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Implications of canister design & materials on closure welding for deep geological disposal canisters for high level nuclear waste & spent fuel

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Materials Joining and Engineering Technologies

TWI – An Extension of your Resources

- Research & Technology Organisation
  - Established in 1946
- Industrial Membership based
  - Effectively owned by Members and run by representatives from Member Companies
- Non-profit distributing
- Five UK locations and 13 international offices
- 900 staff

Scope

- Global drivers
- Spent fuel and high level waste
- Geological disposal
- Materials selection
- Long term integrity
- Closure welding
- Summary

Global Drivers

- Proliferation of nuclear power – low C energy
- Nuclear Power Generation wastes
- (31 countries) expanding volumes
- Research reactors
- Medical isotopes
- Military waste
- Spent nuclear fuel (SNF)
- Vitrified (high level)waste -reprocessing(HLW)

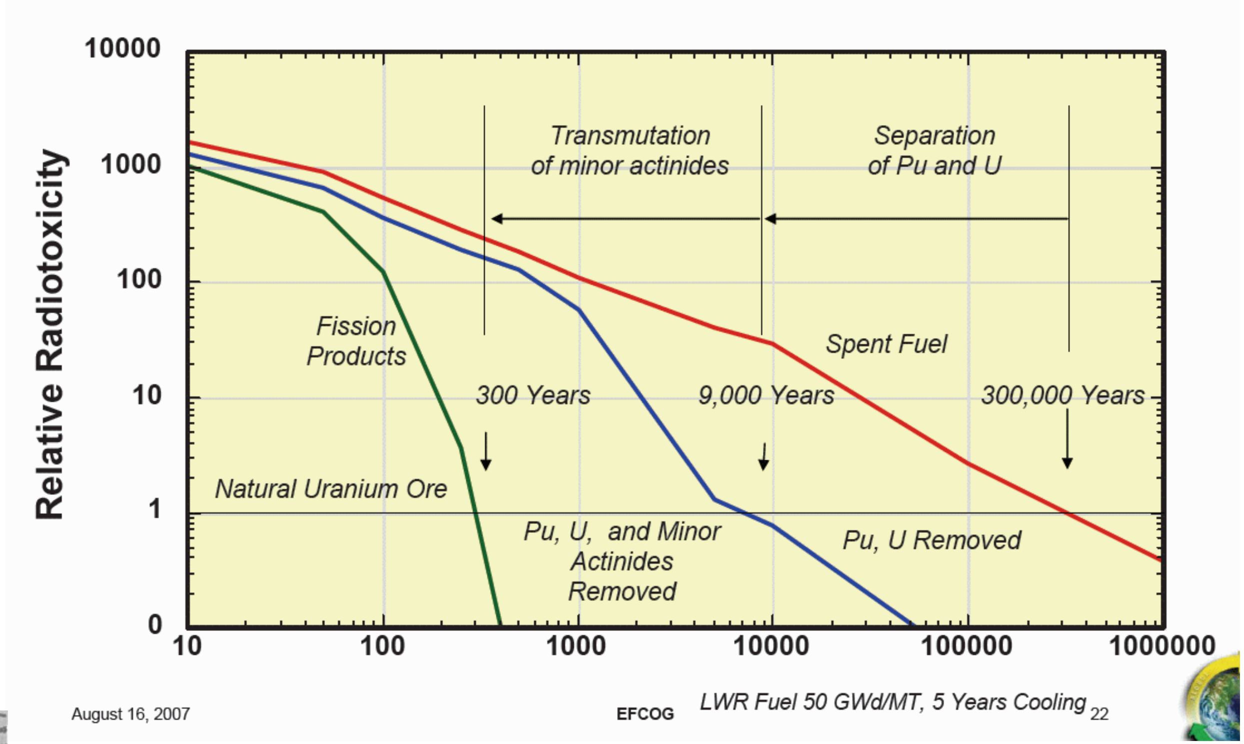
"Each country is ethically and legally responsible for its own wastes"

SNF and HLW

- 1000MW (1GW) nuclear reactor - 27 tonnes of spent fuel/yr
- Reprocessed – $3m^3$ vitrified waste
- 1000MW coal fired– 400,000tonnes/yr of ash

Waste solutions

- Avoid
- Re-use
- Re-process
- Disposal
  - Deep sea
  - Off planet
  - Transmutation



