IGD-TP EF7 Canister Design

# Manufacturing considerations for nuclear storage canisters

October 2016

**Dr Mike Blackmore**
Development Engineer

**Contributing aurthors**
J. Ashmore, S.S Al-Bermani, P.S. Davies, L. Lisiecki, E.J. Pickering, J. Talamantes- Silva, N Bagshaw

# Overview

- Company overview & experience
- Ingot and steel making
- Casting
- Forging
- Machining
- Fabrication
- Conclusions & Challenges

# Company Overview & Experience

- Over 200 hundred years old (originated 1805)
- 64 acre site in Sheffield
- A world leader in large scale forging and casting technology
- Largest forge and foundry capability in Europe
- Holds multiple manufacturing accreditations;
  - BS EN ISO 9001 Quality Management Standard
  - ASME approved Material Organization
  - ASME NPT  (weld assembly/fabrication)
  - RCC-M approved (French Nuclear)
  - UKAS accredited Test House


# Company History & Experience

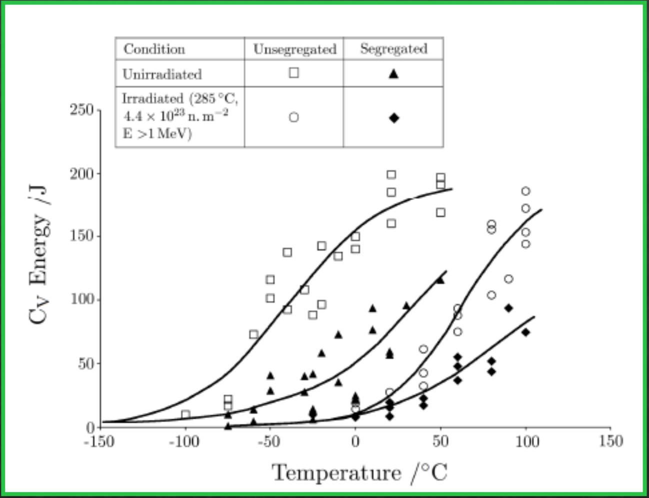
**Forge**
- 10,000 Tonne Press
- 4,500 Tonne Press
- 2,500 Tonne Press

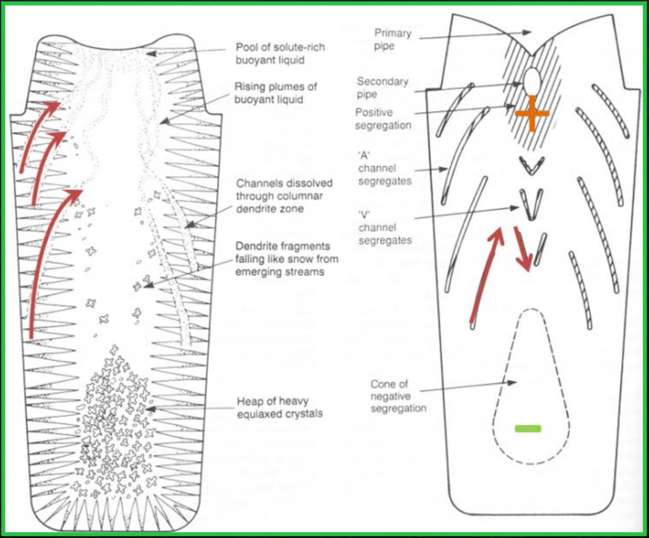
**Foundry**
- Annual capacity of 8,000 Tonnes
- Max. casting size 16m x 7.7m x 4.8m
- Max. weight casting of 360 Tonnes
- Largest ever cast weight 650 Tonnes

**Machining**
- Milling, turning & boring
- Turning up to Ø8 and 21m long
- Can bore lengths up to 20.5m
- Handle parts up to 400 Tonnes

