Ontario Power Generation
Darlington Unit 2 Refurbishment
ALARA Achievements

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Darlington Nuclear Refurbishment

ONTARIO POWER GENERATION

Ontario Power Generation

- 10 Operating Nuclear Stations at 2 sites
- 2 Shut Down Nuclear Stations in Safe Storage
- 3 Dry Fuel Storage Sites
- 1 Nuclear Waste Facility
- 65 Hydroelectric Stations
- 3 Thermal Generating Stations
- 2 Wind Power Turbines
- Generating Capacity >16,000 MW

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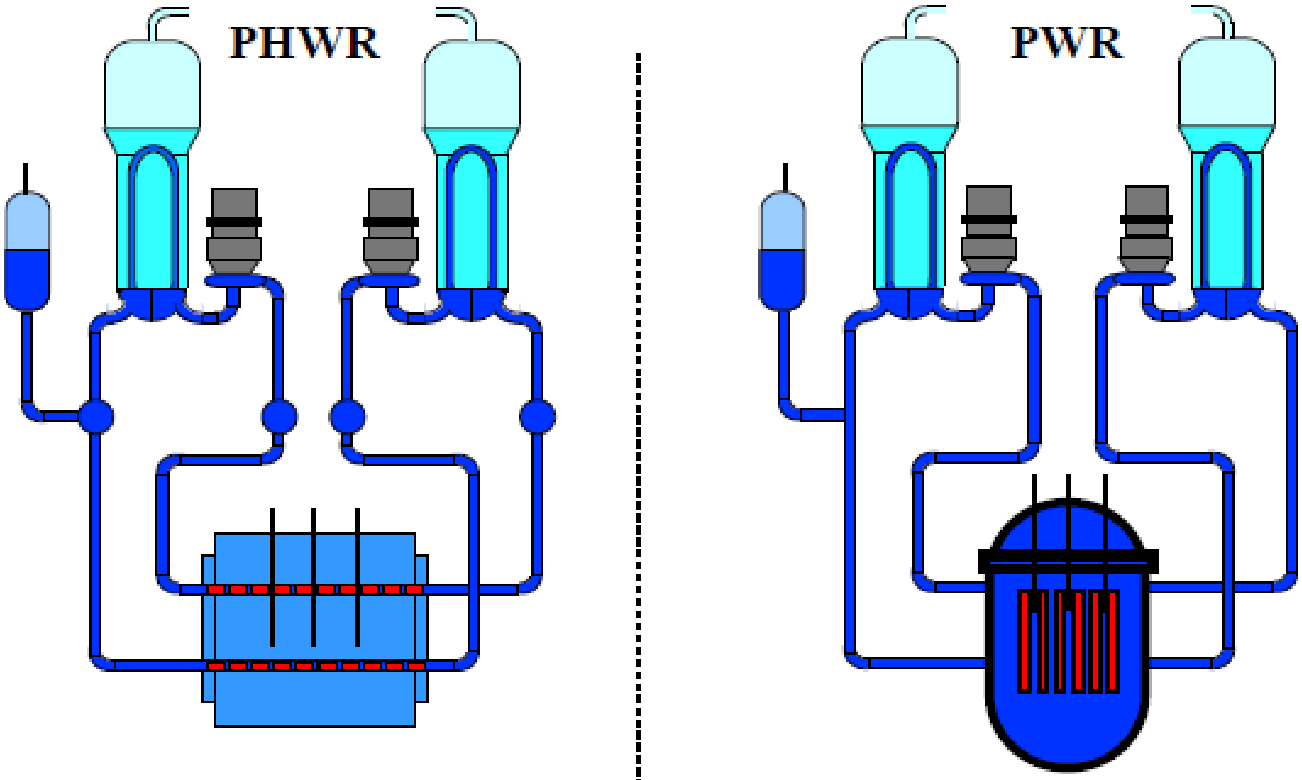
Darlington Nuclear Details

Item	Value
Unit electrical output (per Unit)	881 MW(e)
Number of Units	4
Number of Fuel Channels per Unit	480
Reactor Outlet Header Pressure	10.0 Mpa (1,450 psi)
Reactor Outlet Header Temperature	306 °C (502 °F)
Minimum Pressure Tube wall thickness	4.2 mm (0.165 “)
Reactivity Control	Liquid Zone Control, plus 4 (cadmium) Control Absorbers
Primary shutdown mechanism/ Secondary shutdown mechanism	32 Shutoff rods/8 Poison injection nozzles
Containment	Multi-unit connected to vacuum structure
Number of Steam Generators/Number of Primary Heat Transport Pumps	4/4
Station Efficiency (net electrical output/total fission thermal power)	31.7%

