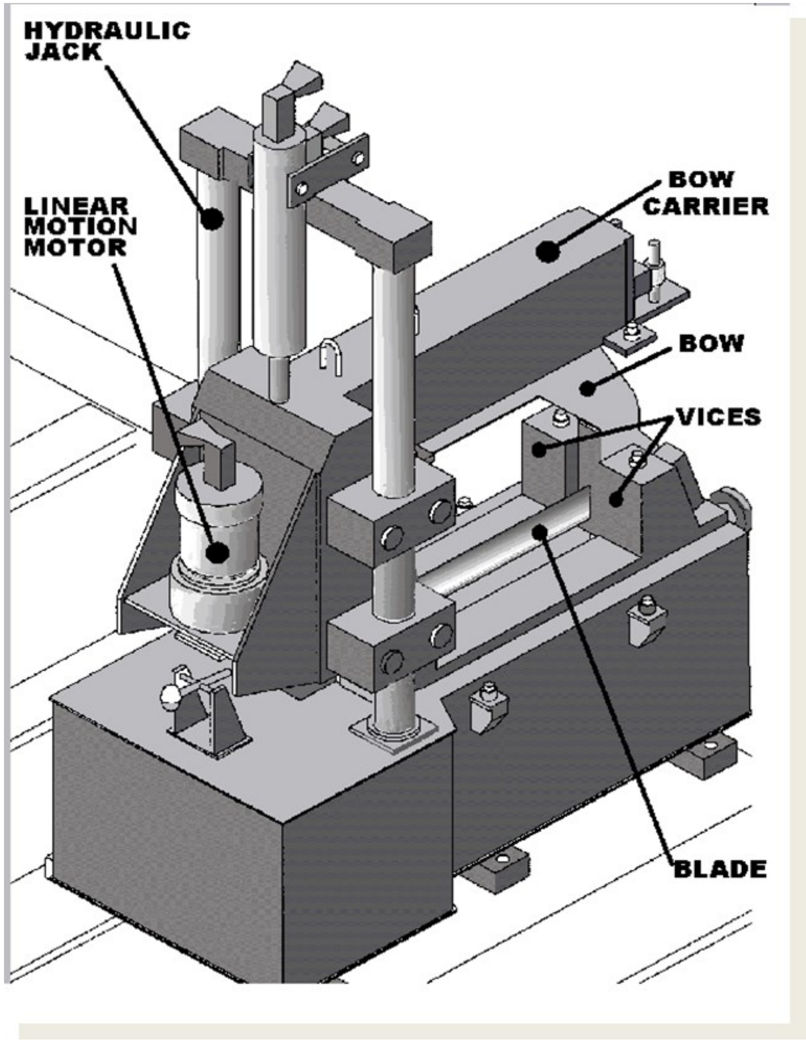
Waste Generation

- Equipment on WVP requires replacement when items fail or wear out
- Some components are relatively small others are large and require size reduction (calciner tube, dust scrubber, melter crucible)
- WVP was fitted with equipment for this purpose:
  - Shear
  - Reciprocating bow saw
  - Line 3 melter crusher & disk saw

