Cold Neutron Source (CNS) Helium Injection Logic Modification

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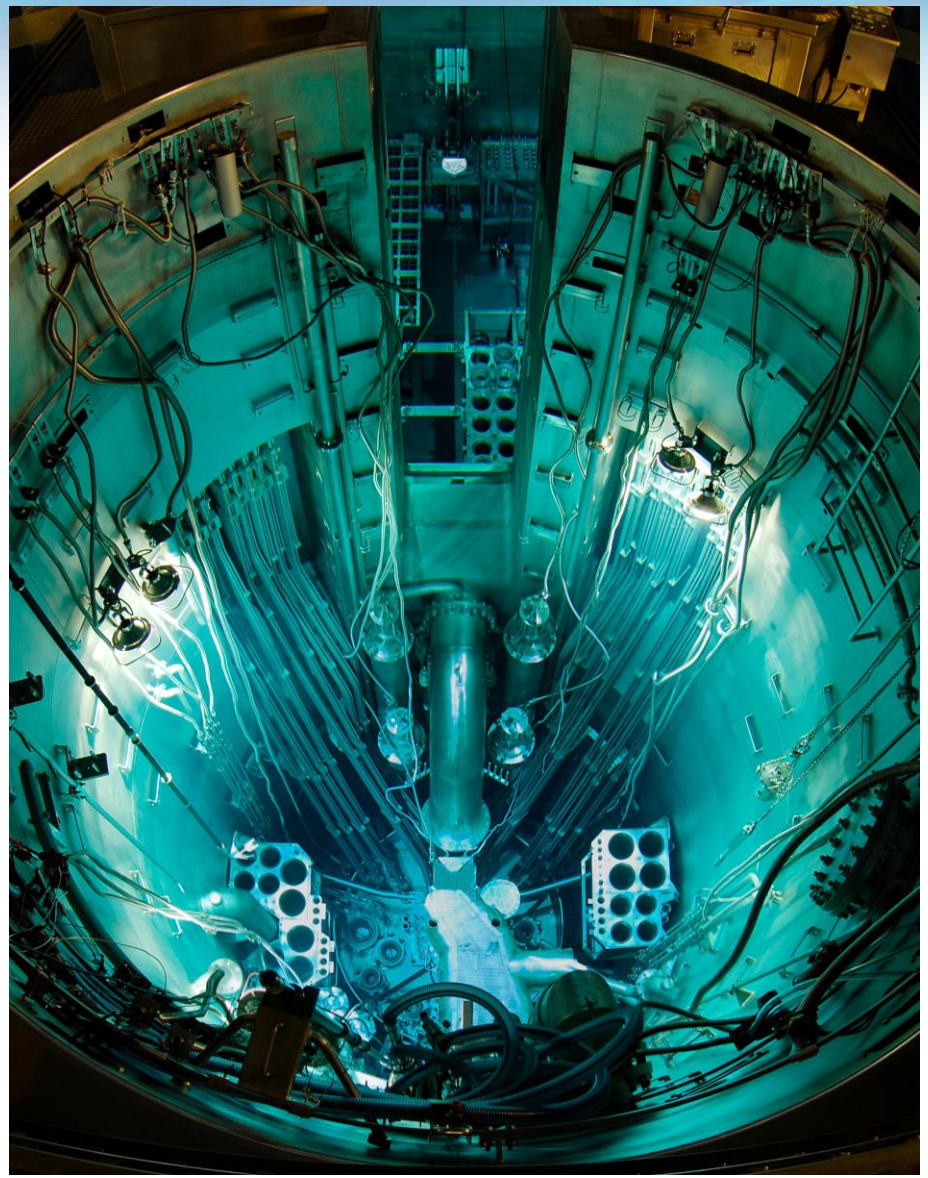
OPAL Research Reactor

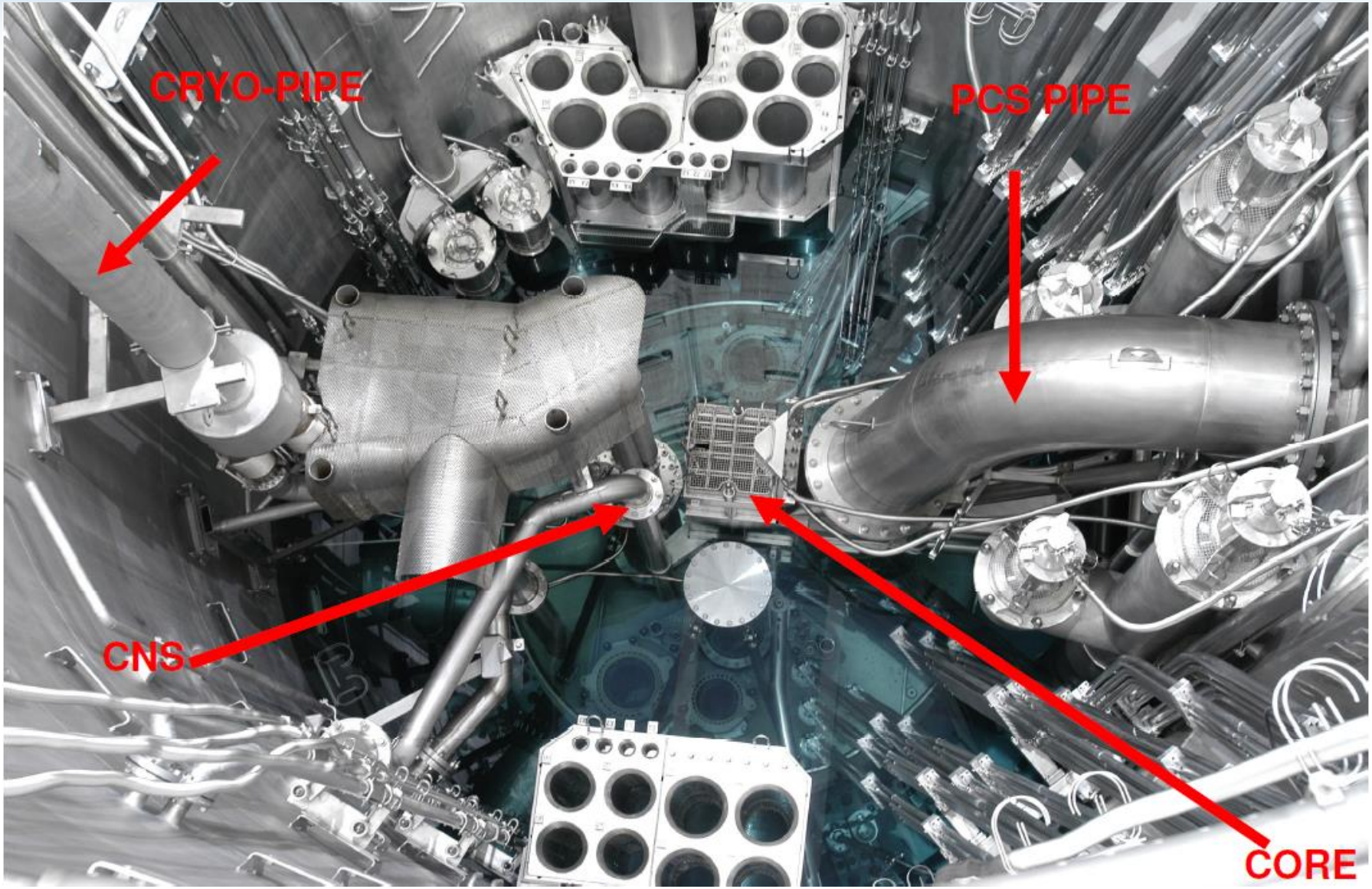
- 20MW Open Pool Australian Light water reactor
- Replaced the 10MW HIFAR research reactor (1958 – 2007)
- Reached criticality in August 2006
- Low enriched fuel used (19.75% U)
- Safe and productive operation for 10 years