PHWR versus PWR



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CANDU Fuel and On-Power Fuelling

- CANDU (CANadian Deuterium Uranium) is unique in using natural uranium. Natural uranium is 0.7% fissile U-235.
- In a CANDU reactor, fueling is a routine operation. A pair of remotely controlled fueling machines insert new fuel and remove old fuel while the reactor is continuously running.
- This has advantages such as
  - Defective fuel can be removed as soon as it is discovered. This helps lower the radiation dose to station staff.
  - The fueling workload is distributed throughout the year instead of conflicting with a busy maintenance schedule during a shutdown.
- Steady operation at full power requires about 100 to 140 fuel bundles per week (about one dozen fuel channels).

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CANDU Moderator

- The concentration of U-235 in natural uranium is low, so the number of neutrons bombarding the fuel must be high.
- Canadian scientists knew that fuel using natural uranium required a D_2O (Heavy Water) moderator. Any other moderator would absorb too many neutrons
- A large tank(Calandria) with hundreds of channels (Pressure Tubes) through it contains the moderator.
- The Calandria is **not** a pressure vessel.
- Heavy water absorbs few neutrons, but is not as effective as light water in slowing them down. For the same power output, a heavy water reactor is larger than a light water moderated reactor.

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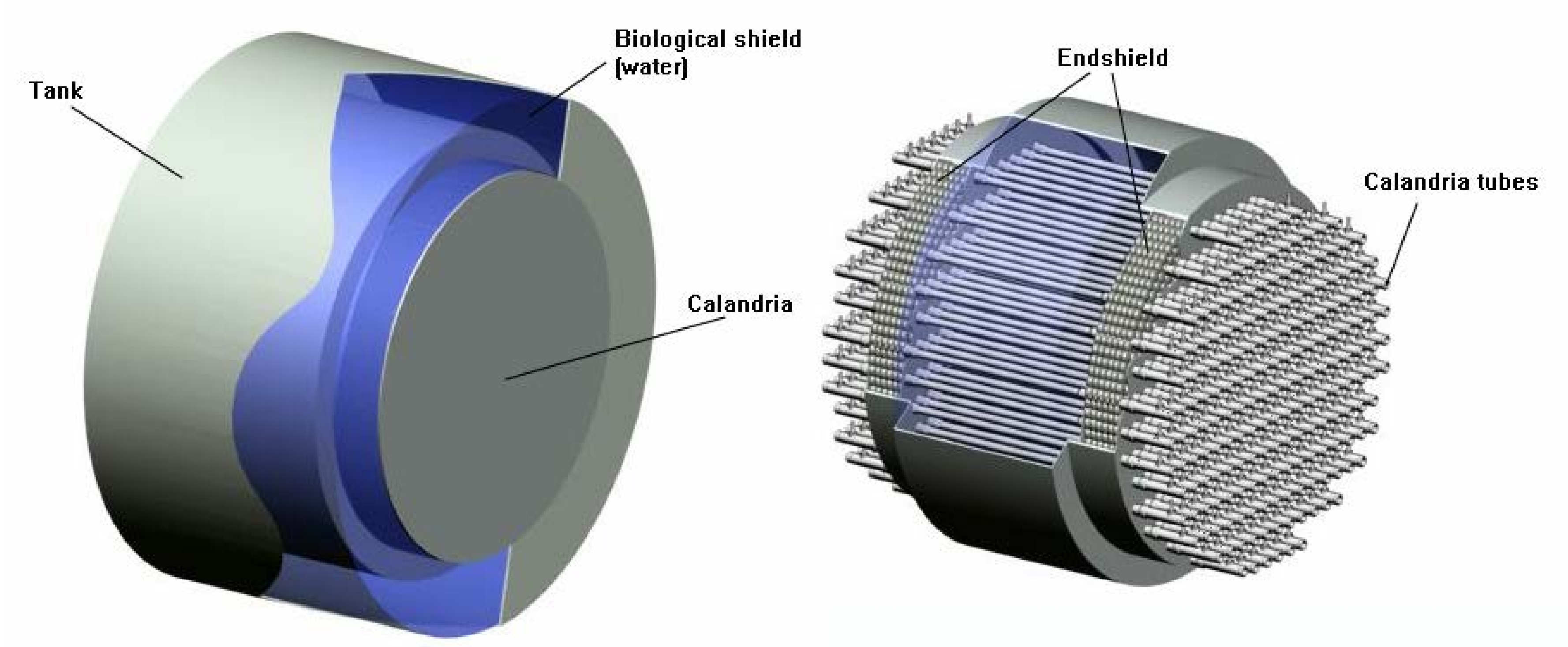
CANDU Calandria



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CANDU Primary Heat Transport (PHT)

- In a light water moderated reactors, the moderator also serves as the coolant.
- Since CANDU design requires heavy water neutron moderation, this makes the reactor large in physical size.
- A large pressure vessel is difficult to build and very expensive.
- A pressure tube reactor design solved this problem. This design separates the moderator and coolant.
- Pressure tubes running horizontally through the Calandria contain the fuel.
- High-pressure heavy water coolant passes through the pressure tube and over the fuel.