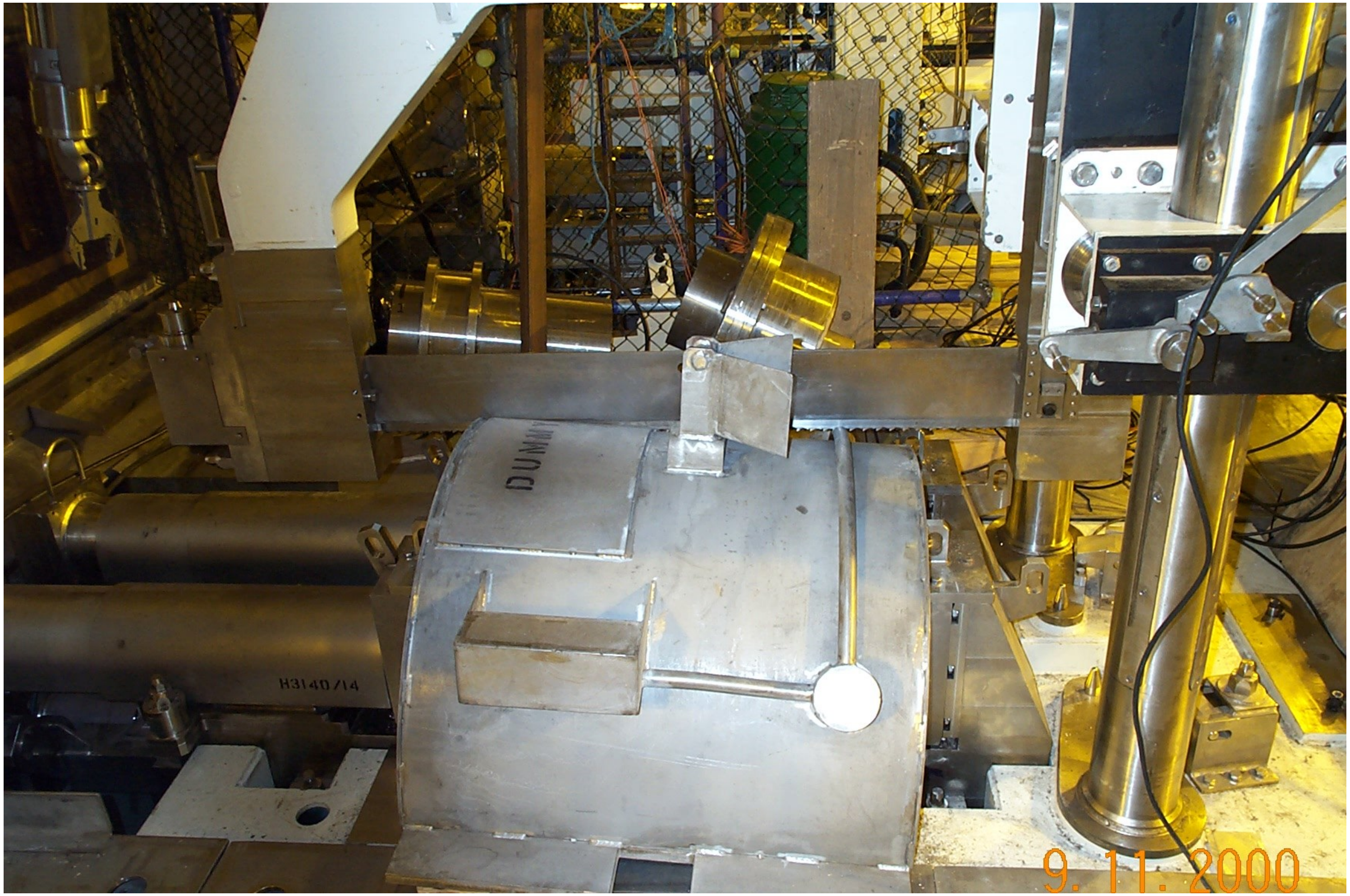
Hydraulic Shear



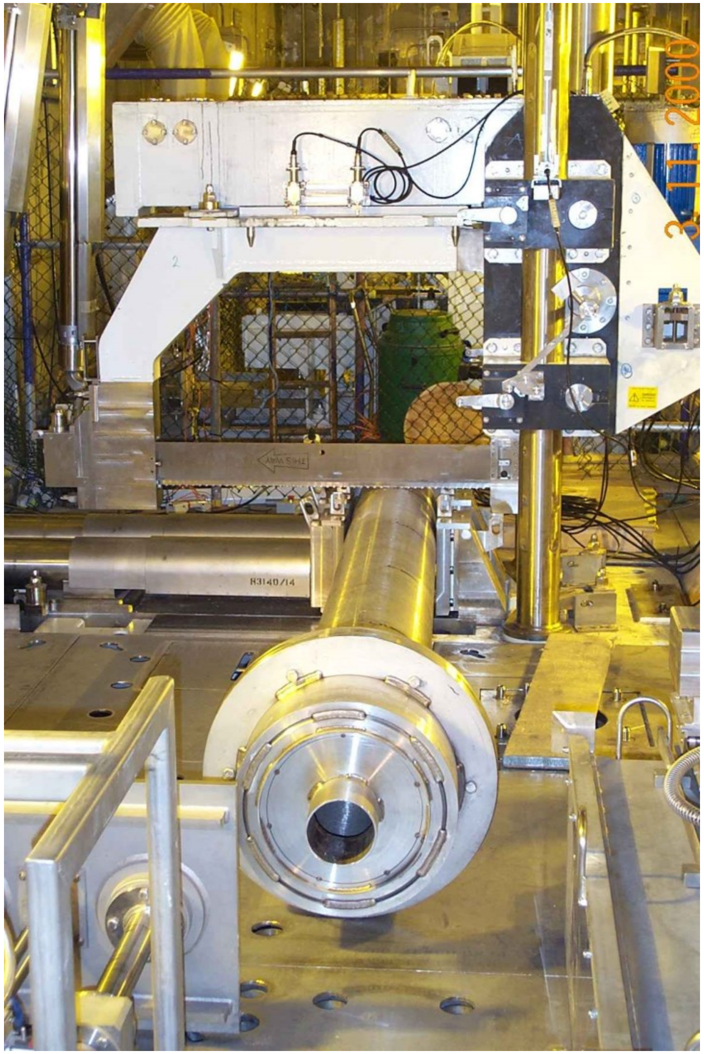
Reciprocating Bow Saw

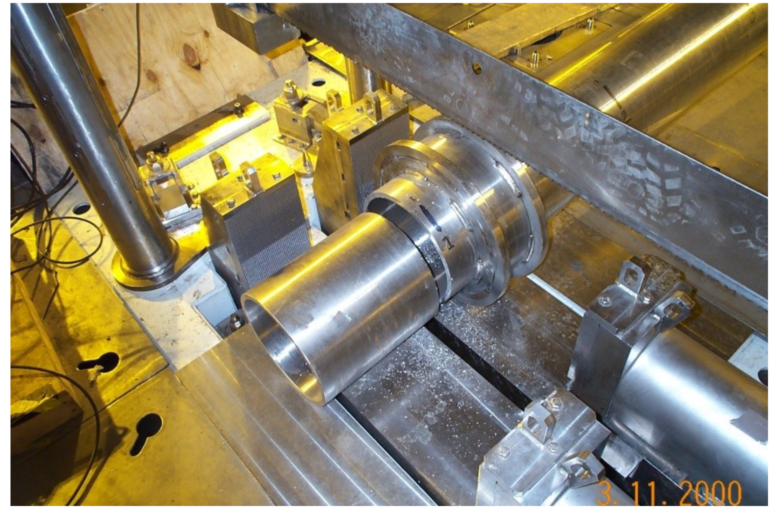


Reciprocating Bow Saw



Reciprocating Bow Saw Commissioning Tests





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Sectioned Melter Crucible

MA Waste Export

MA liner is filled with cut waste, monitored, put into black bin, lid bolted on, put into flask, monitored, exported to MBGW store

Historic Waste Disposal Problems

- Failure rate of WVP process equipment higher than expected
- Size reduction equipment unreliable
- Bow saw can't cut glass
- Bow saw vices worked loose (cut direction) – 118 blades/year
- Crane in Line 1 & 2 dual use: plant rebuild & waste disposal
- Crane & MSM reliability
- Lack of equipment, e.g. portable hydraulic shears
- Decontamination tanks not in use
- Focus: HAL stocks reduction (No. 1 UK risk) not waste disposal
- Large inventory of waste accumulated
- Waste interferes with plant rebuilds – no laydown area

Waste Processing Improvements

- New design of bow carrier bearing for bow saw
- Development of a new hydraulic power pack for better control of breakdown cell bow saws
- Feedback control and filters to existing incremental ram
- Line 3 anvil shear repaired
- Waste segregation – e.g. melter sections containing glass, floor sweepings in paint cans, HA waste in liners

- Permanent MA Waste coordinator appointed
- Waste tracking introduced

Continuing Improvements

- Increasing operational life of plant equipment
- Repair of existing equipment
- Dedicated waste operations team
- Higher packing factor in MA bins
- Target 1te/y waste reduction per line
- Restore Line 1 & 2 filter export route
- Establish HA waste route

Waste Strategy

- Avoid: not possible
- Reduce:
  - Equipment life increased (calciner seals, rabble bar, melter crucible)