# Ingot and steel making

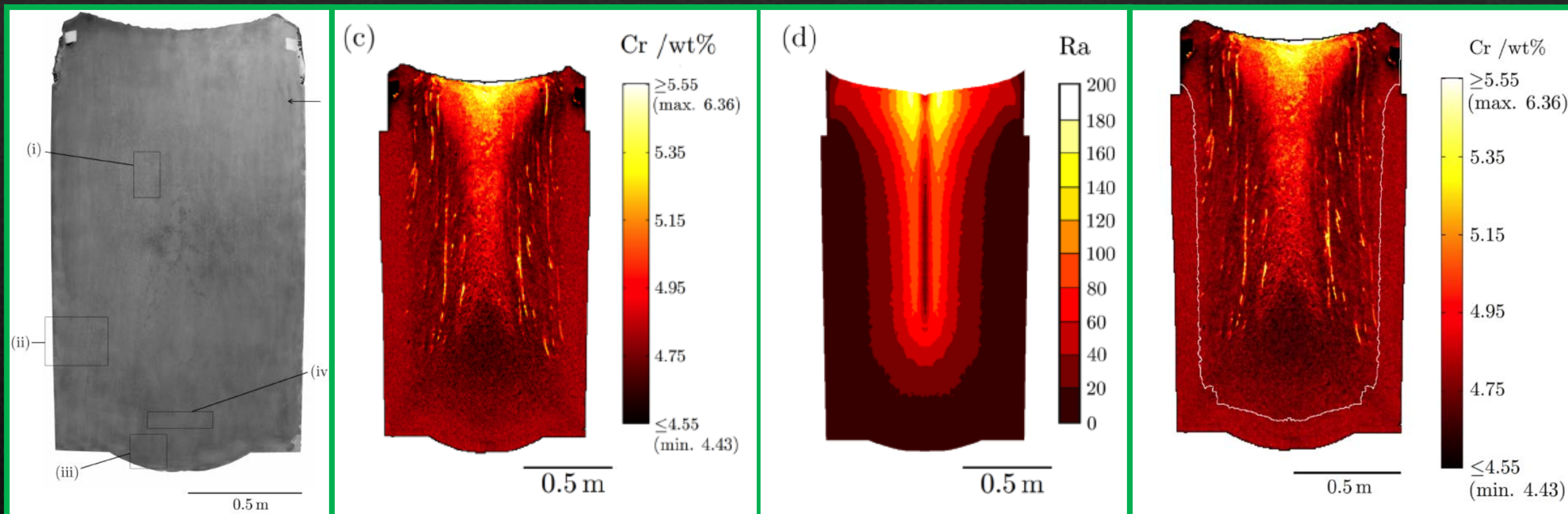
- Mechanical/design engineers should appreciate metals are not homogenous elastic bodies
- They contain variations in;
  - Chemistry (segregation)
  - Microstructure
  - Mechanical properties
  - Density (defects)
- This is especially true for large cast and forged products
- The material supplier and processor must understand this and design the processing route to minimise any detrimental impact on the finished component



# Ingot Development

- SFIL have worked for many years to develop segregation prediction methods and minimise the effects in large steel ingots
- Full scale ingot (~13t) sectioned and mapped within a PhD project with Cambridge University
- Segregation model developed and verified against measured values




*Ingot sectioning* | *Segregate measurement* | *'A' segregate prediction* | *'A' segregate free material*