International Consensus

Long Term Deep Geological disposal

The last 100k years

100,000BC Modern Homo sapiens in Omo, Ethiopia

30,000BC

Oldest known art

10,000BC

End of the last ice age

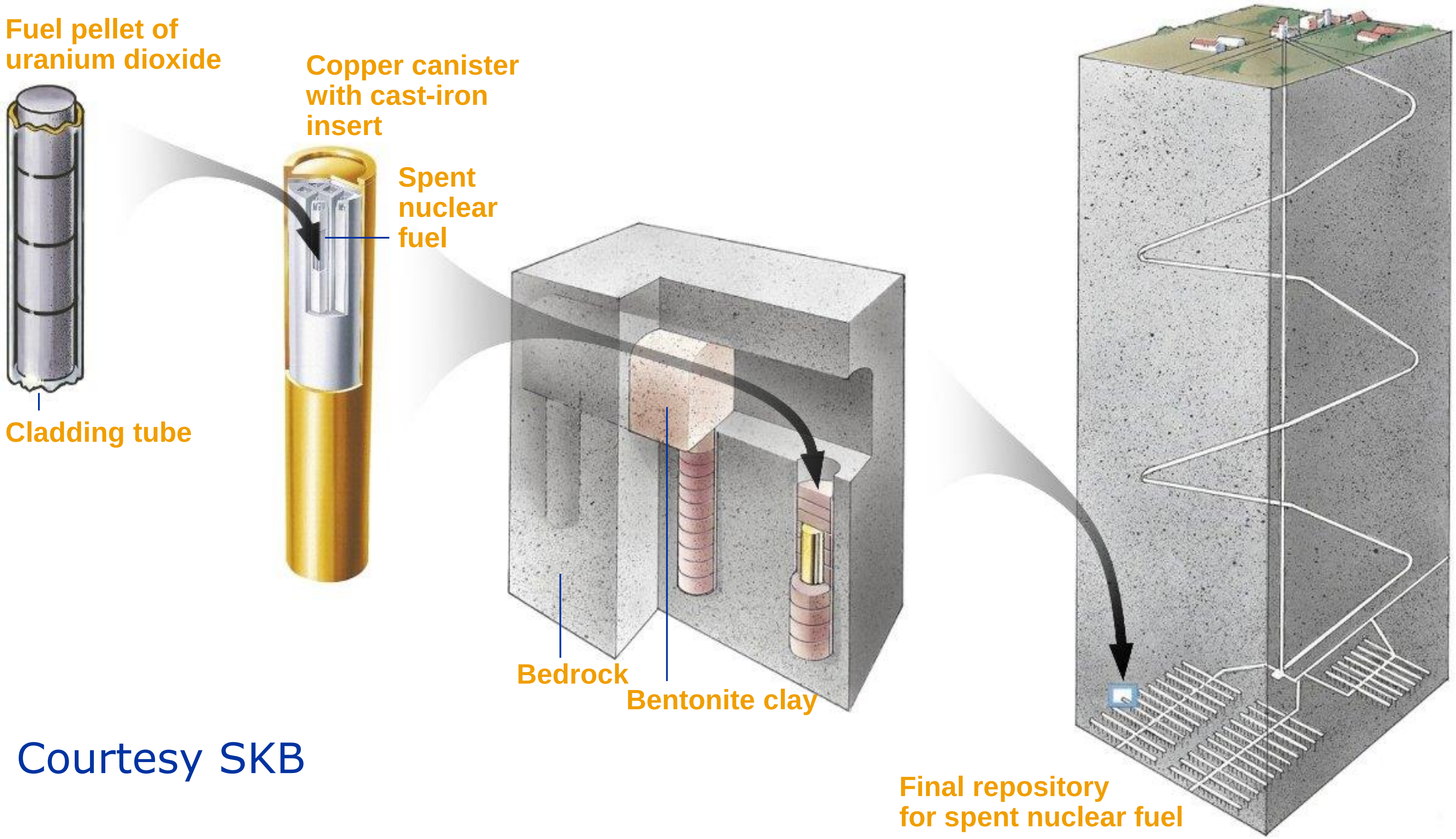
3,100BC Stonehenge complete

28,000BC Neanderthals Extinct

2016 AD

2,500BC Giza

Geological disposal Strategy - Multiple barriers



Courtesy SKB

POSIVA/SKB - copper and cast iron Engineered barrier system

Courtesy SKB/Posiva

National Projects

Nation	Favoured materials
Sweden	Copper/cast iron
Finland	Copper/Cast iron
France	Steel/ Alumina
Switzerland	Steel / copper
Japan	Steel
USA	Nickel Alloy/steel - dry storage
Canada	Copper/steel
S.Korea	Copper/cast iron
Belgium	Steel
UK	Copper/cast iron
Spain	Steel
Ukraine	Copper/cast iron

Others:-
Germany
Czech republic

Geology of Repository site



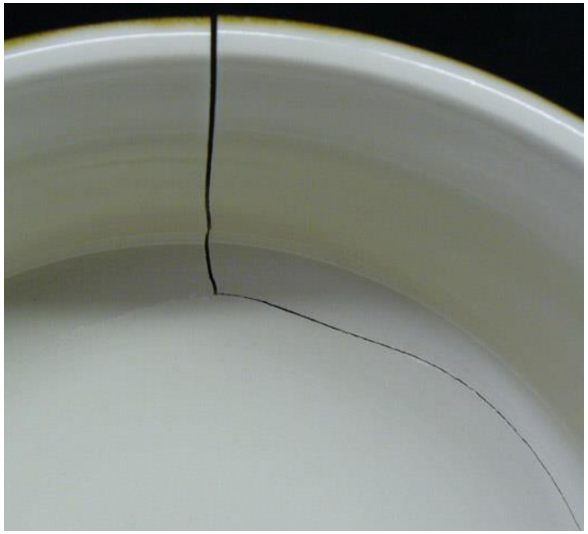


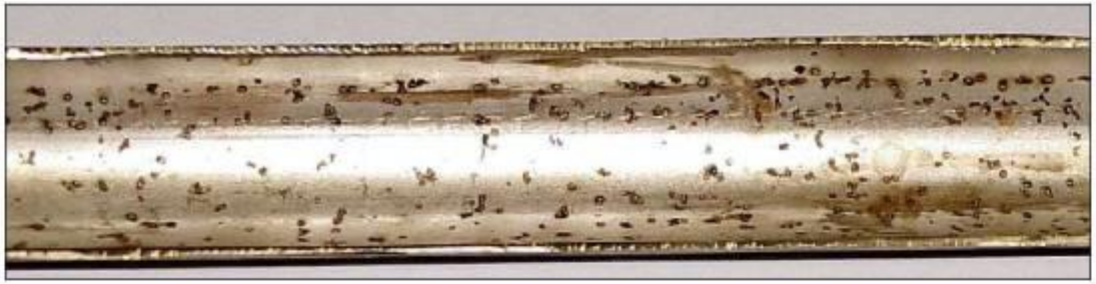

Canister Performance

- Containment and immobilisation
- Lithostatic pressure - rock overburden
- Hydrostatic - Ground water pressure
- Bentonite Swelling pressure
- Ice Load – next ice age
- Local corrosion
- Long term corrosion
- Handling and emplacement
- Retrieval for re-use
- Legacy
- Identification

Canister Materials

- Ceramics
- Metals
- Composite – coated metals
- Copper – OFHC
- Cast Iron
- Steel - plain carbon steel
- Stainless steel
- Titanium alloy
- Nickel alloy
- ODS alloys





Copper Corrosion Barrier





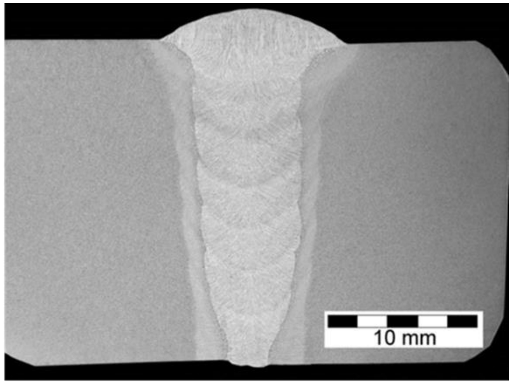

Manufacture of Iron Insert

Closure processes

- Bolting – Gaskets
- Adhesives – Durability
- Brazing – Galvanic corrosion
- Thermal spray – possibilities
- Welding
  - Fusion
    - Arc processes
    - Power beams
  - Solid state
    - Friction
    - Forge processes

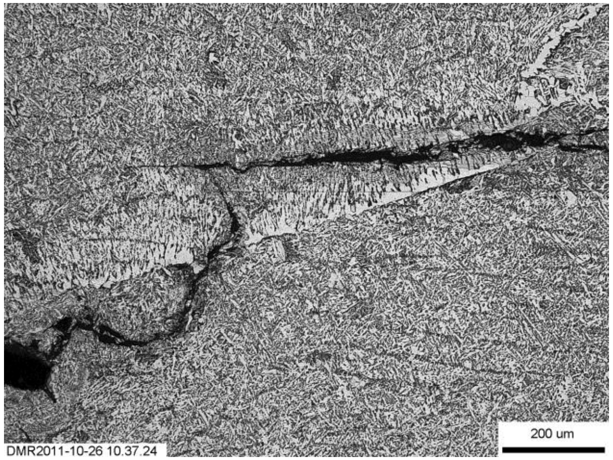
Closure weld process requirements

- Robust - simple
- Remote and automatic
- Radiation hard
- Proven
- Inspectable
- Repairable
- Low defect rate
- Sufficiently rapid
- Mechanical properties
- Corrosion performance
- Defect tolerant