OPAL features

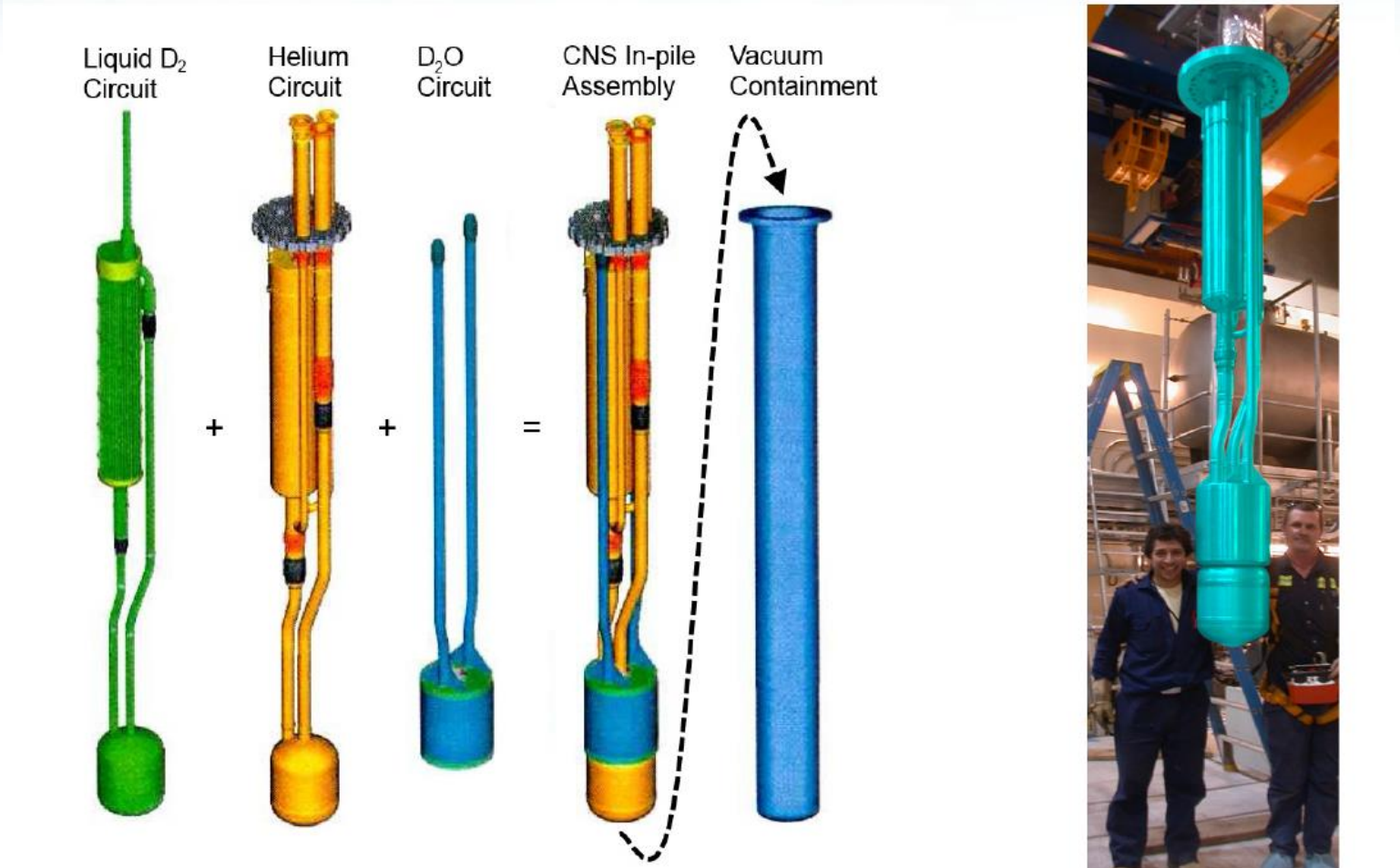


- Open Pool 20MW design
- Compact core - 16 fuel assemblies in 13 m deep pool
- Plate type Low Enriched uranium/silicide fuel
- No in-core irradiations
- D_2O zircaloy reflector
- 2 independent & diverse shutdown systems
- Demineralised light water provides cooling and shielding (~ 300 kW/L upwards forced light water cooling of core).
- Heavy water surrounds the core in an enclosed reflector vessel
- 300 days of operation in 2016

OPAL Reactor and its CNS

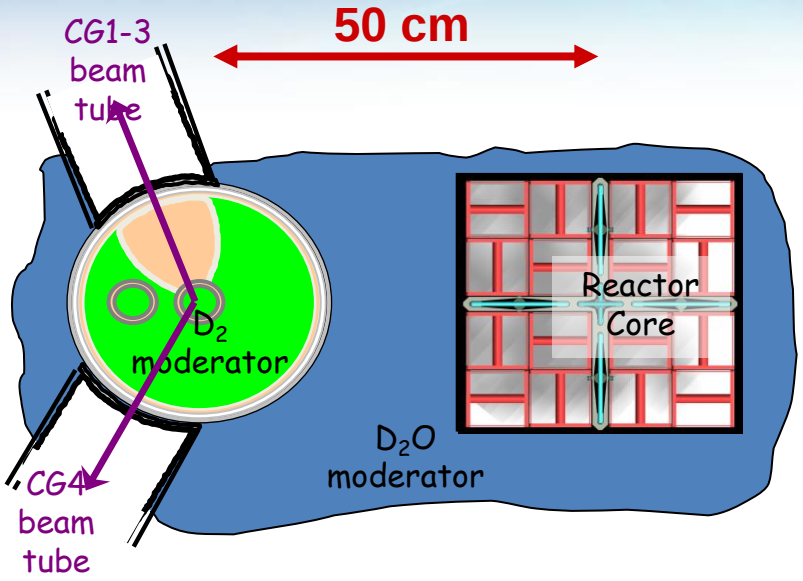


OPAL CNS Structure

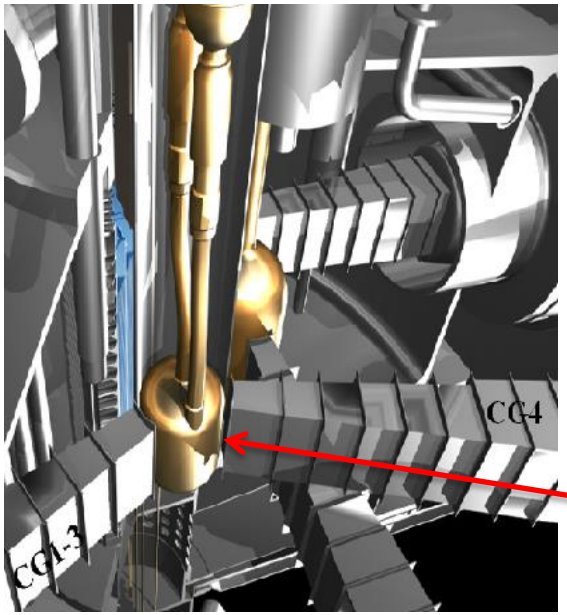


Vacuum containment vessel designed to withstand in-pile rupture / over-pressurisation event and protect reflector vessel

OPAL CNS Statistics



- 20L of sub-cooled (full) liquid deuterium at average 25K
- Vertical thermosiphon in heavy water reflector
- Located 50cm centre-to-centre from reactor core
- 5kW heat load – cooled by 500 kW helium refrigeration cycle (2 x 250 kW compressors)
- Two tangential beams followed by 5 neutron guides serving 8 instruments
- Early outages due to process system faults, but near perfect reliability since 2013.