# Hollow Ingot Technology

Furnace exit

Transfer to 10,000T press

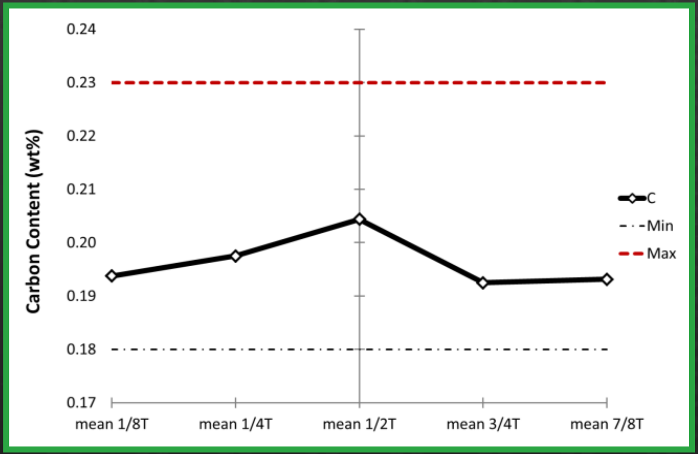
Becking

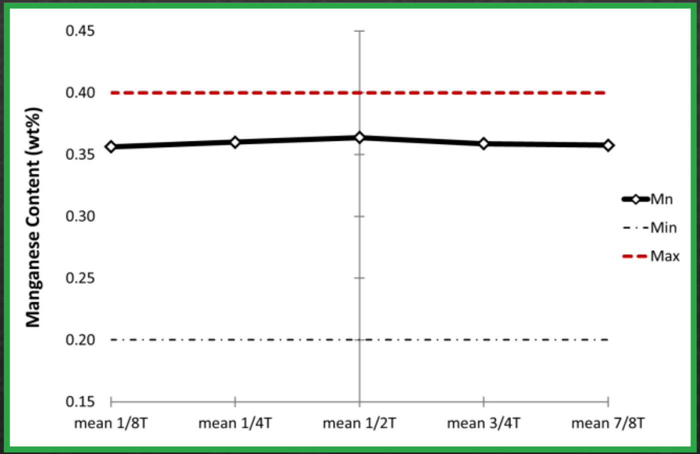
Breakout time:

- *150t hollow ingot – 16hrs*
- *150t solid ingot – 37hrs*

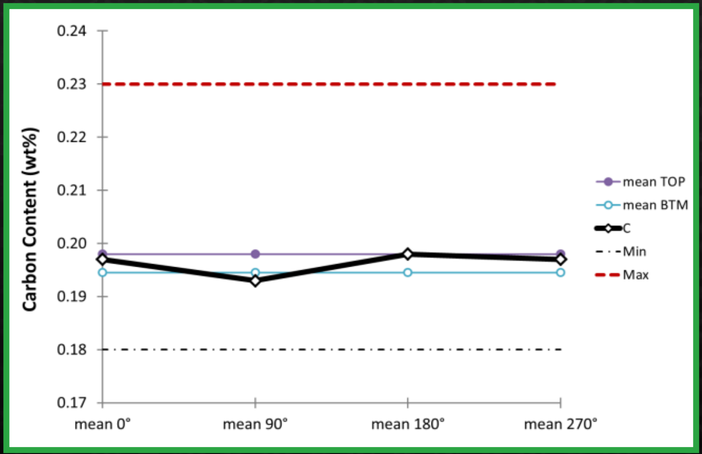
# Hollow Ingot Technology – SA508

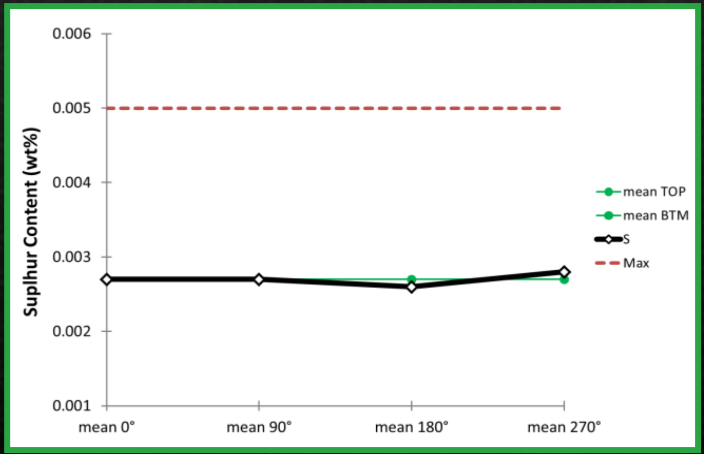
## THROUGH THICKNESS VARIATION



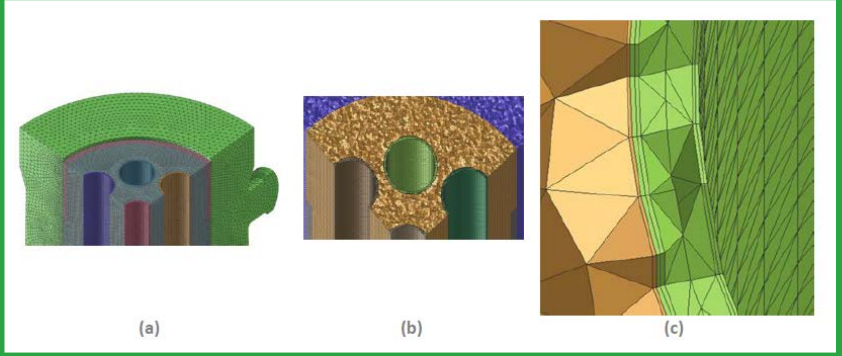

## MEAN ANGULAR VARIATIONS



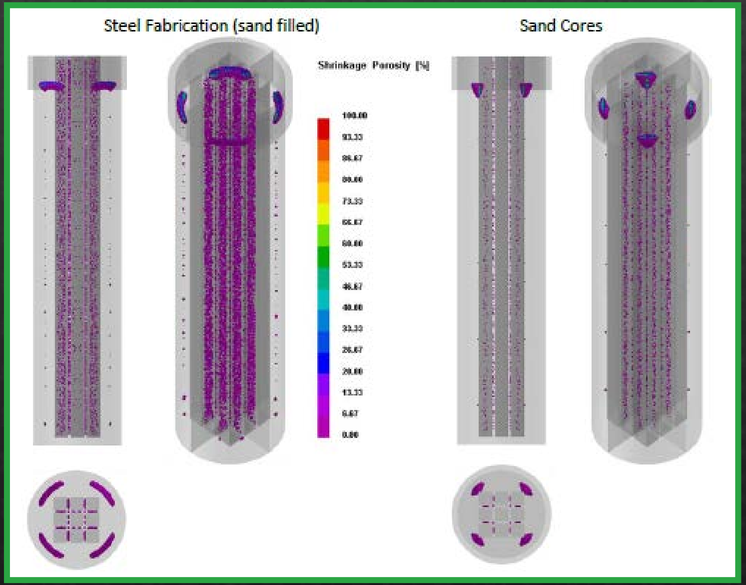
# Casting

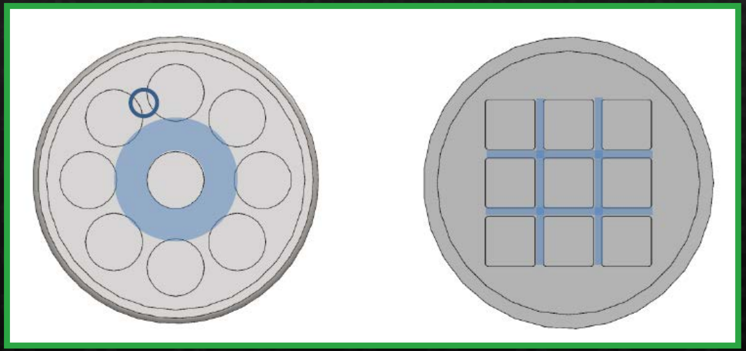
- Casting modelling carried out on high aspect ratio canister geometry
- Two methods explored – sand cores and steel cores
- Foundry and Melt Shop casting processed (sand or iron moulds)
- Two configurations of fuel rod assemble channels – square and round
- Very challenging;
  - Feeding problems during solidification inducing porosity
  - Parallel sidewalls are more difficult to feed than tapered geometries
  - Non tapered objects are difficult to strip
  - Manufacturing robust moulding cores