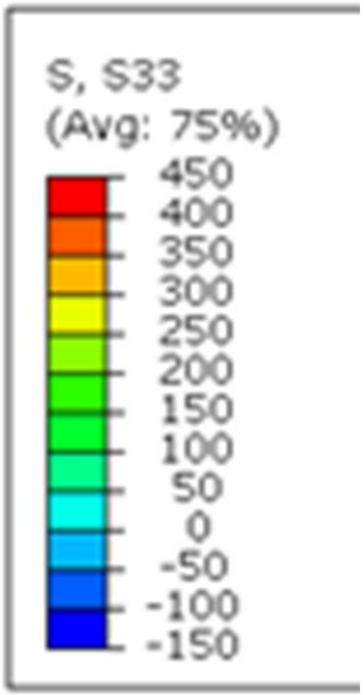
Closure Weld characteristics

- Practical, implementable, inspectable
- Long term reliability
- Resistant to all potential failure mechanisms
- Mechanical properties – avoid breaching
  - Applied stresses
- Corrosion mechanisms
  - Material
  - **Welding induced residual stress**
  - Existing flaws
  - Environment
  - Hydrogen/radiation embrittlement



Welding induced Residual stresses

EB weld in steel – hoop direction as-welded and after PWHT



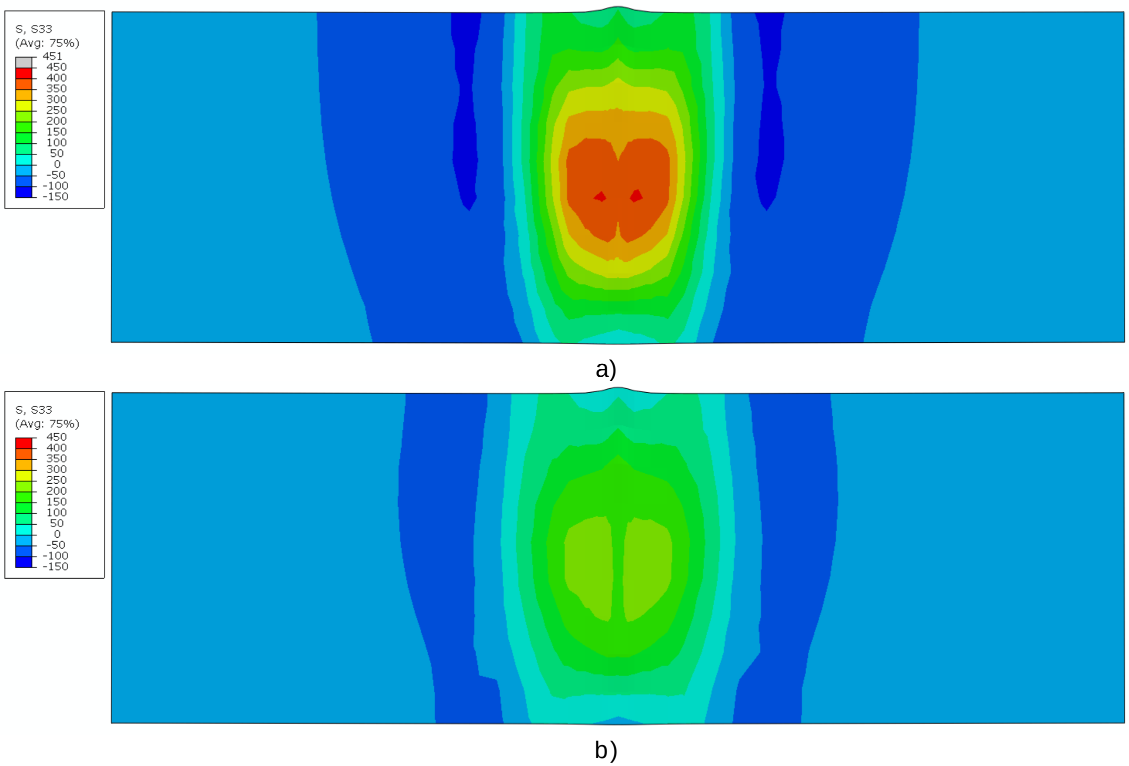


*Figure **Error! No text of specified style in document.**-1 Predicted residual stresses midway along the 2 halves of the flat plate model in the a) as-welded condition and b) in the PWHT condition.*