Small gap between guide and vacuum containment filled with light water

CNS – Refrigeration Cryogenic (Helium) System

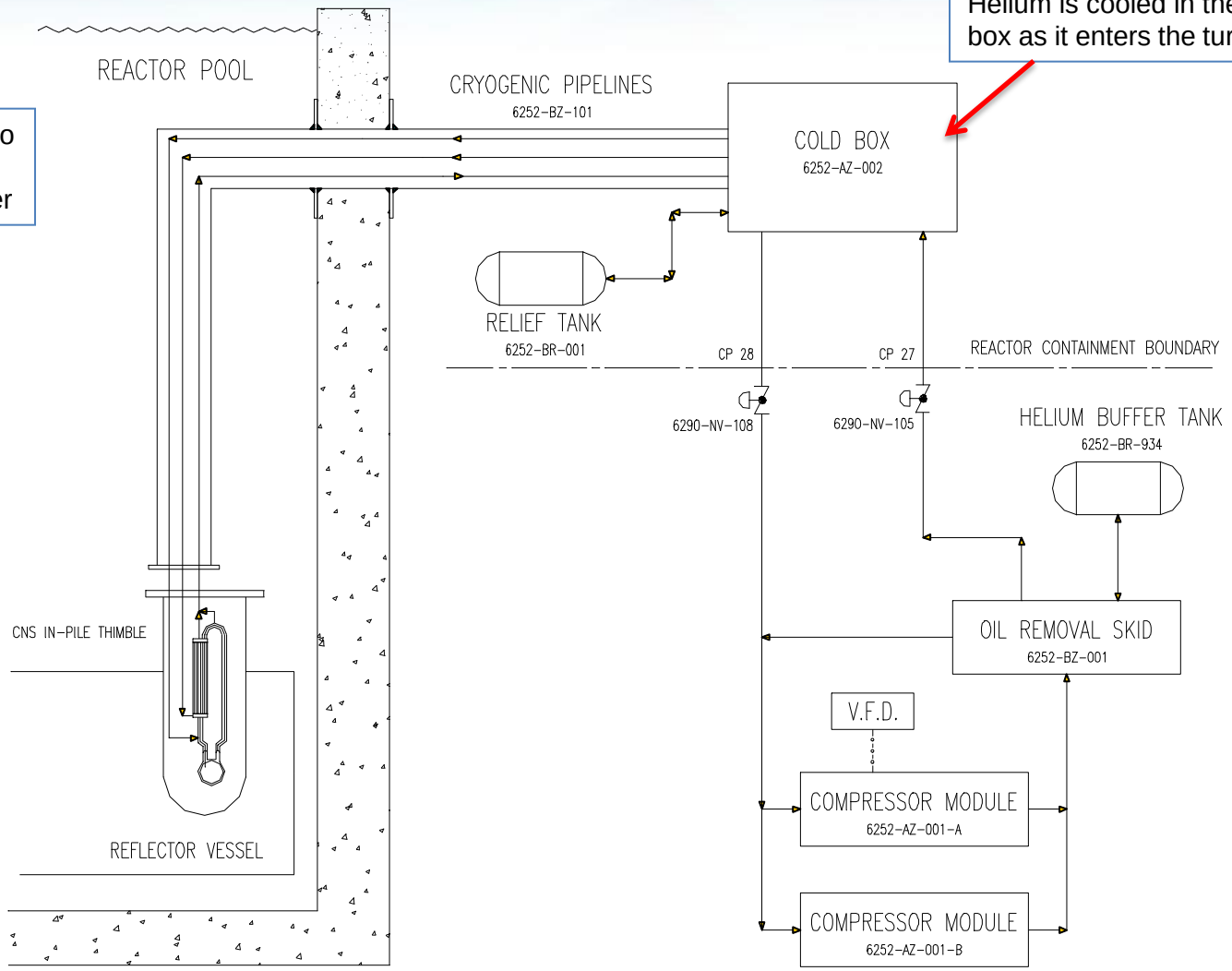
Two inlet pipes, one to moderator chamber, one to heat exchanger

SS

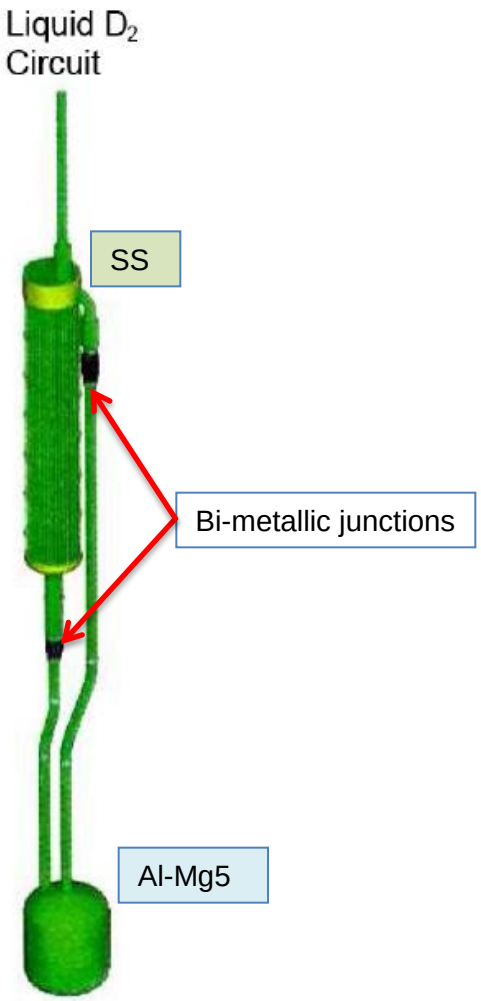
Bi-metallic junctions

Al-Mg5

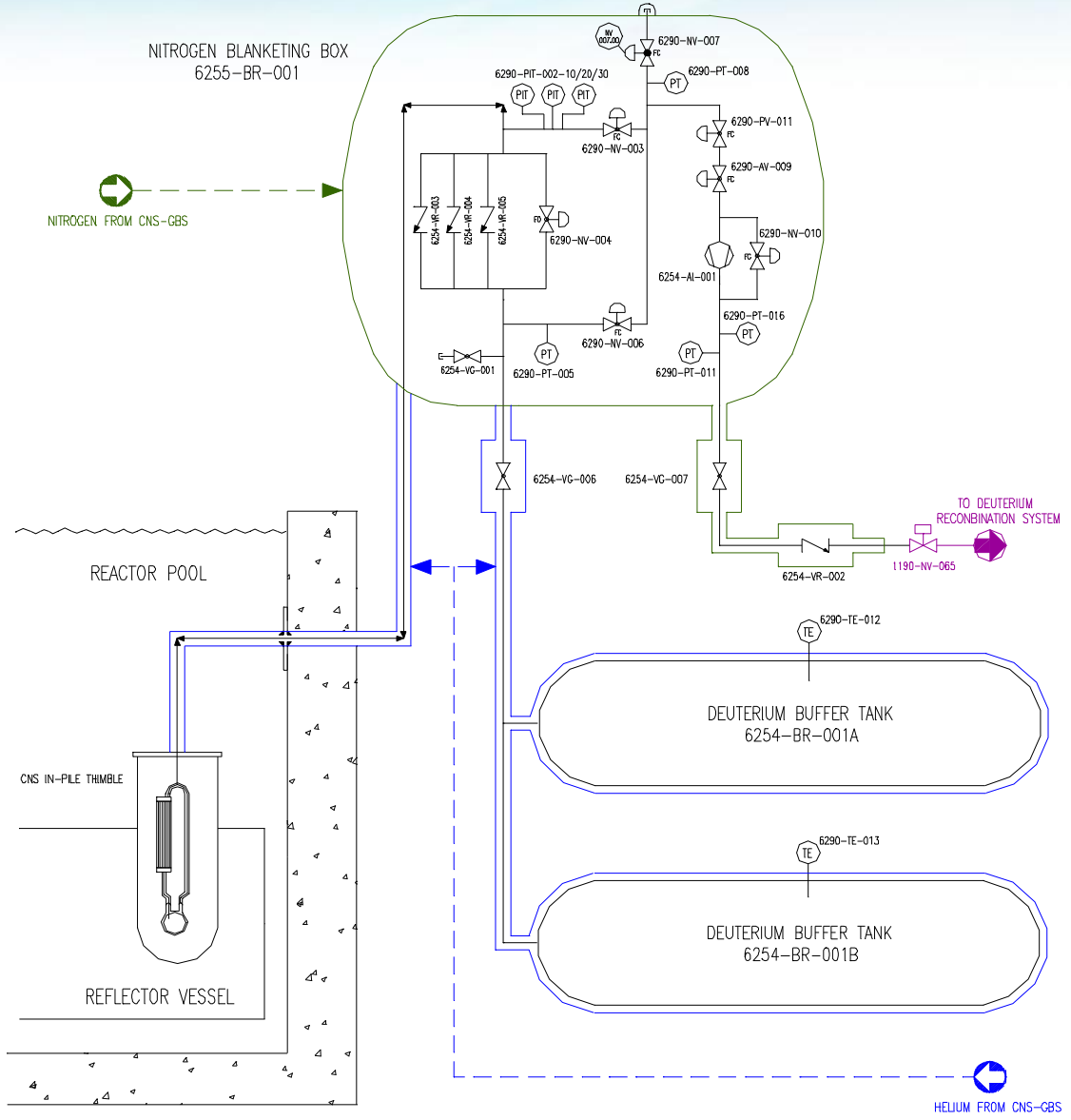
Helium is cooled in the cold box as it enters the turbine