  - Less waste (welding torch tip, smear brush, HP wash unblocking)
  - Increased packing factor in bins not bin numbers exported
- Reuse:
  - Refurbishment (welder heads, replace calciner drive cog not tube)
- Recycle: not feasible
- Dispose: consign MA waste to MBGWS, segregate HA waste for future disposal

HA Waste

- Waste too active for MBGWS
  - Melter heels / other glass contaminated items
  - Calcine residues / dust scrubber solids
  - Pour extract filters
- Design provided for HA technical waste on each Line
- Shoulder welded container, designed for storage in VPS
- Welding equipment in breakdown cell, plus routes to decontamination tank, commissioned inactively but now U/S
- No HA waste processed to date
- Equipment now all derelict, in cell and out cell cabinets

HA Waste Disposal Method

- Melter crucibles heels and glass
  a) Large pieces within basket in technical waste container
  b) Crushed glass in normal vitrification container or re-melted glass (glass loaded into melter and poured)
- Calcine / floor sweepings in containers within technical waste container
- Pour extract filters in technical waste container
- Non-issues (due to low inventory) – glass surface area & product quality (e.g. yellow phase)
- Key issues to be resolved before route can be licenced
  - Spillages / containment during transport (drop test)
  - Fire performance of package
  - Chemically reactive waste – calcine & Cs in extract filters

Acknowledgments

Grateful thanks to Sellafield Ltd and Nuclear Decommissioning Authority for continuing to fund research in support of new feeds, operational improvements and vitrification knowledge expansion and retention

Special thanks to the VTR operational & glass technology support teams without whom there would be no results only ideas

Thank You For Your Attention