Electron Beam closure welding

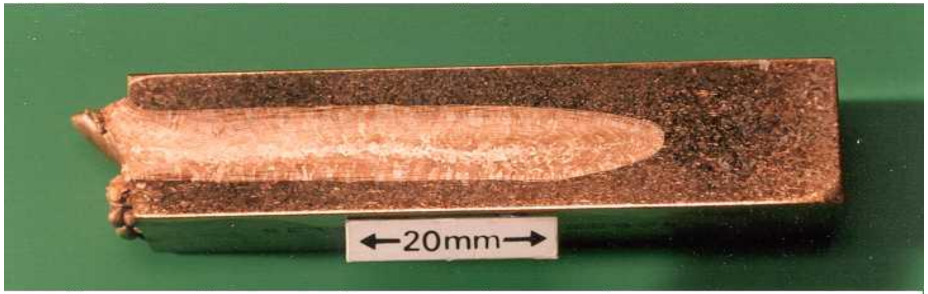
Canister remote lid placing mechanism

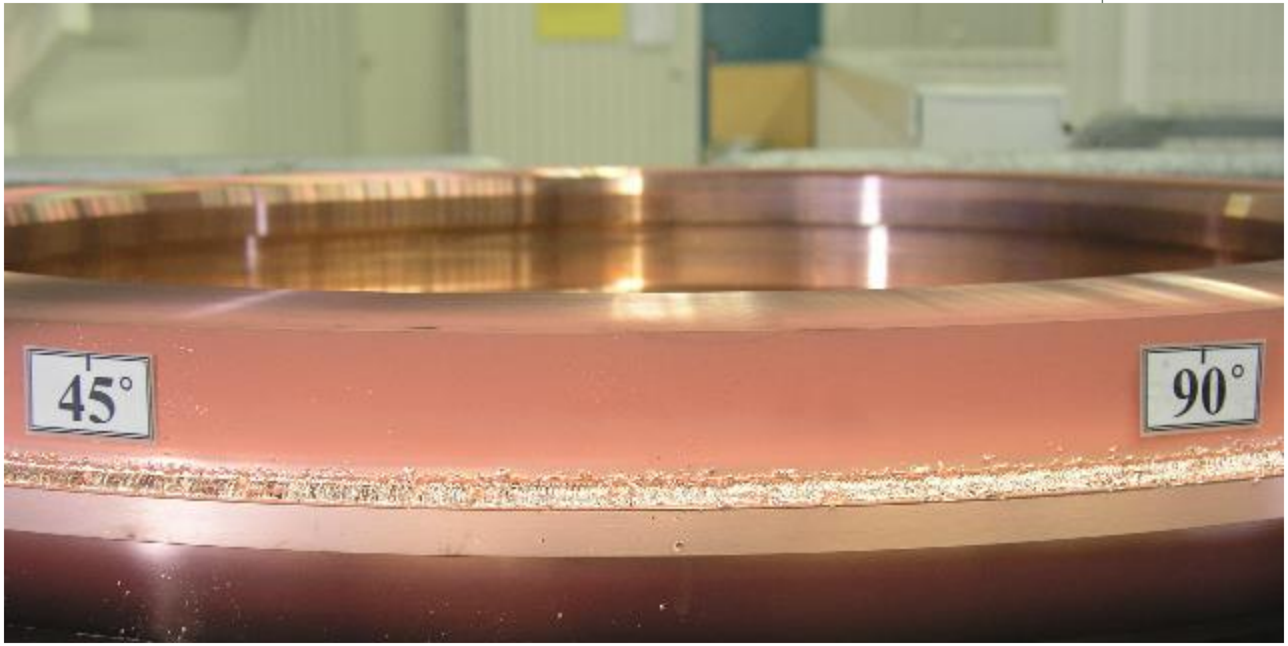
Gun column

Canister

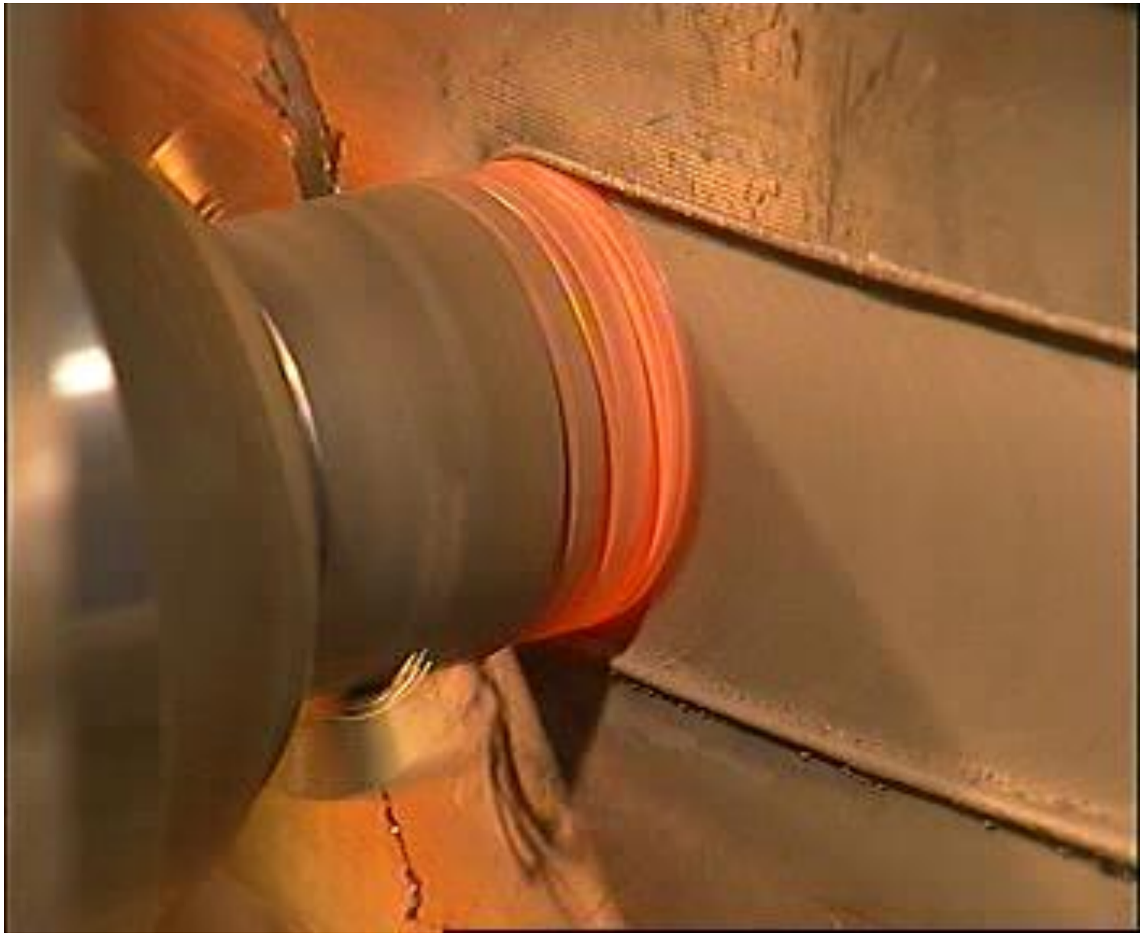
Canister lid

EB welding of copper





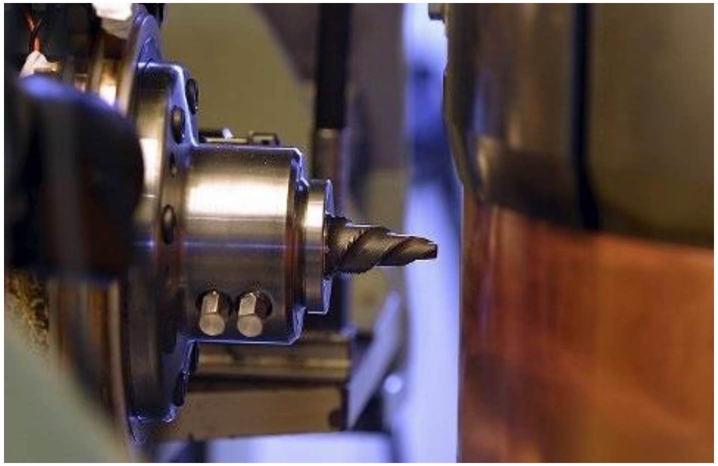
Friction Stir Welding



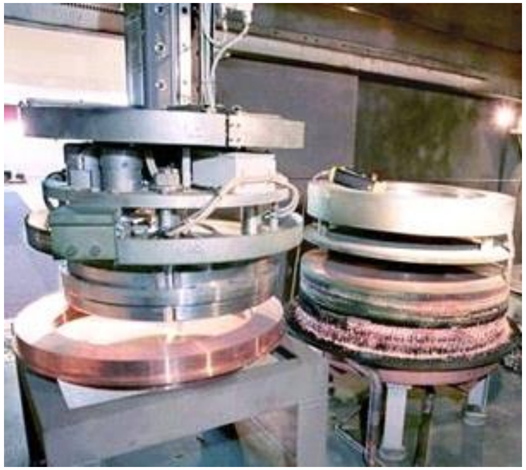
Friction Stir Welding (FSW) of 50mm Thick Copper