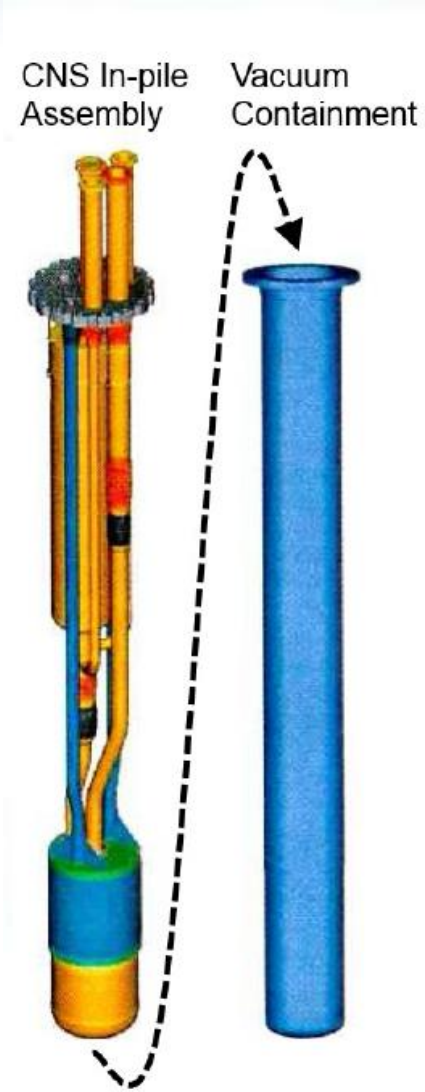
CNS – Moderator (Deuterium) System

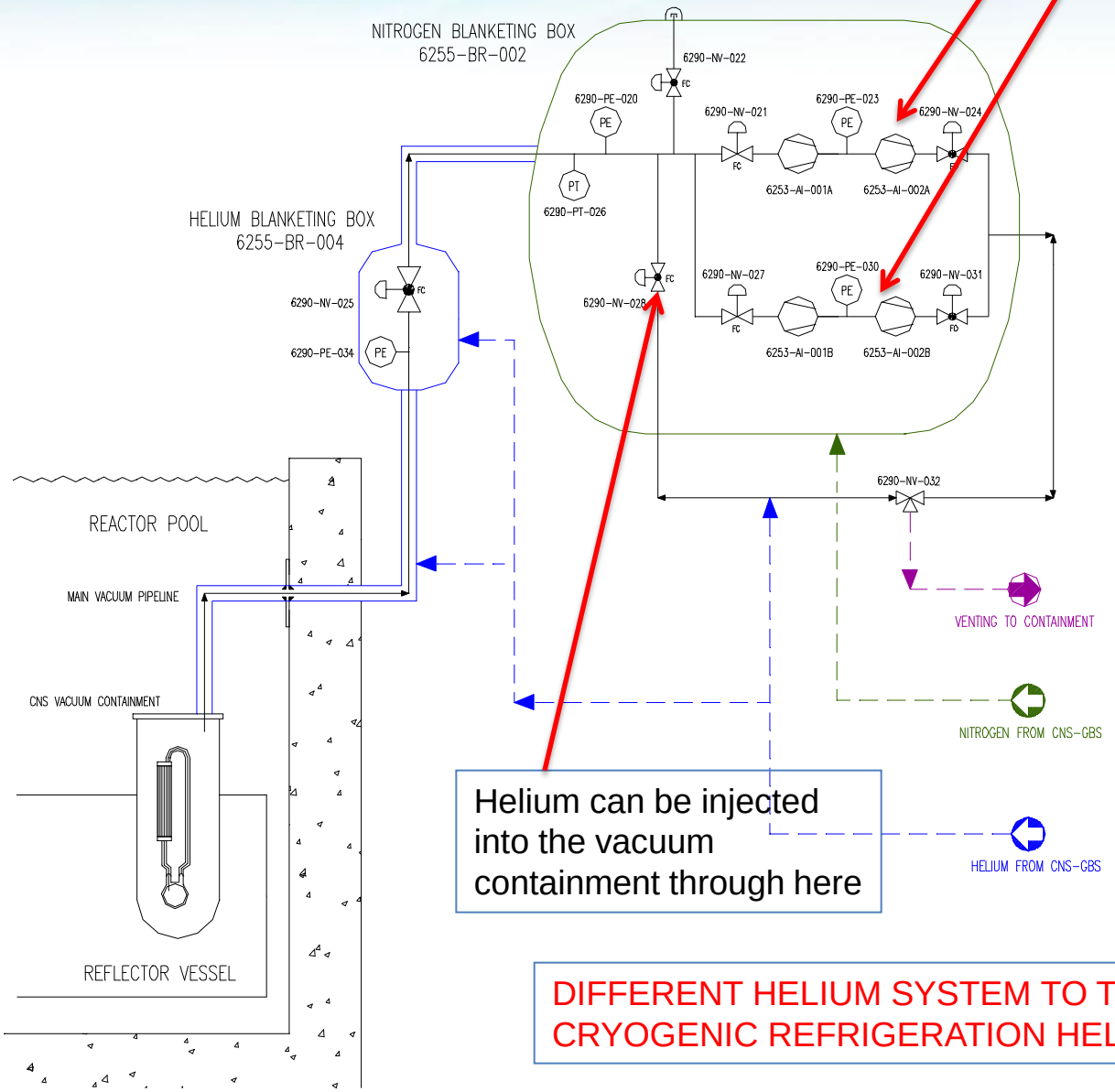


Fills with Liquid Deuterium when refrigerant helium is cryogenic temp (< 31K)



CNS – Vacuum System





Vacuum pumps

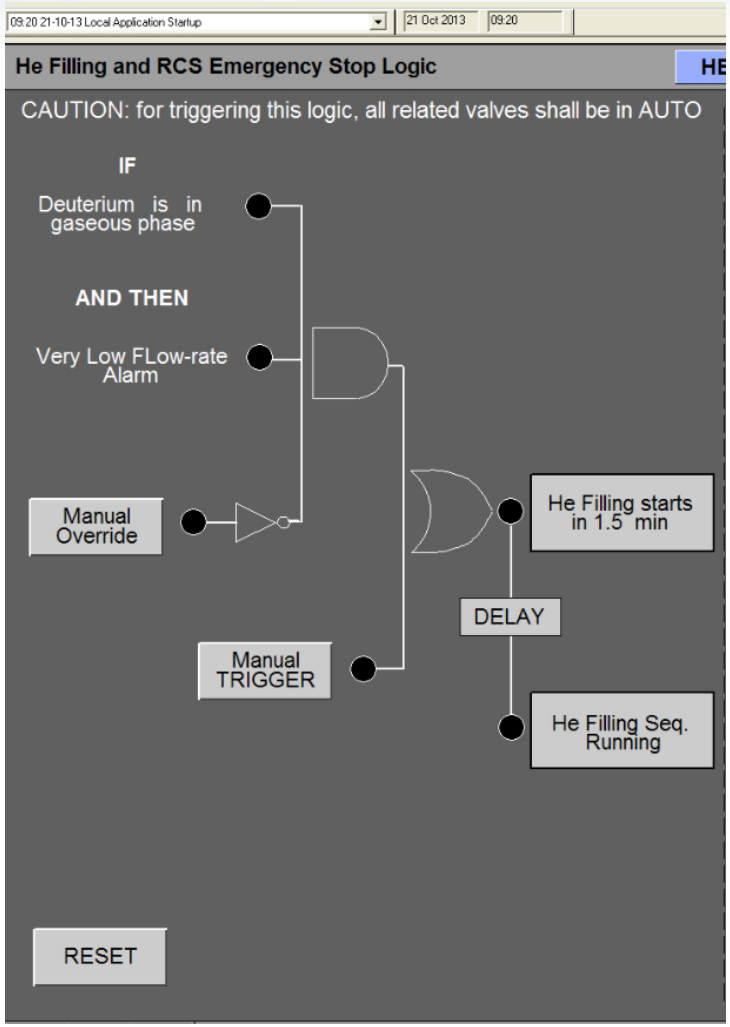
Helium can be injected into the vacuum containment through here

DIFFERENT HELIUM SYSTEM TO THE CRYOGENIC REFRIGERATION HELIUM!

Helium Injection – What is it?

- The most important process condition is RCS helium flow – removes heat from in-pile.
- If helium flow stops, automatic REACTOR TRIP.
- CNS TRIP → decay heat from reactor imparted onto CNS - “HOT DAMAGE”
- Original design → INJECT helium into vacuum containment (if deuterium not liquid) to remove heat to prevent in-pile from overheating, into heat sink (reflector vessel)
- Did not take into account thermal stresses on the CNS in-pile structure “COLD DAMAGE”