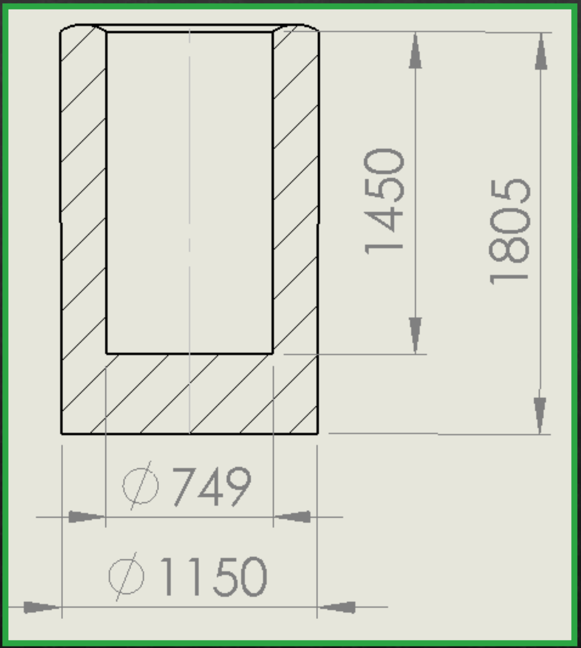

# Casting

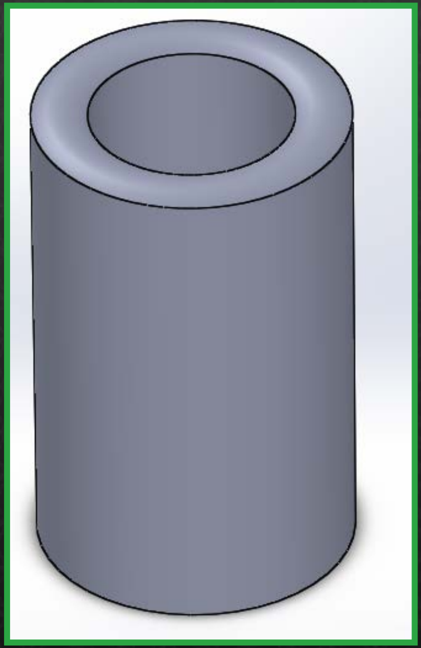
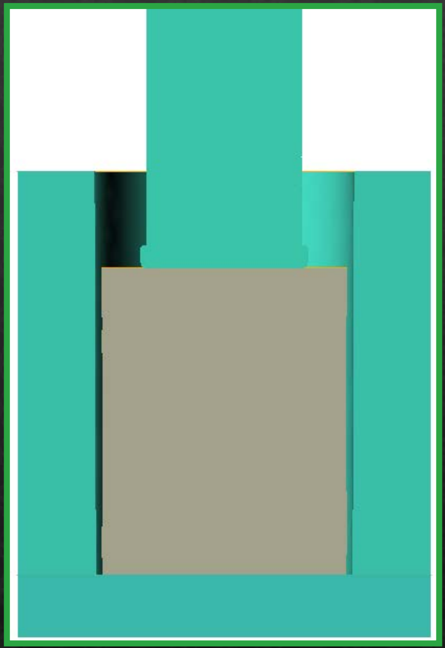
- Square fuel channels result in higher shrinkage defects due to increase ligament area and reduced thickness
- Sand cores result in a lower population of shrinkage defects compared to a fabricated steel core assembly
- A foundry method of casting generates a small population of shrinkage defects due to the slower heat extraction of the sand mould compared to the iron mould used in the Melt Shop method
- NDT challenges exist in the vast majority of the component volume
- Foundry sand casting , with sand cores generates the most favourable results, but challenges to make this a robust and repeatable process still exist.