Canister closure welding - process selection

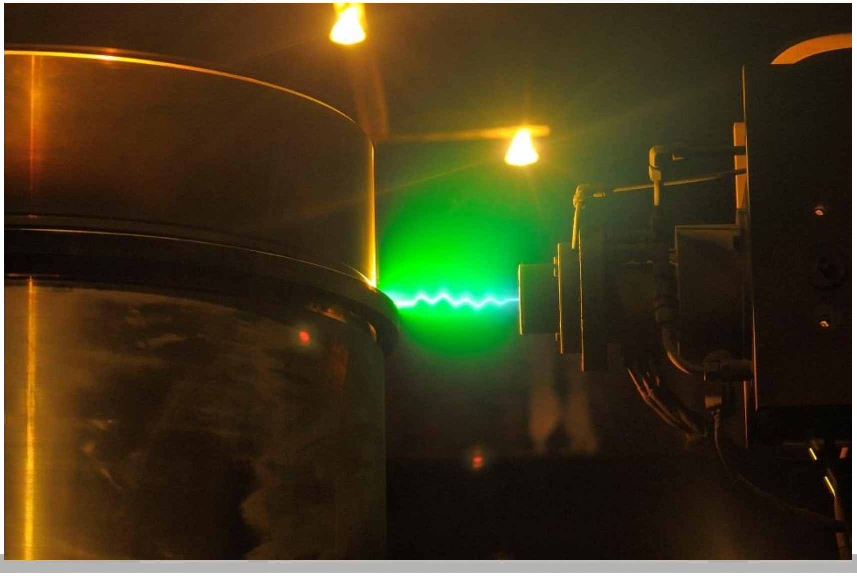
Electron Beam Welding



Friction Stir Welding

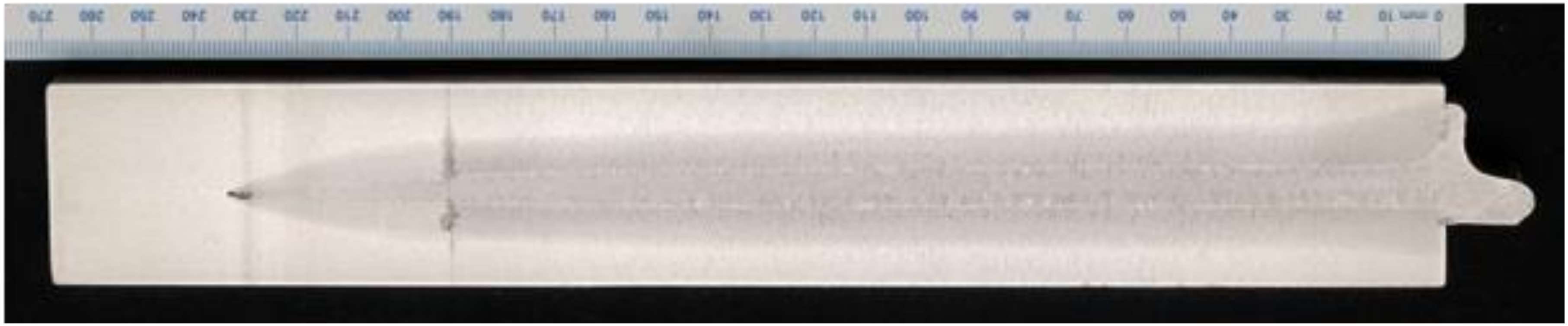


Mock-up welding demonstrations



C-Mn steel
190mm thick EB closure weld

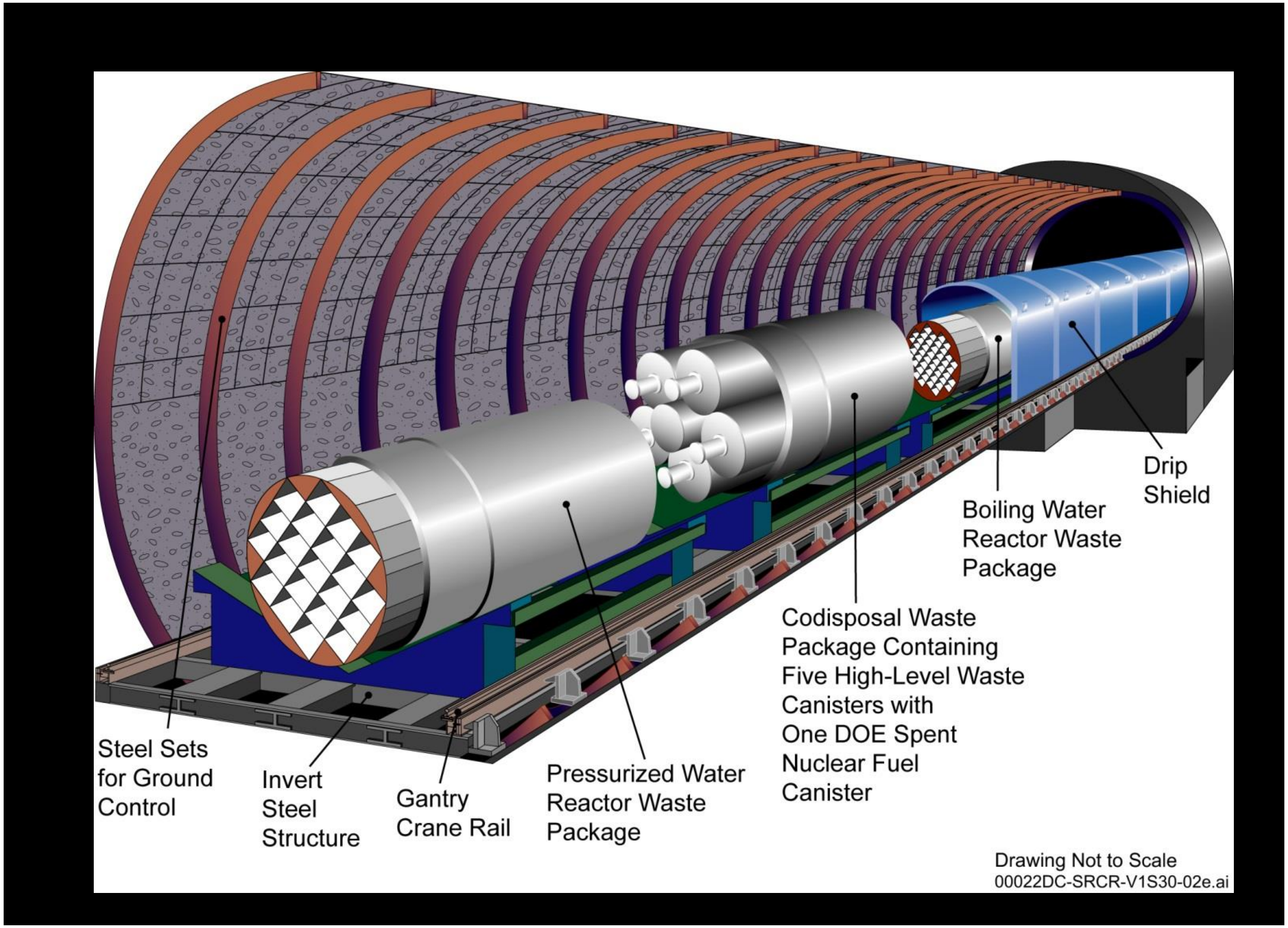
RWMC C-Mn steel weld 190mm wall thickness