Helium Injection in the Spotlight

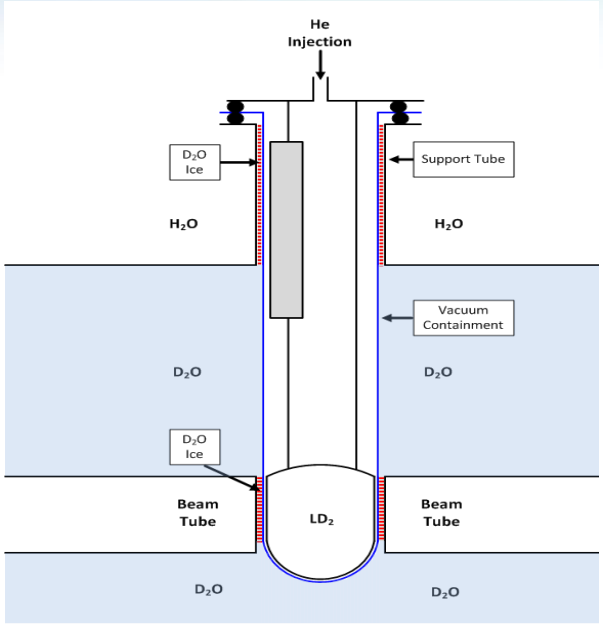


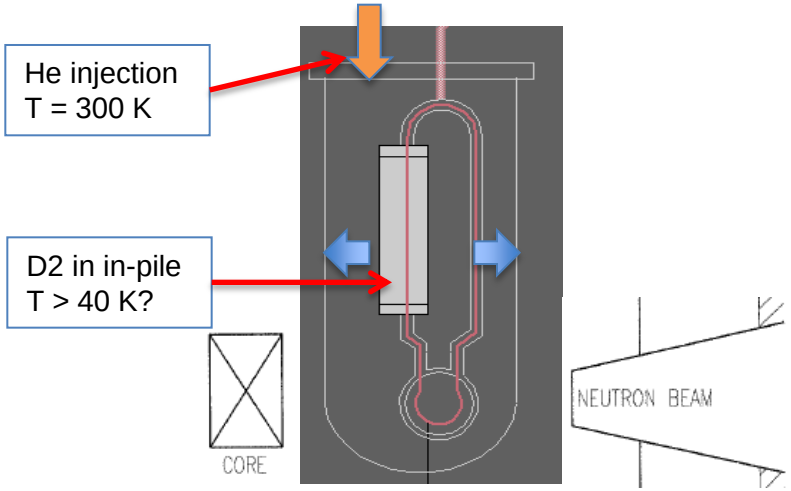
1. Vulnerable if CNS trips when it warms up or cools down. Deuterium could be vapour inside in-pile, but still cryogenic (e.g. 50 K)

2. REAL LIFE EVENT:
   a) Helium flow ceased FIRST, deuterium naturally vapourised
   b) Logic was RESET
   c) HELIUM INJECTION PROCEEDED!

No evidence, calculation or modelling to know when it is safe to inject after a trip.

Consequences of Helium Injection when Cold



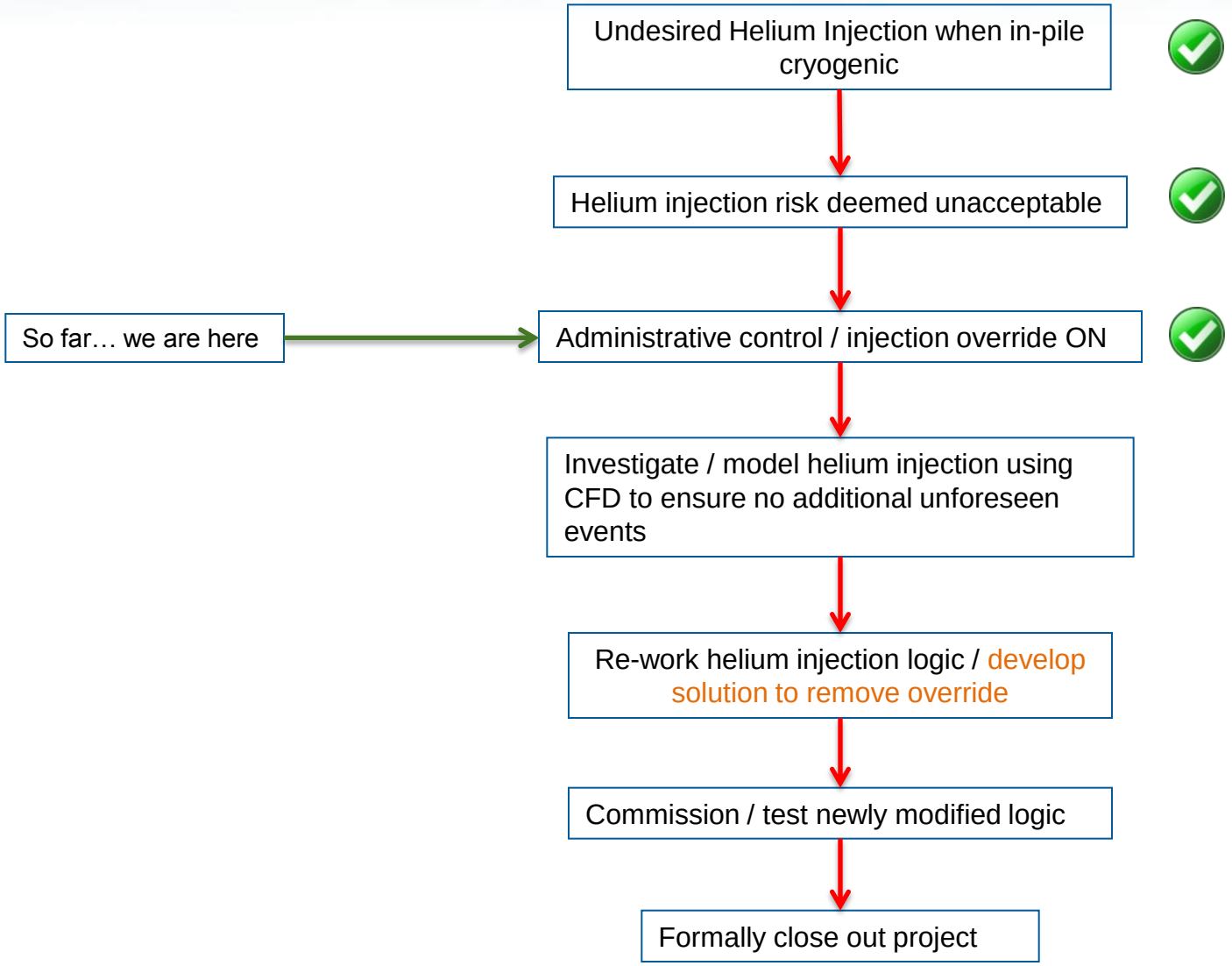


- Large thermal stress due to the large temperature difference between the in-pile structure and injected helium.
- Possible damage to in-pile structure
- Possible heavy ice formation between the support tube and vacuum containment vessel – detrimental?
- Quenched thrice in LN post-manufacture – but AlMg5 properties unknown after 10 years of neutron bombardment

Although no subsequent damage was observed, ANSTO felt this risk was not acceptable to operate with.

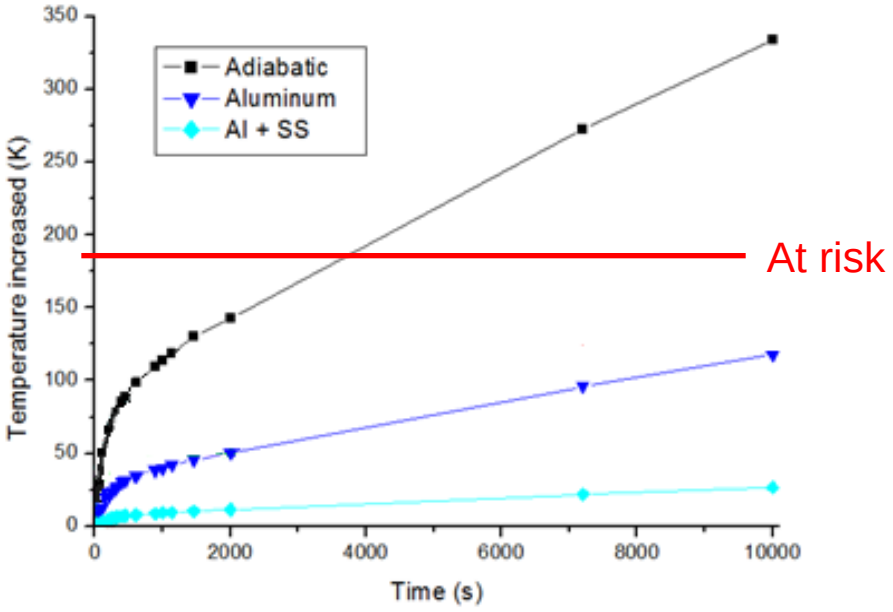
Administrative control (Override turned on indefinitely)

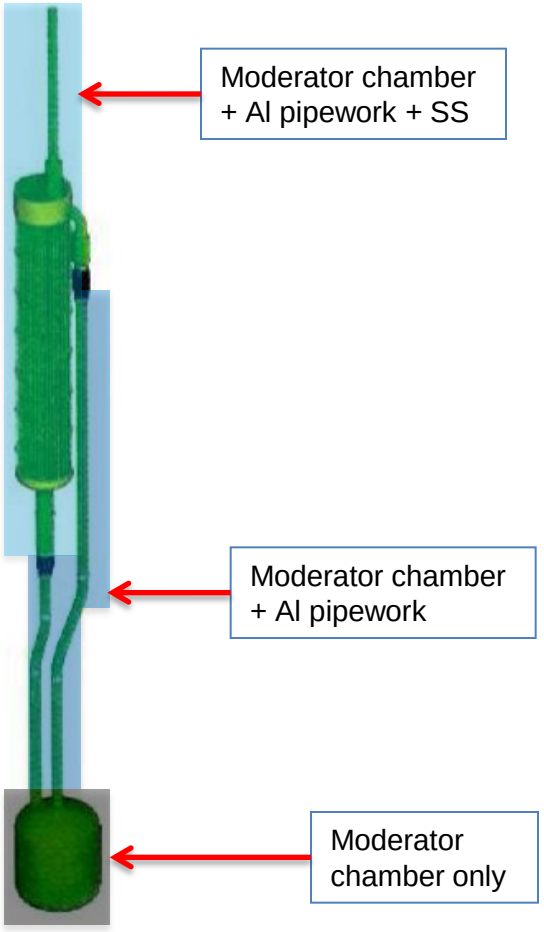
The Story so Far



Modelling the In-Pile

- ANSTO modelled adiabatic temperature rise and distribution in the event of reactor Trip + decay heat (no helium injection).