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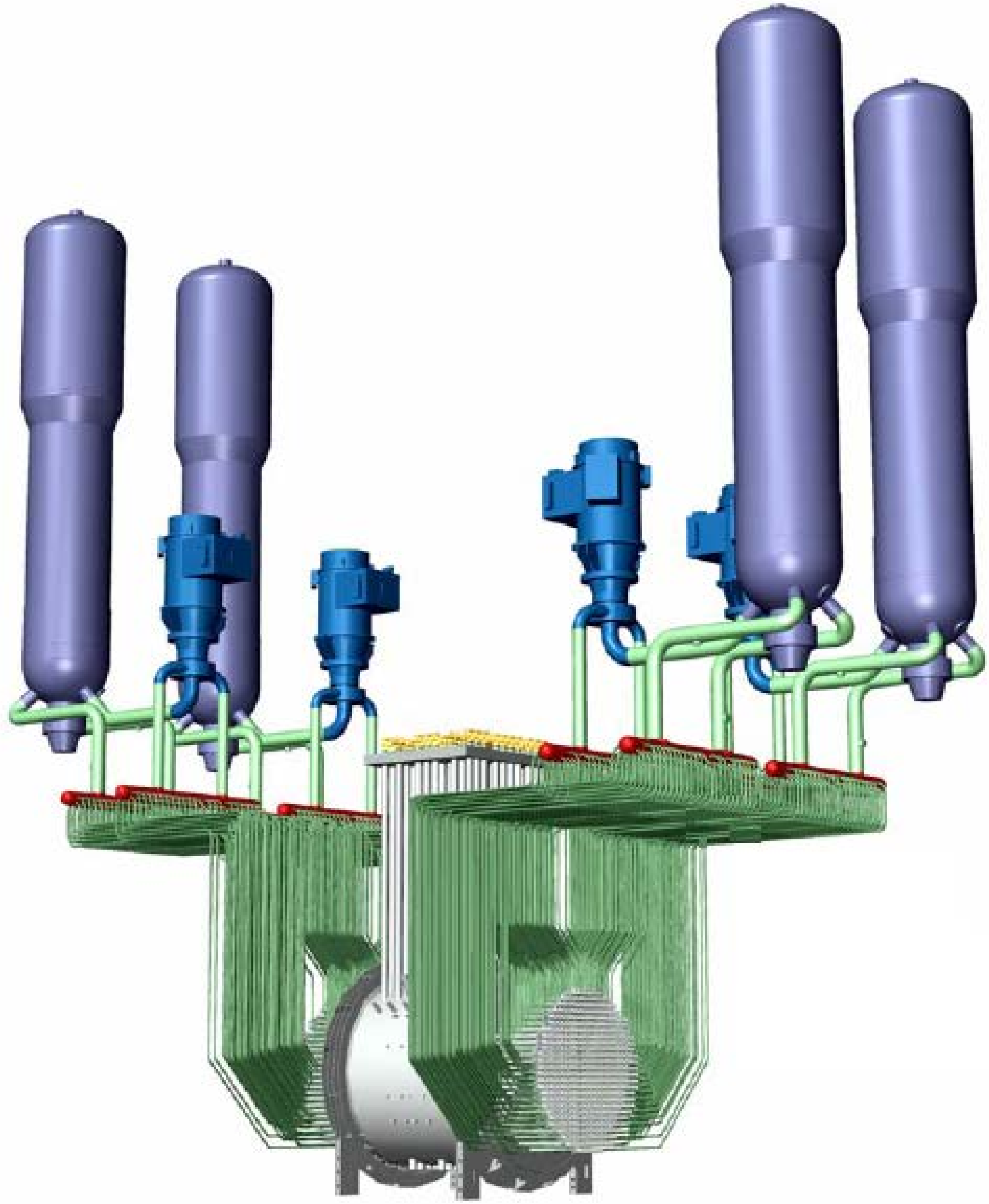
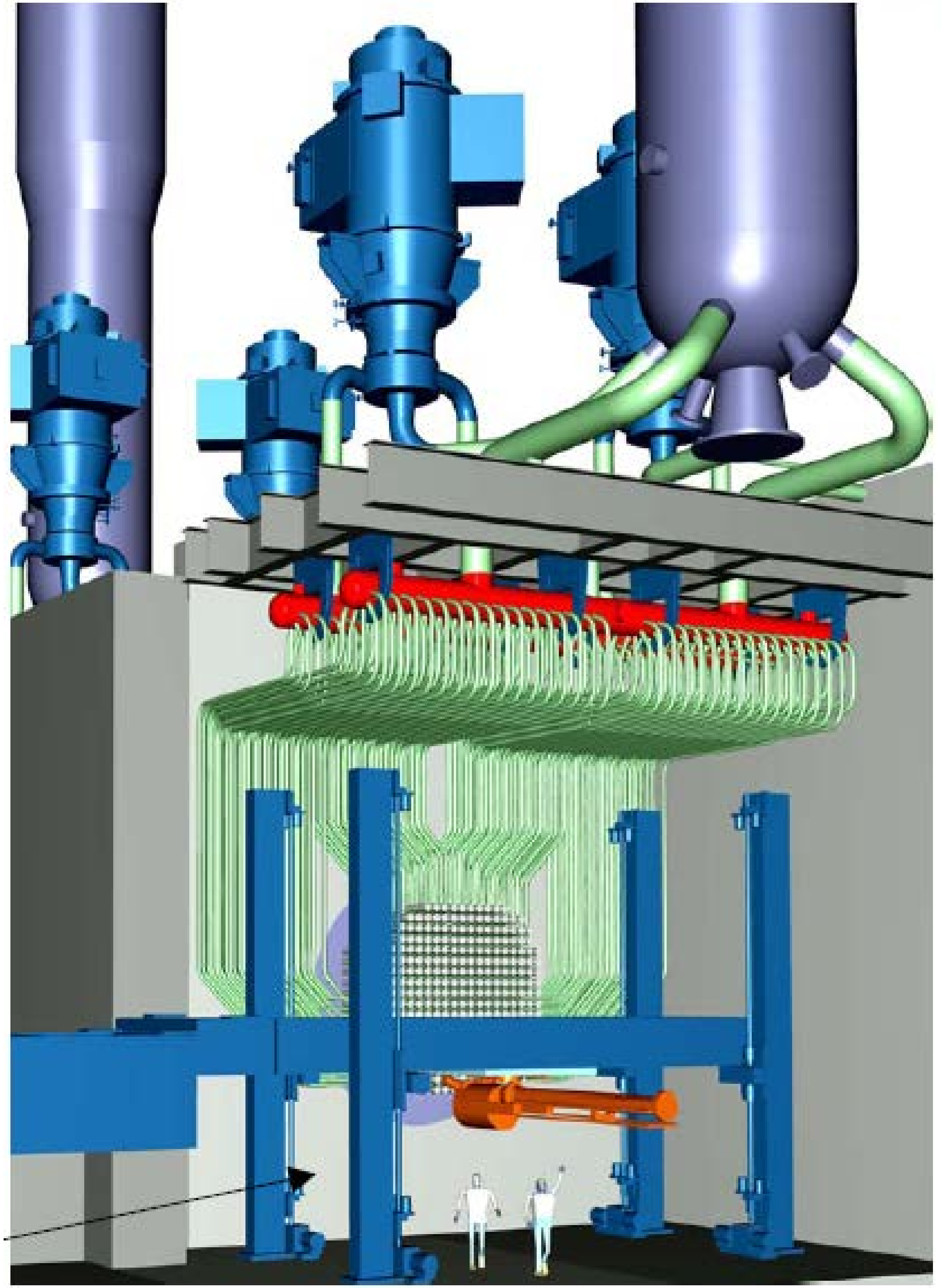
CANDU