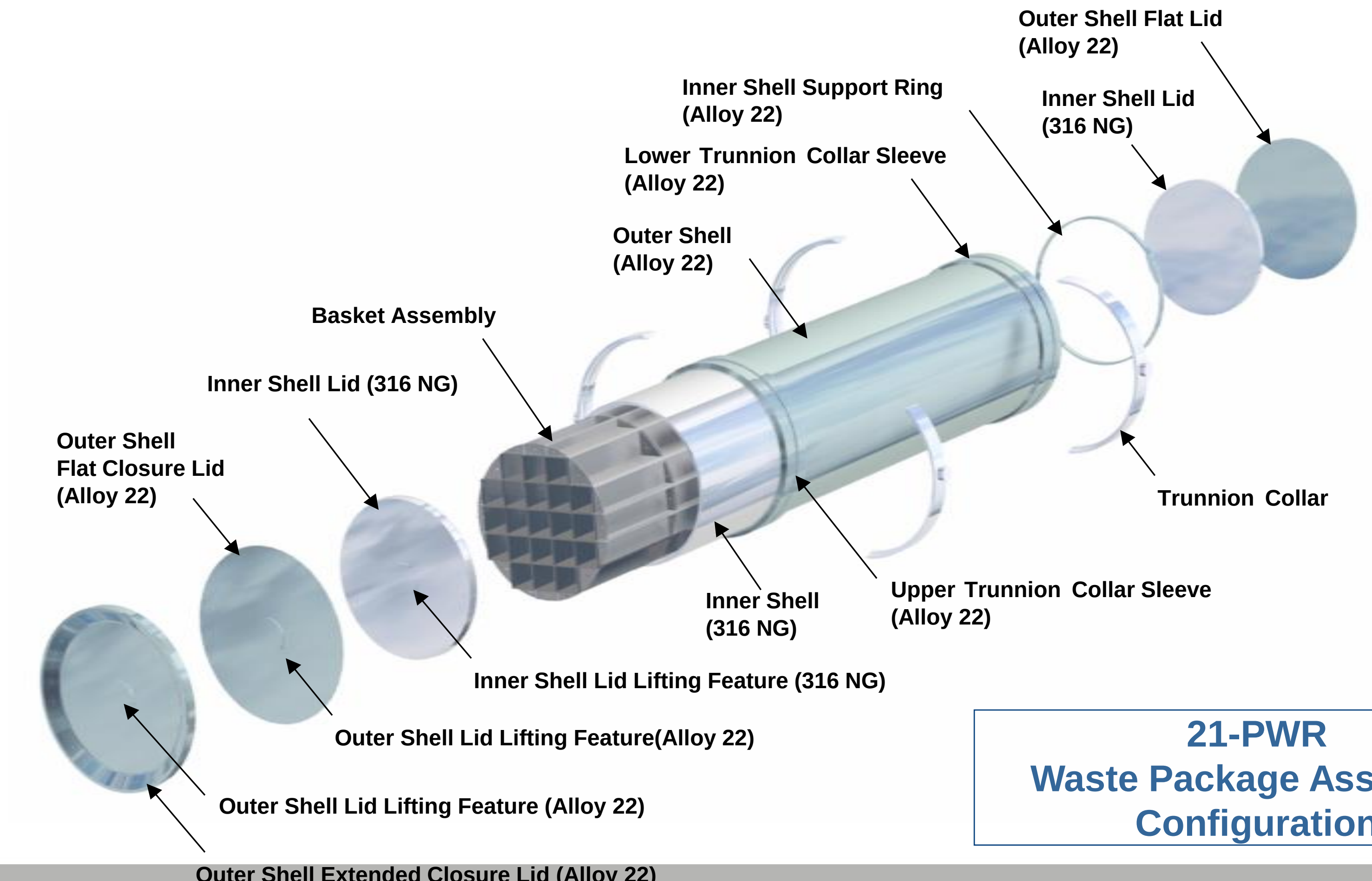
EB welding cell

SKB Canister Laboratory

Yucca Mountain Emplacement strategy



Waste Package Design



21-PWR
Waste Package Assembly Configuration

Alloy 22

- UNS N060220
- Nickel 56%, Chromium 22%, Molybdenum 13%, Iron 3%, Cobalt 2.5%, Tungsten 2.5-3.5%, Vanadium 0.35%
- Cost ~$62k/tonne (1 can requires up to 10t)