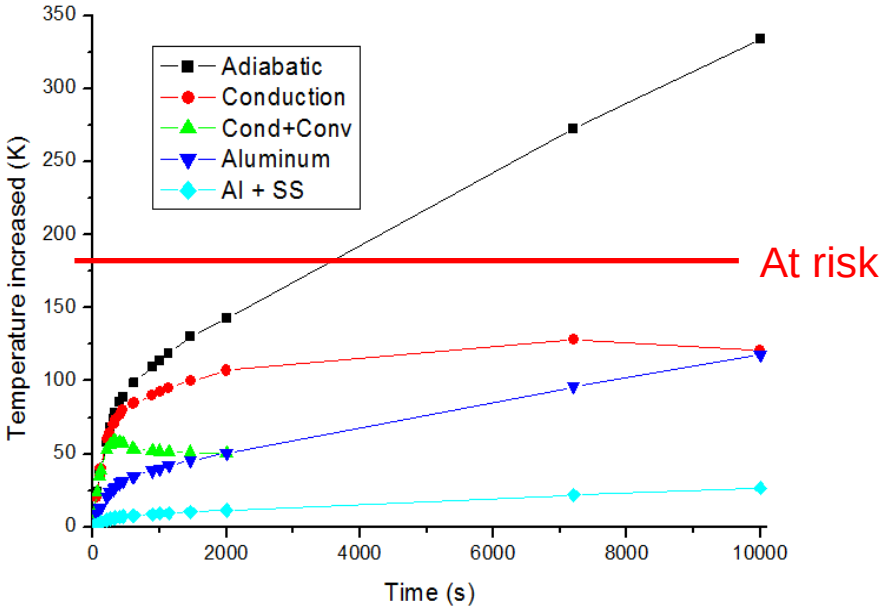




Moderator chamber ΔT:

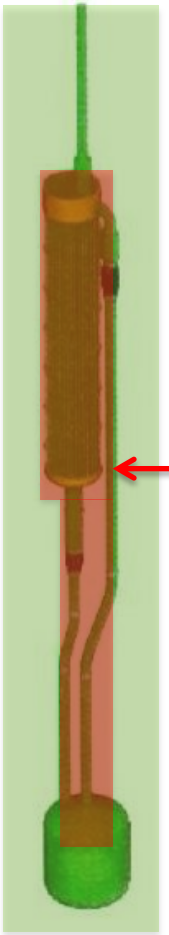
- Temperature rise modelling moderator chamber only
- Temperature rise including connecting aluminium pipework
- Temperature rise including connecting Al + SS pipework

Modelling the In-Pile



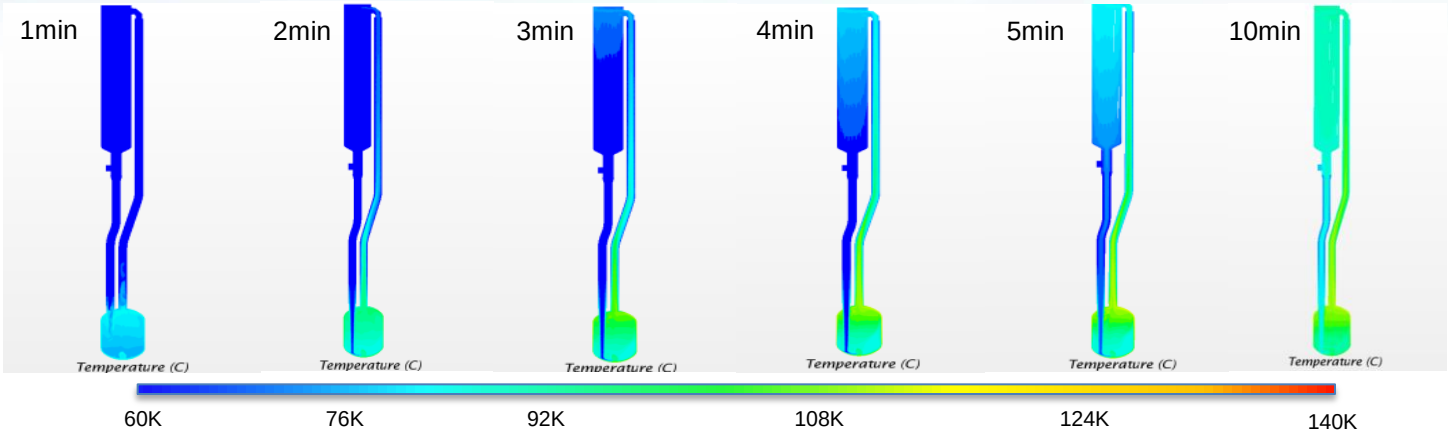
Moderator chamber ΔT:

- Temperature rise taking into account conduction effects of aluminium
- Temperature rise combining effects of conduction from in-pile material and convection from natural movement of deuterium