- This diagram shows
  - Calandria
  - Heat Transport piping
  - Heat Transport pumps
  - Steam Generators



CANDU

- This diagram shows
  - Reactor Face
  - Fuel Channel Feeder Piping
  - Feeder Headers
  - Fuelling Machine and Fuelling Bridge



CANDU Design

CANDU Design

Darlington Refurbishment

- Refurbishment of CANDU reactors is an aspect of their design and assumed to be required at the mid-point in their operational service life.
- Darlington Refurbishment and Continued Operation Project will involve two phases:
  - Refurbishment of the four reactors; and
  - Continued operation of each reactor for a period of approximately 30 years followed by a safe storage period of approximately 30 additional years.
- During the Refurbishment phase, major components in each reactor will be inspected, serviced, and replaced.
- A key refurbishment activity is the removal and replacement of the fuel channel assemblies and feeder pipes in the reactors (Retube and Feeder replacement or RFR).

Darlington Refurbishment

- Darlington Nuclear is one of Ontario's most important assets
- It has reached the mid-point of its operating life and requires a significant refurbishment
- Refurbishment adds 30 more years of clean, affordable power
- Will also create thousands of jobs & economic benefits in Ontario:
  - Average increase of 8,800 jobs per year from 2010 to 2026
  - Will boost Ontario's nominal GDP by $14.9 billion from 2010 to 2026
  - Projected to boost household income in Ontario by an average of $502 million per year from 2010 to 2026 (total of $8.5 billion)
- Breaker Opened on October 15th 2016

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Darlington Refurbishment - ALARA

Vision:

Darlington Nuclear Refurbishment strives to be an industry leader in Radiation Protection through leadership effectiveness, technological innovation and adherence to RP fundamentals. We will take prudent measures to minimize collective radiation exposures and control contamination at the source. We will embrace continuous learning to meet or exceed industry standards. We will know we have achieved our objectives when:

a) Our regulator and peers recognize our programs as one of the best in the industry

b) Collective dose during refurbishment and post refurbishment is within the top deciles in the CANDU industry

Nuclear Refurbishment ALARA Committee

Terms of Reference

Name: Nuclear Refurbishment ALARA Committee

Vision and Mission: Darlington Nuclear Refurbishment strives to be an industry leader in Radiation Protection through leadership effectiveness, technological innovation and adherence to RP fundamentals. We will take extraordinary measures to minimize radiation exposures and control contamination at the source. We will embrace continuous learning to meet or exceed industry standards. We will know we have achieved our objectives when:

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Membership:

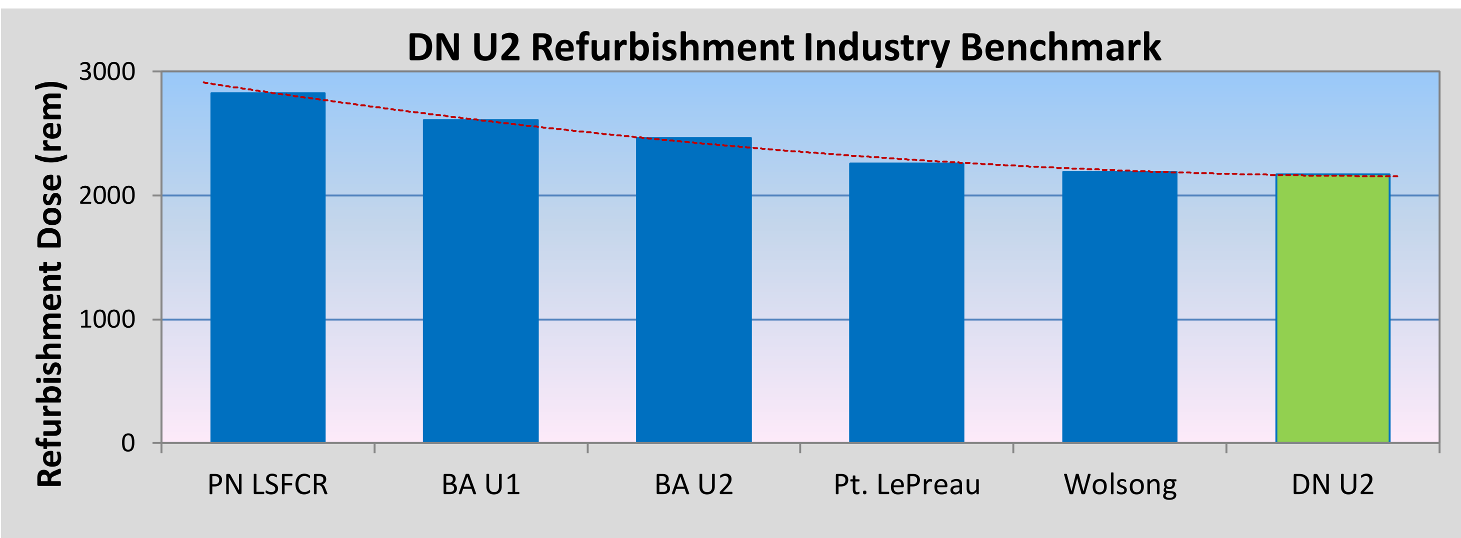
- SVP, Nuclear Refurbishment - Committee Chair *(Alternate at DR level)*
- VP, Refurbishment O&M
- VP, Refurbishment Execution
- VP, Refurbishment Engineering
- Senior Director, Re-tube and Feeder Replacement
- Radiation Safety Director
- Manager, Refurbishment Radiation Protection
- Manager, Refurbishment Chemistry and Environment
- ALARA Section Manager – Meeting Coordinator
- Union Co-chairs, Joint Health and Safety Committee