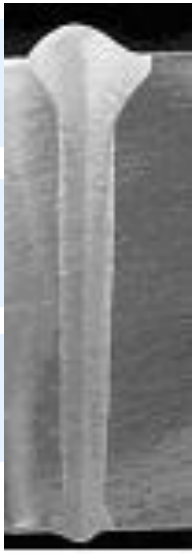
Solution anneal 1150 deg C + quench

Canister fabrication & Closure welding

Full Diameter – short length closure trials

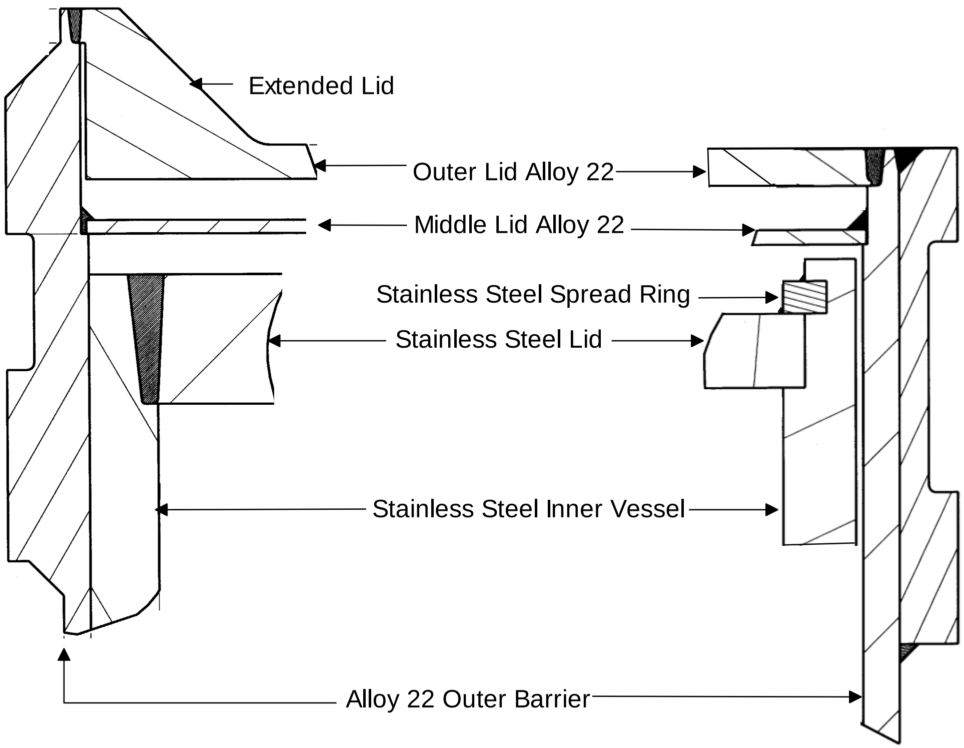
Alloy 22 closure weld - EB vs TIG

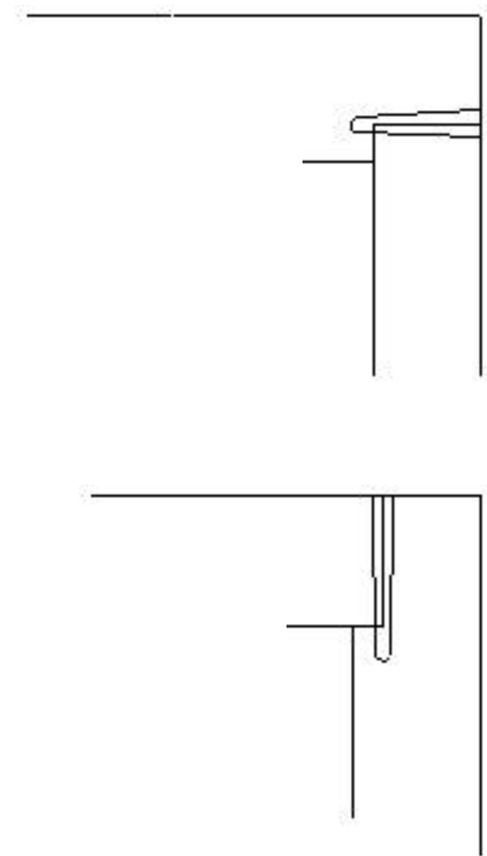
Multi-Pass GTAW Weld		Single-Pass RPEB Weld
200	Travel Speed (mm/minute)	750
8	No. of Passes	1
251.3	Lid Weld Time (in minutes)	8.4



Comparison of Estimated Welding Times for GTAW and RPEB Welding for Alloy 22

Simpler closure weld



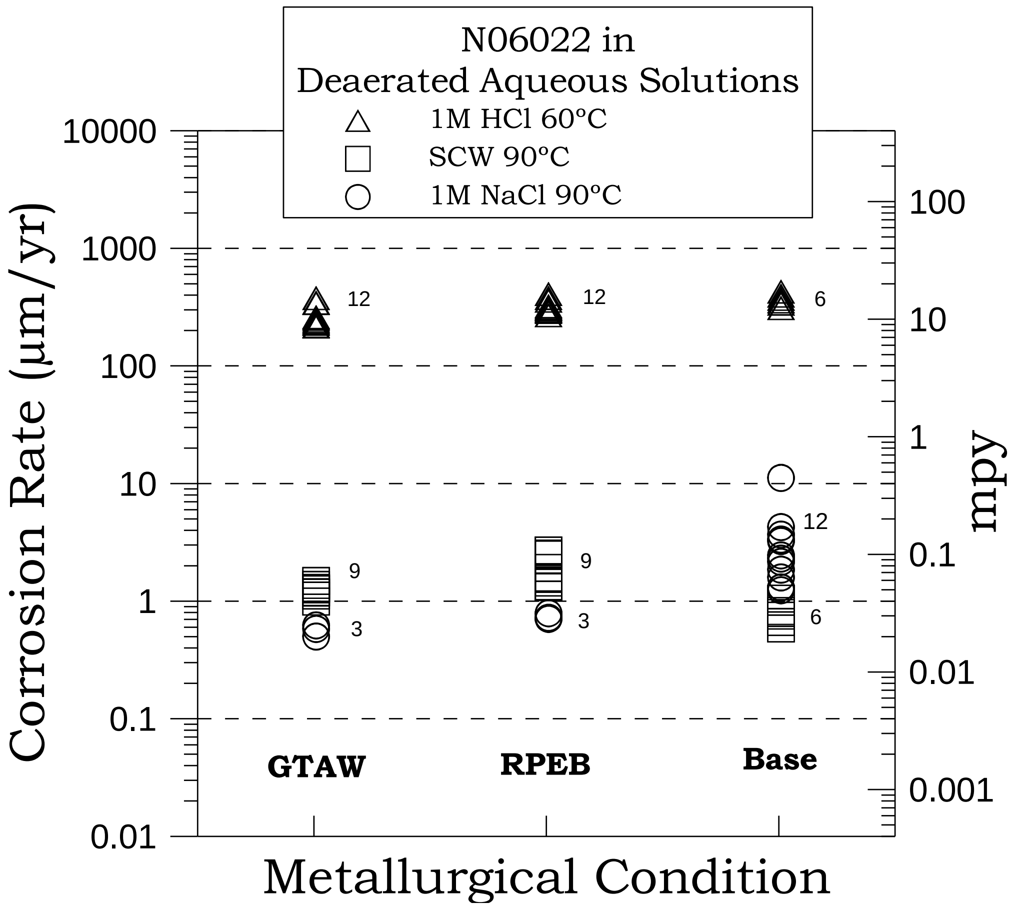


Site recommendation design

Current design

Potential RPEB designs

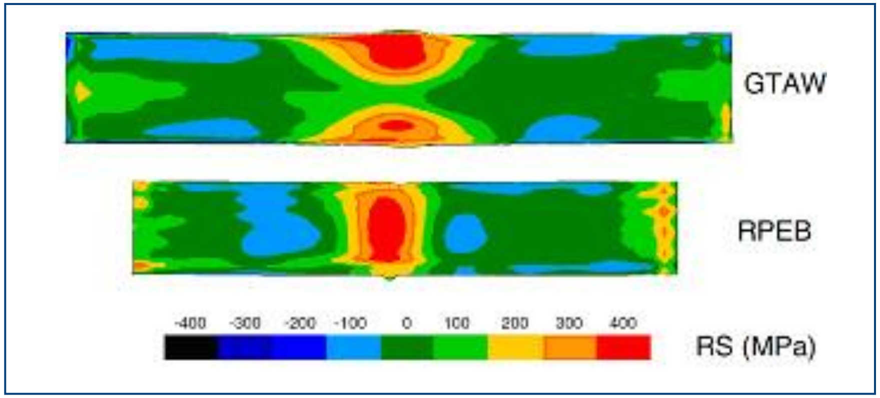
Corrosion Rate



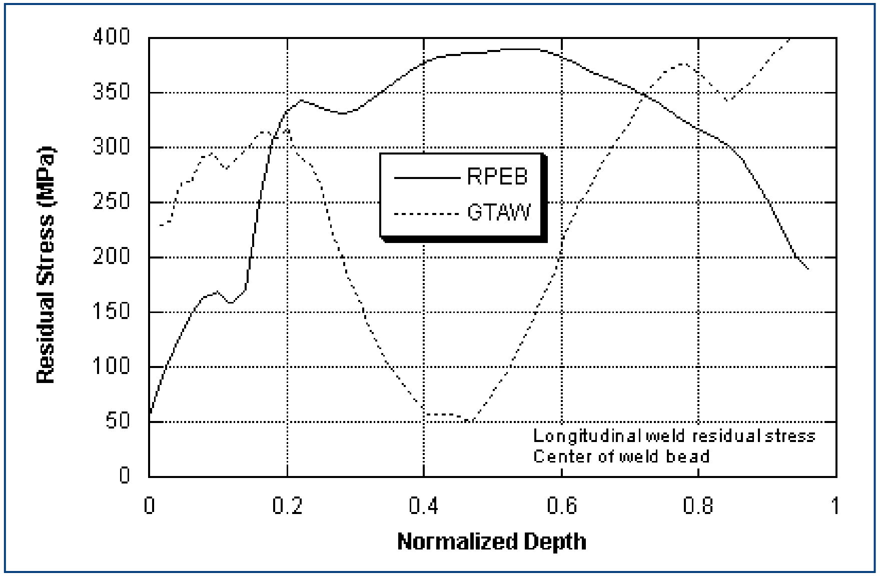
Comparative corrosion rates for GTAW, RPEB weld, and base metal specimens in SCW, 1M HCl, and NaCl solutions.