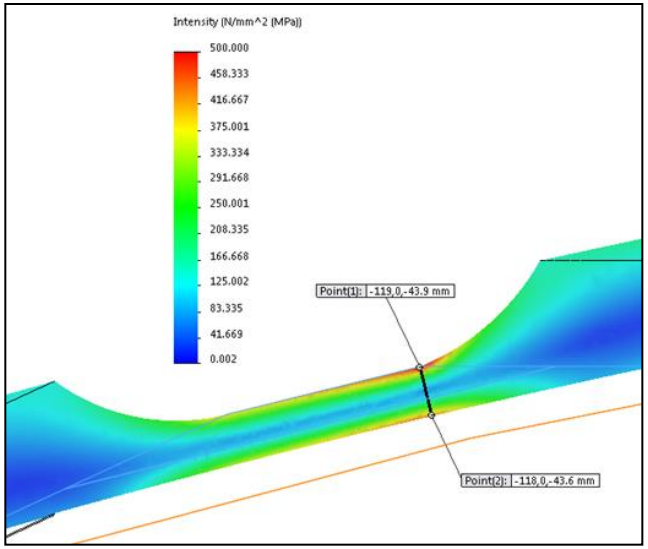


Deuterium naturally provides convection, stabilising temperature rise

Modelling the In-Pile



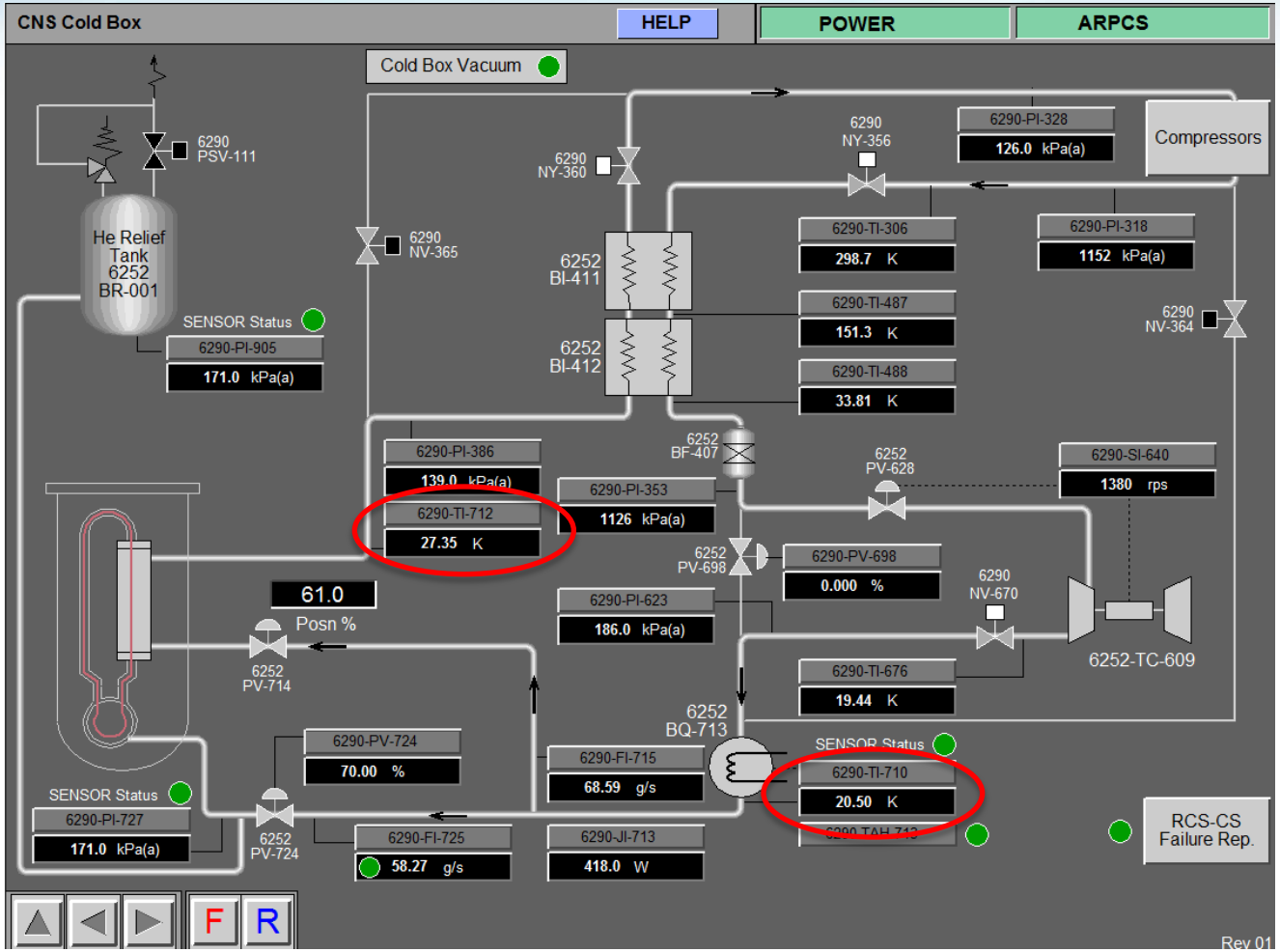
Temperature rise of in-pile (conduction effects only) – HOT DAMAGE NOT a credible occurrence



- Modelling of helium injection at cryogenic temperature (100 K) unacceptably high stresses
- This reinforces our reasoning and further justifies preventing injection.

We can relax the helium injection logic for hot damage

Development of a Solution



- There is no direct method of measuring the temperature of the in-pile.
- Can only be “estimated” using temperature sensors TT-710 and TT-712 AND there is helium refrigerant flow.

Development of a Solution

- Before injection should proceed automatically the following will need to be satisfied:
  - Deuterium needs to be in vapour state
  - Refrigeration Helium flow is ceased (very low alarm)
  - NEW: The refrigeration helium flow was greater than 273K before the CNS tripped / turned off.
- We need some way to retain what the temperature was! → a new variable??
- Still desired a MANUAL TRIGGER for maintenance purposes.
- Should still be allowed to proceed if there is helium refrigeration flow and it is adequately warm (STANDBY MODE)

Revised Helium Injection LOGIC

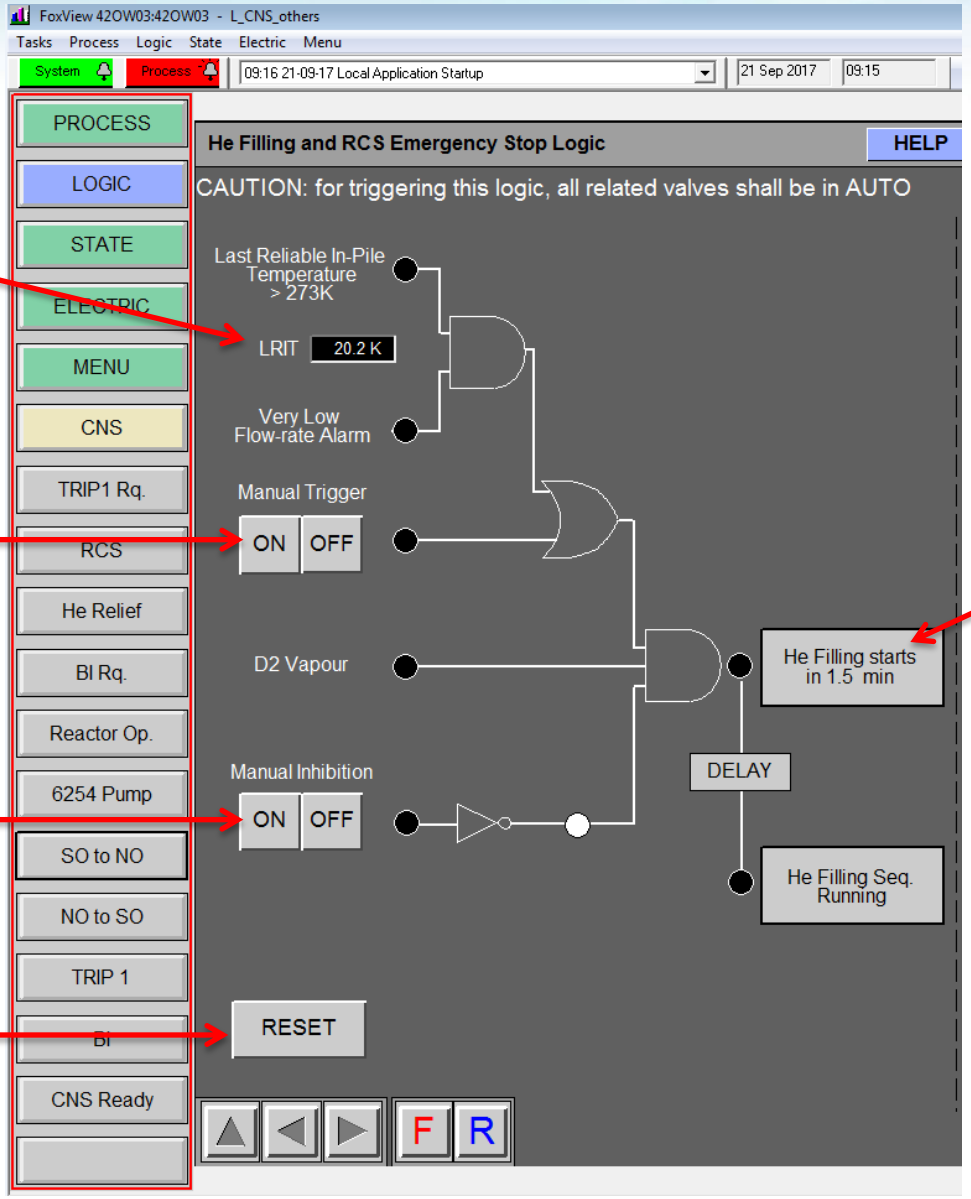
New condition: “LAST RELIABLE IN-PILE TEMPERATURE” (LRIT)

Manual Trigger can be used during: maintenance (eg vacuum pumps)

Manual Inhibit option kept for “operational familiarity” but no envisaged to be used in day-to-day operation

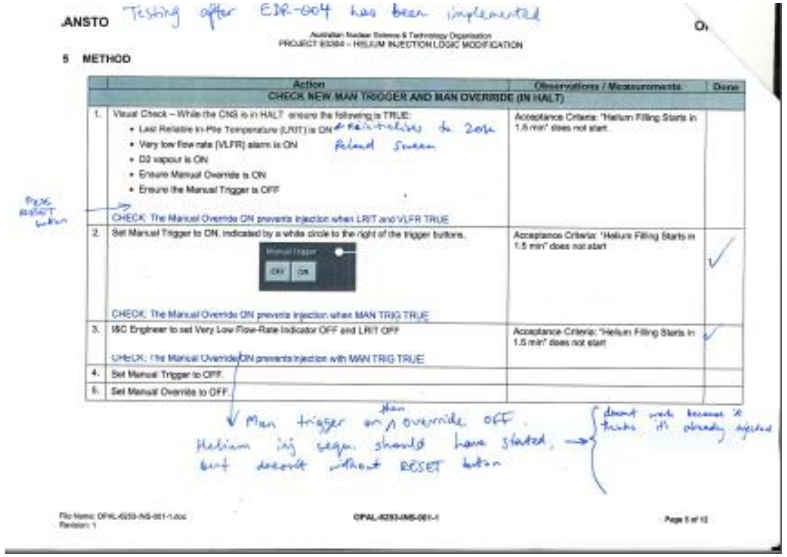
RESET cancels injection sequence if no activating trigger remains, closes injection valve