Functions: To champion Nuclear Refurbishment ALARA programs by providing a forum to ensure that radiation protection issues receive the attention warranted by their significance:

- Establish ALARA priorities and provide strategic insight on matters pertaining to radiation dose reduction and contamination control
- Review the status of dose and source term reduction initiatives, assess their effectiveness, and set direction for improvements
- Review and approve dose performance goals and NR 5-year ALARA plan
- Approve project (CWP) ALARA Plans where collective dose ≥ 3 person-rem.
- Establish and sponsor ALARA sub-committees as required to address ongoing dose reduction and contamination control issues.

Darlington Refurbishment - ALARA

- Refurbishment work programs vary greatly from unit to unit. Three simple factors were considered in data normalization to arrive at a meaningful comparison:
  1. Refurbishment work scope (e.g. RFR scope, Bulkhead)
  2. Reactor size (e.g. number of fuel channels and feeders)
  3. Radiation source term (e.g. decay time, as found radiation fields before refurbishment)
- Consistent with the top decile requirement, a business target of 2172 person-rem was approved for Unit 2 Refurbishment (3 year duration)



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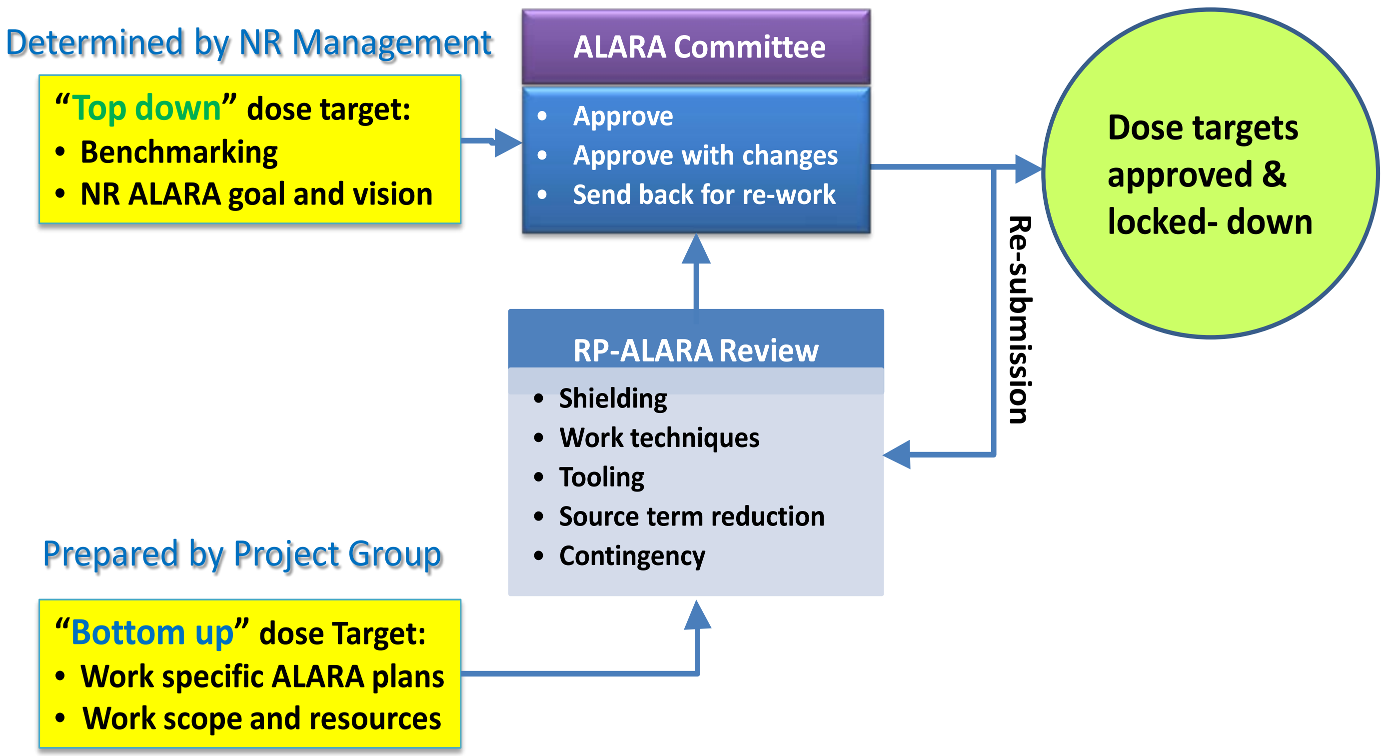
ALARA Plan and Approval Process