![TWI logo]

As-welded residual stress

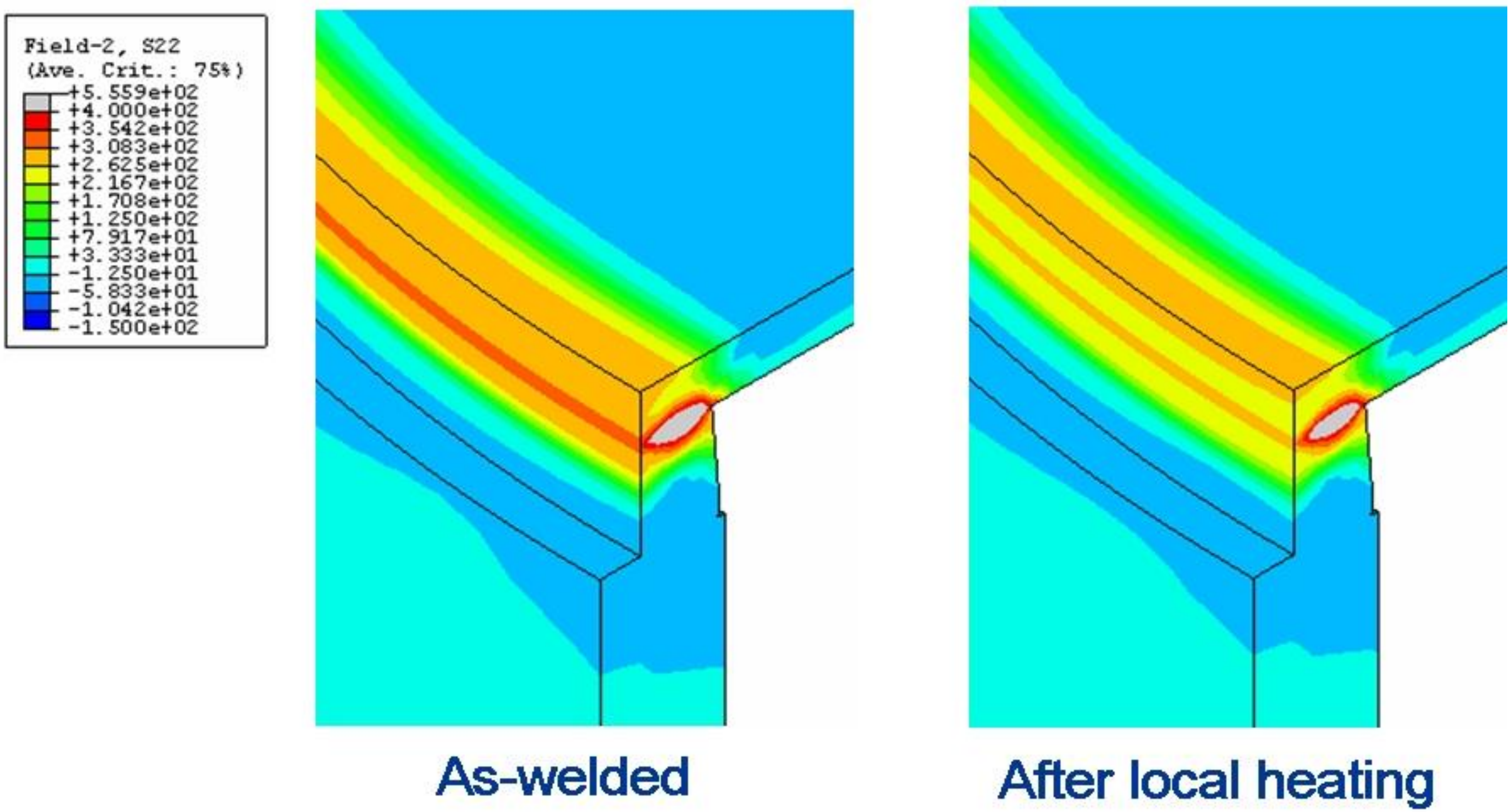


Longitudinal (weld direction) residual stress contour plots in the as-welded condition for the GTAW and RPEB weld samples



RPEB welding peak tensile residual surface stress ~75% less than GTAW

Local heating for residual stress control



RPEB Benefits

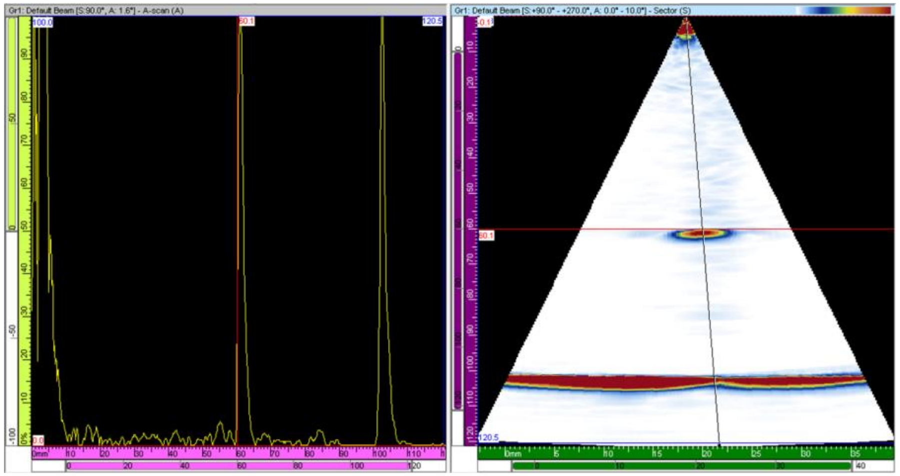
- Equal or better materials performance in terms of corrosion, metallurgical stability, and as-welded residual stress
- Welding repeatability and reliability
- Cost savings
- Hot cell operation

Cost savings
Influenced by Welding process selection

- Reduced distortion - minimum overstock
- Faster welding times (X30)
- Elimination of weld filler metal
- Reduced machining times
- More favorable distribution of residual stresses

Inspection

- Surface inspection critical
- Initiation of environmentally assisted cracking
- Volumetric inspection – high static load
- Accidental damage
- Remote/automatic
- Radiation hard
- Phased Array UT
- Eddy current
- Radiography - Linac



Automated UT inspection

Summary

- Deep geological disposal of SF and HLW – recognised most favourable option
- Material selection influence –
  - geological conditions
  - activity of waste
  - lifetime requirements
- Canister Design & material - profound influence on closure welding process selection & inspection methods
- Safe and reliable closure method essential for continuation of nuclear energy generation


Thank you
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