90 second delay



Since Implementation…

Commissioned and tested AUGUST 2017 Shutdown



ANSTO — Testing after EDR-004 has been implemented

Australian Nuclear Science & Technology Organisation
PROJECT 6290/4 – HELIUM INJECTION LOGIC MODIFICATION

5 METHOD

	Action	Observations / Measurements	Done
	CHECK NEW MAN TRIGGER AND MAN OVERRIDE (IN HALT)		
1.	Visual Check – While the CNS is in HALT ensure the following is TRUE: • Last Reliable In-Pile Temperature (LRIT) is ON — Reinitialise to 200s • Very low flow rate (VLFR) alarm is ON — Reload Screen • D2 vapour is ON • Ensure Manual Override is ON • Ensure the Manual Trigger is OFF CHECK: The Manual Override ON prevents injection when LRIT and VLFR TRUE	Acceptance Criteria: "Helium Filling Starts in 1.5 min" does not start	
2.	Set Manual Trigger to ON, indicated by a white circle to the right of the trigger buttons. CHECK: The Manual Override ON prevents injection when MAN TRIG TRUE	Acceptance Criteria: "Helium Filling Starts in 1.5 min" does not start	✓
3.	I&C Engineer to set Very Low Flow-Rate Indicator OFF and LRIT OFF CHECK: The Manual Override ON prevents injection with MAN TRIG TRUE	Acceptance Criteria: "Helium Filling Starts in 1.5 min" does not start	✓
4.	Set Manual Trigger to OFF.		
5.	Set Manual Override to OFF.		

Press RESET button

✓ Man trigger on then override OFF. Helium inj seqn. should have started, but doesn't without RESET button

doesn't work because it thinks it's already injected

OPAL-6253-INS-001-1

Changes to HMI Alarm Text and Operator Response to Alarm Manual

6290_08: HE_INJ_90S

CNS HELIUM INJECTION IN 1.5 MIN

Alarm Limit: Last Reliable In-Pile Temperature > 273K AND Very Low RCS Helium Flow Rate alarm AND D2 is Vapour AND Manual Inihbition OFF
—OR—
Manual Trigger ON AND D2 is Vapour AND Manual Inhibition OFF

RCMS Screen: L_CNS_Others

Signal Tag/s: 6290_08: HE_INJ_90S

Automatic Action: Starts "He Filling starts in 1.5 min" sequence, i.e. helium will be injected into the CNS vacuum containment after a delay of 1.5 minutes from whence the "He Filling starts in 1.5 min" sequence was activated.

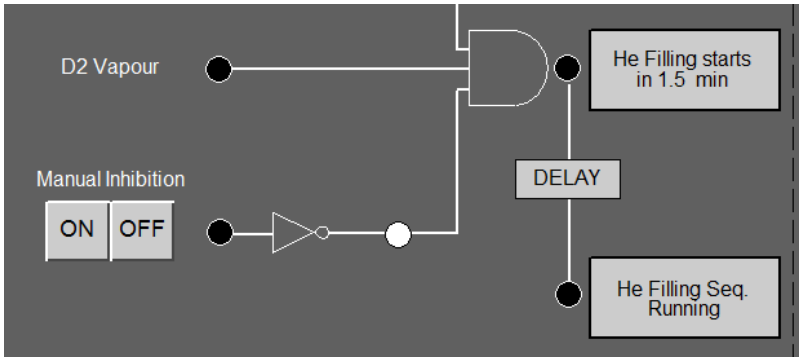
Note: It is possible for helium injection to be manually requested by Reactor Operator (if D2 is vapour).

Step	Action	RCMS Screen	Additional Information
1.	He Injection into vacuum containment will occur in 1.5 mins	L_CNS_Others	Helium will be injected into the CNS vacuum containment after a delay of 1.5 minutes from whence the "He Filling starts in 1.5 min" sequence was activated. The "He Filling starts in 1.5 min" can be cancelled setting MANUAL INHIBITION to ON.

Approved: OPAL Reactor Manager	Date Approved	22/8/12
Custodian: Operations Manager	Revision: 01	Page 1 of 1
		6290_08: HE_INJ_90S

Hard Copy Uncontrolled

Administrative Override Removed, no manual override



Formally close out project

Australian Government | ansto

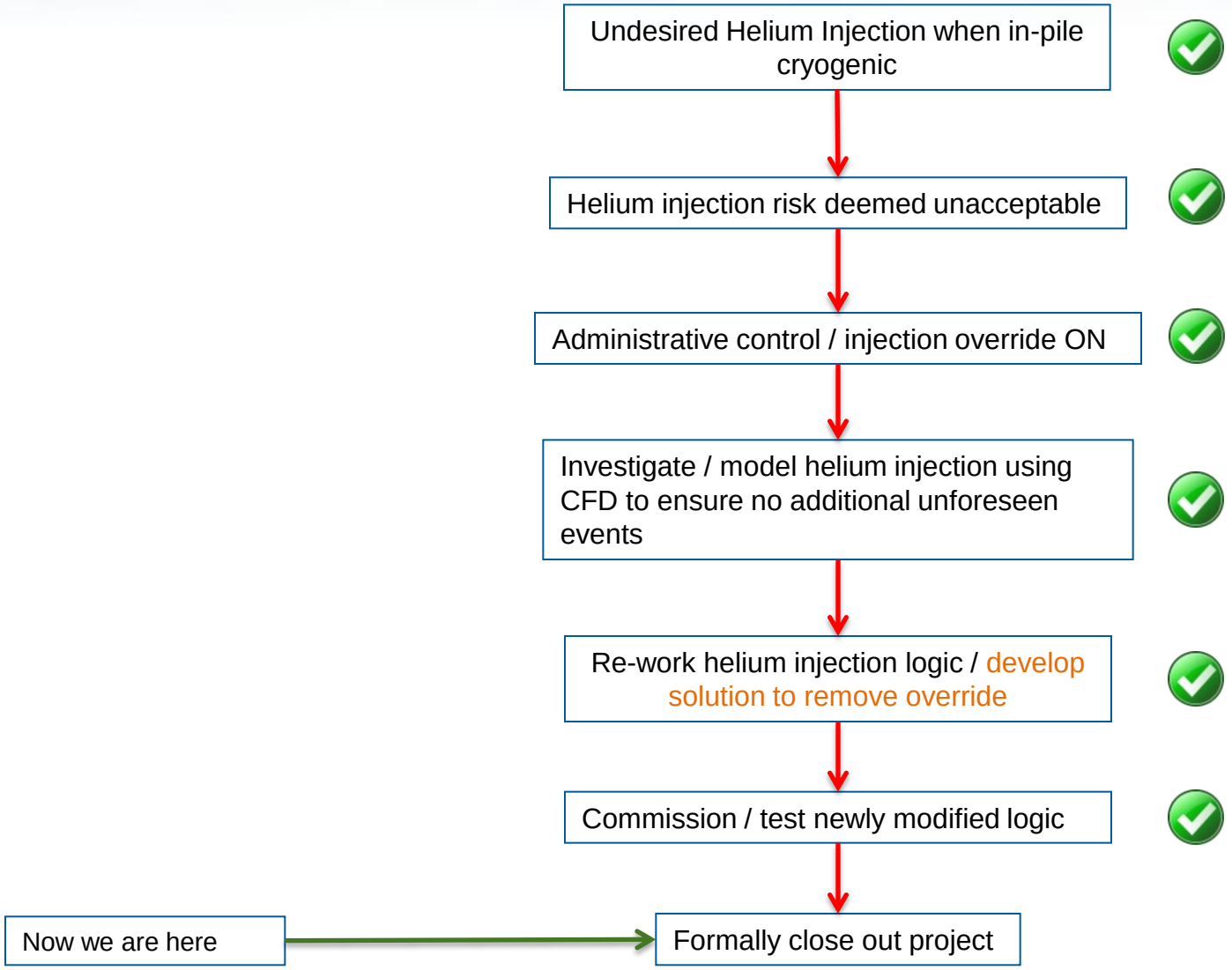
OF 35

Project Completion Check Sheet

Project Number	E0304
Project Title	Helium Injection Logic Modification

Item	Acceptance Criteria	Not Required	Complete	Comments/Notes/References
Manufacture, Installation and Commissioning				
Manufacture, installation and commissioning work	Work completed as per documentation (e.g. SPE, ITP, INS)	☐	☒	OPAL-6253-INS-001 18-07-2017, 19-07-2017, 21-07-2017, scanned in Project Folder OPAL-6253-SWMES-004 OPAL-6253-SPE-001 E0304-EDR-001 / 002 / 003 / 004 / 005 / 006 OEF 019_E0304 OEF 019_E0304 – Additional for Alarm Removal

The Story so Far



Thank you.
Questions ???