Unit 2 Refurbishment Dose Target Approval Process



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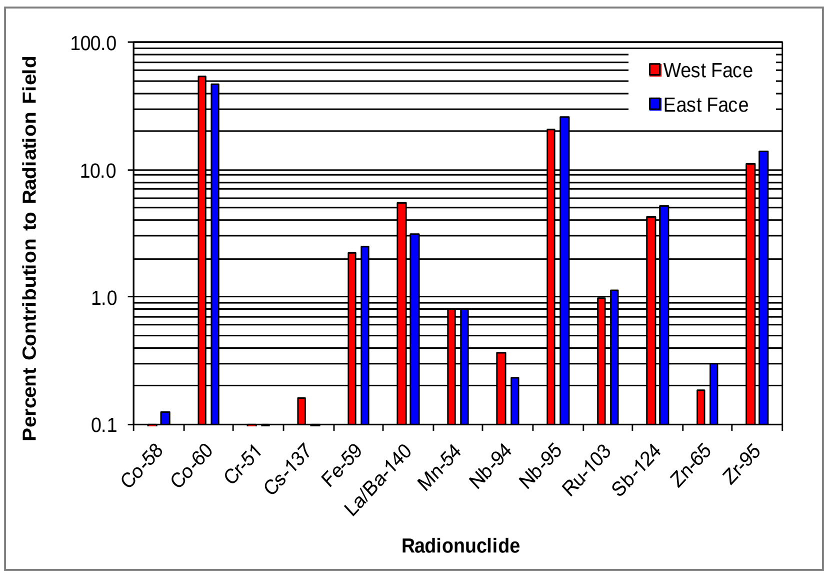
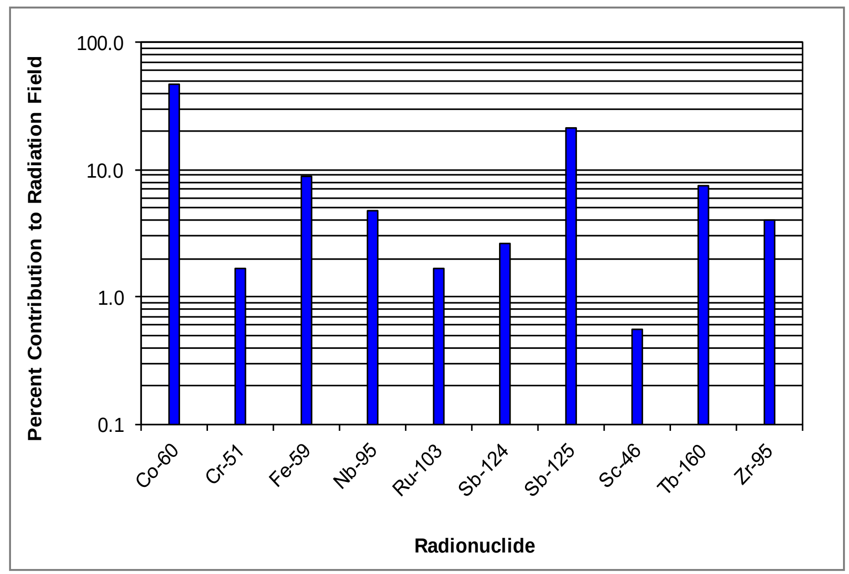
Unit 2 Source Term

- Defuel operations provided approximately 90 days of decay before full vault activities commence.
- Major activities are: *Co-60 (63%), Zr/Nb-95 (27%), Sb-124 (5%), Fe-59 (3%)*
- The dominance of C0-60 presents challenges in shielding design and long decay