# Forming – Backwards Extrusion



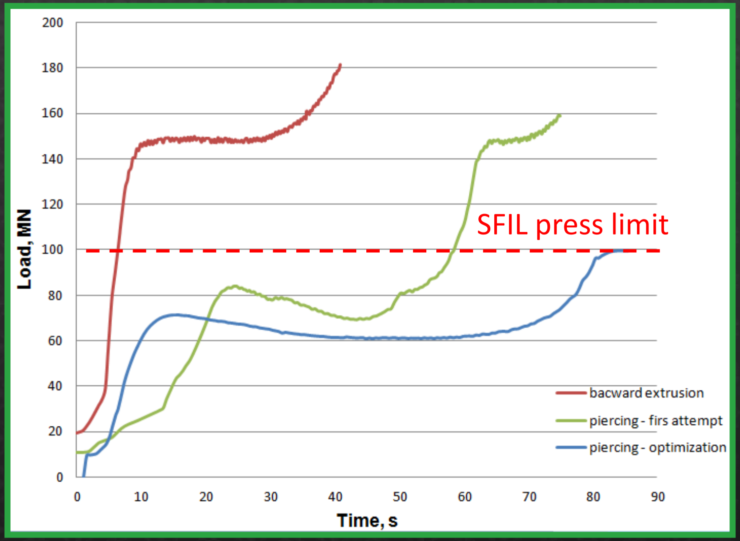



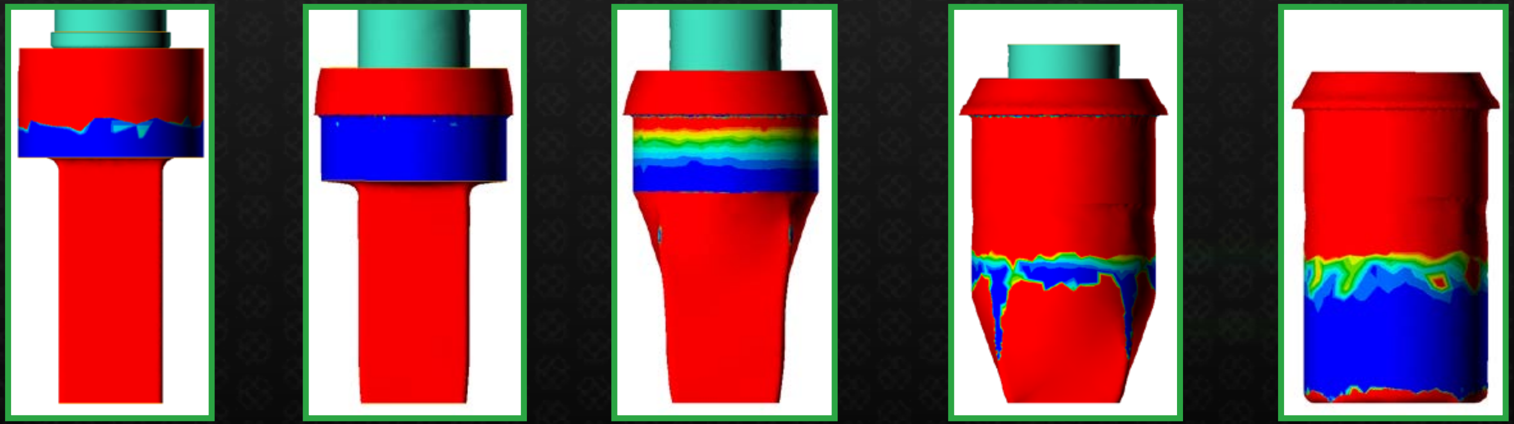
- SFIL hydraulic press limited to 100 MN (10 000 t)
- Materials modelled - AISI 304, AISI 1015
- Forming temperature -1225 °C

# Forming – Backwards Extrusion

- KPV's investigated in current study
  - Friction coefficient
  - Forming temperature
  - Work piece cooling time
  - Cooling due to tool contact
  - Cross head velocity ($\equiv \dot{\epsilon}$)
  - Billet geometry
  - Mandrel geometry

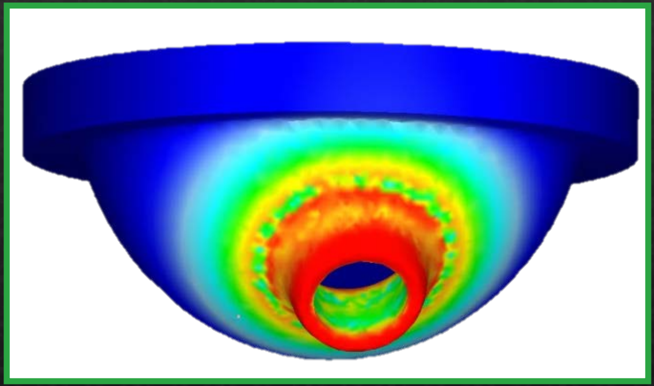
- On going work to optimise process and reduce manufacturing costs



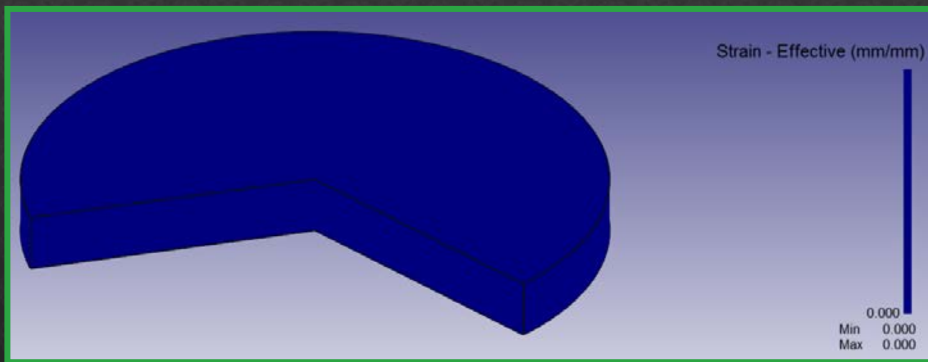
# Forming – Head Forming

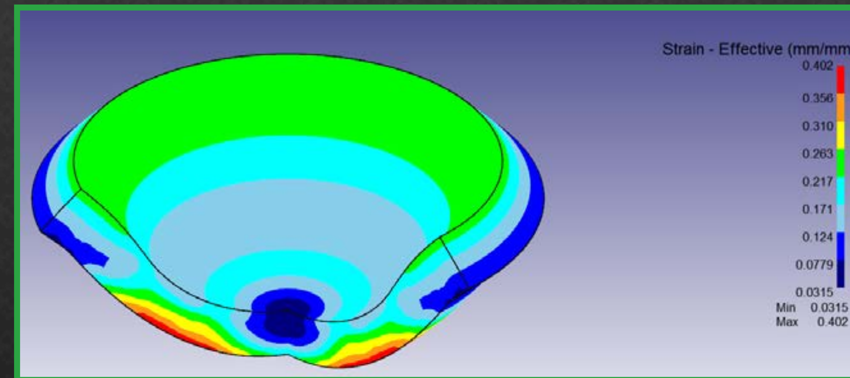
Large scale civil nuclear head

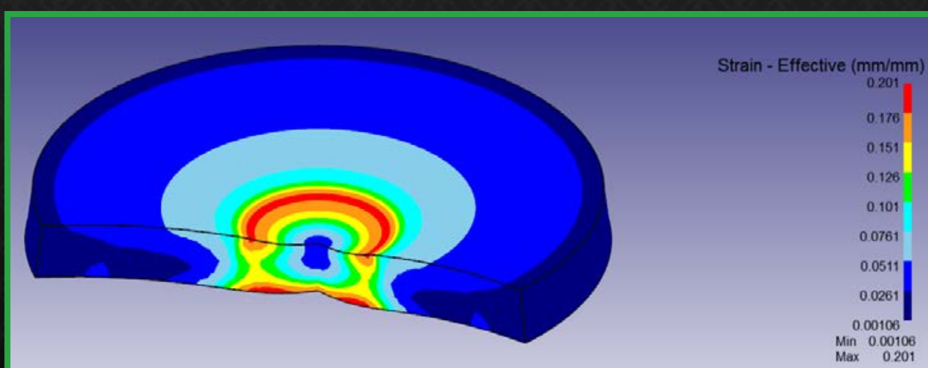


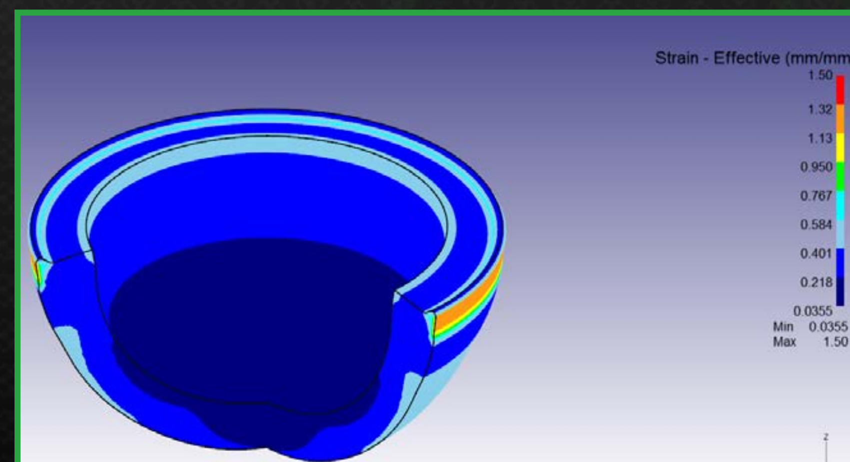
# Small scale canister closure head

Formed plate – Ø 1000mm, 100mm thick



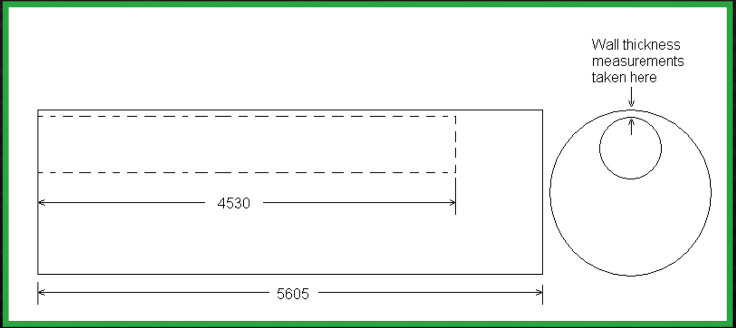



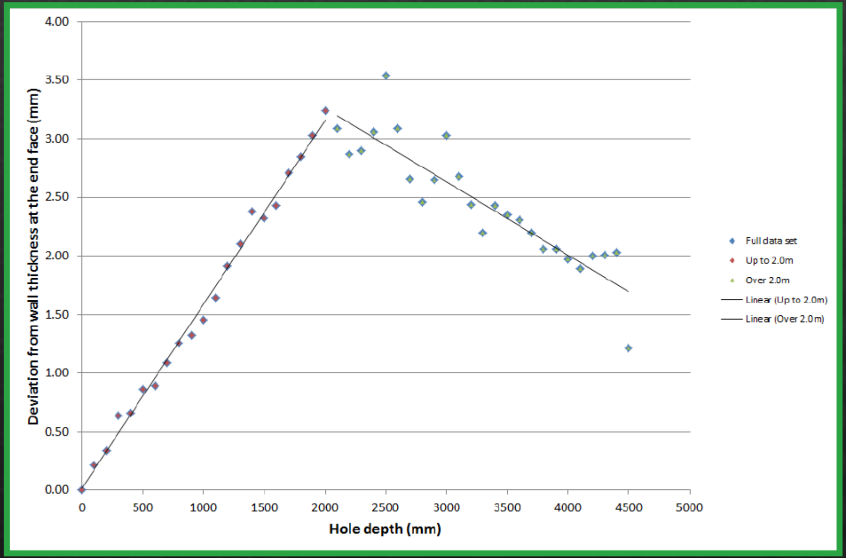
# Machining

- Off centre boring trials conducted on 4145H modified steel
- 210mm hole bored to a depth of 4530mm (AR ~ 22)
- Wall thickness was measured by UT scan
- Deviations in wall thickness used to infer hole deviation from its axis

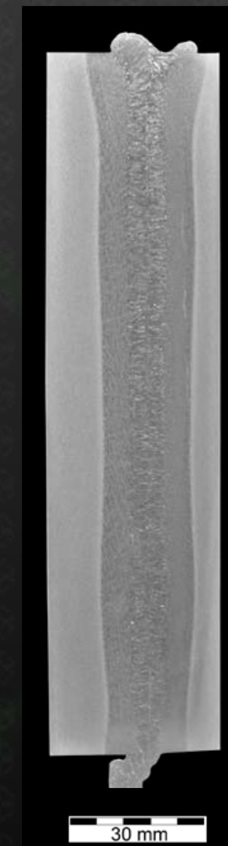


# Fabrication

- Along the length of the hole was 3.5 mm deviation, and can be considered a worse case estimate of the straightness that can be achieve
- Deviation of up to 1.7mm/metre
- Machining time was 26 hours comprising 14 hours of machining and 12 hours for setting and tool changes - 9 holes, ~234hrs, ~10 days
- The production of the containment canister via this method of manufacture is technically feasible and considered by SFIL as low risk
- Forgemasters are confident in their ability to produce the hole configuration
- Future work will aim to reduce cycle time and tool changes



# Fabrication - RPEBW

# Fabrication - RPEBW

Unstable key hole

Stable key hole

- Unstable, fluctuating key hole results in collapse of the melt pool and trapping of weld vapour pockets leading to large voids in the weld root

# Fabrication - RPEBW

160mm
Wall thickness

200mm
Wall thickness

# Conclusions & Challenges

- Understanding, predicting and controlling segregation in steel making are key to product integrity and consistent mechanical properties
- Casting of integral fuel assembly channels into steel canisters presents many manufacturing challenges that severely detriment canister consistency and integrity.
- Machining of high aspect ratio bores and holes is possible, but canister design and tolerances must be flexible enough to align with achievable manufacturing tolerances
- High integrity fabrication methods such as out of chamber EBW demonstrate excellent welding characteristics but require more development and qualification in the nuclear industrial
- Advanced forging and forming techniques are transferable to smaller scale components, but this is yet to be carried out and validated/approved
- FE modelling has shown backwards extrusion of steel canisters is possible with process optimisation to remain within the operation limits of SFEL's heavy forge
- **Early supplier engagement is essential to drive design for manufacture to make canister designs achievable and affordable**