Radionuclide Mix: PHT Rooms



Radionuclide Mix: Mod Rooms



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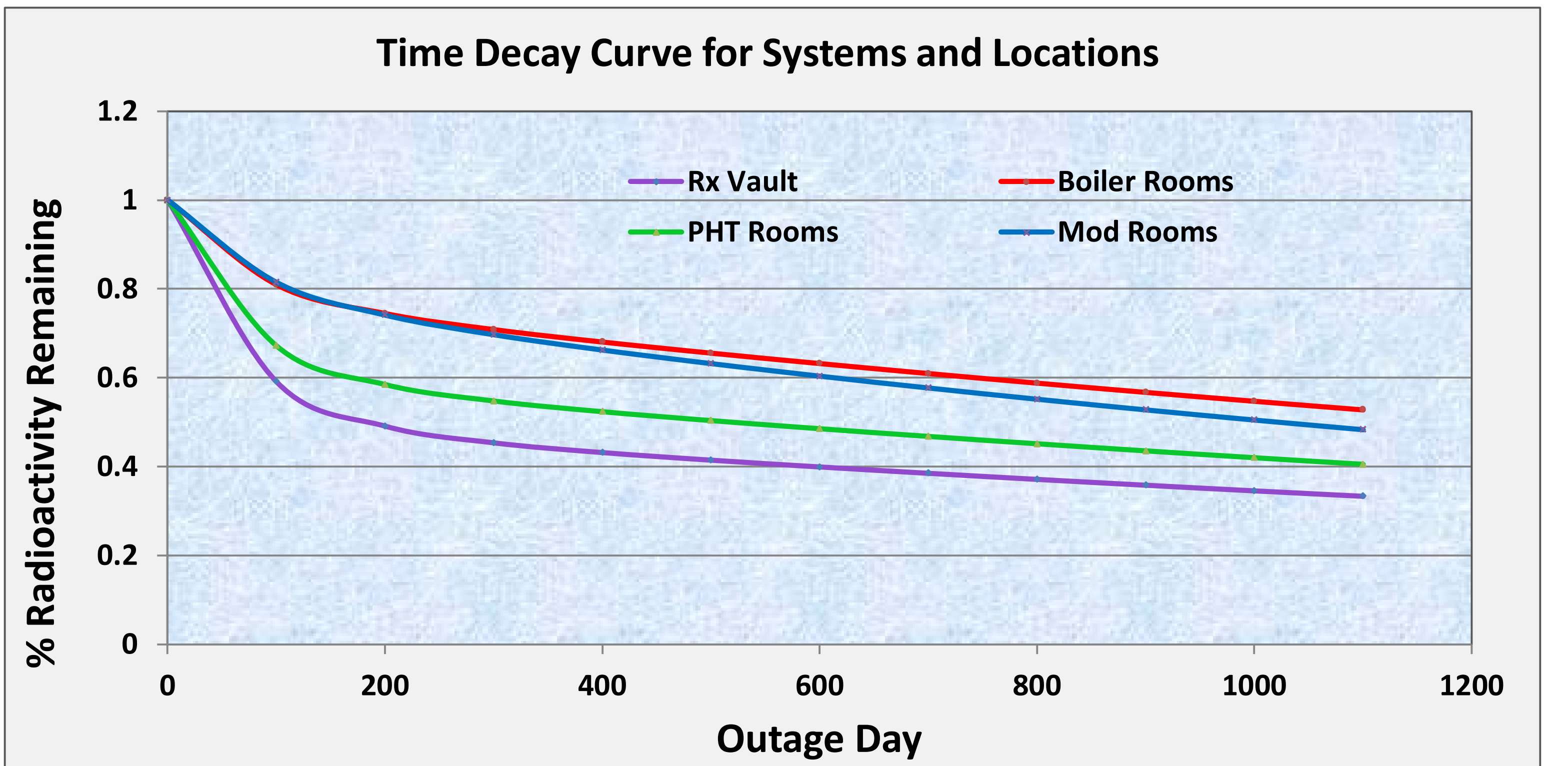
Unit 2 Source Term

On average, dose rates will decay by:

- 30% after Unit 2 Reactor Defuel
- 50% when Retube and Feeder Removal is 60% complete
- 60% when Unit 2 is in Return To Service state



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Unit 2 Source Term

In addition to decay, Reactor Vault dose rates depend on component removal:

- Dose rate immediately after shut down – 24 mrem/h
- After Feeder removal series – 4.7 mrem/h
- During installation series and RTS – 2 mrem/h

This presents an opportunity for planners to schedule long float items later in the outage, particularly after feeder removal

	Project Phase	Refurb Outage Day	Estimated % Change	Average Ambient	Decay Corrected
Lead-in	Reator S/D	0-3	0%	24	24
Lead-in	Defuel Reactor	4-116	-2%	23.2	14.9
Lead-in	Rx Face Shielding	117	-25%	17.4	11.2
Lead-in	PHT /Mod drain	118-149	20%	20.9	11.6
Removal	Removal of shielding	249-250	25%	26.1	12.3
Removal	Feeder Removal	270-317	-60%	10.5	4.7
Removal	EF removal	371-423	-25%	7.8	3.5
Removal	FC Removal	422-573	-15%	6.7	2.9
Installation	FC &EF Installation*	696-857	-10%	6.0	2.3
Installation	Feeder Installation**	857-972	-10%	5.4	2.0
RTS	RTS	972-1095	0%	5.4	2.0

*Calandria Fill **PHT Fill

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TOP 10 ALARA INITIATIVES

1. Clean up PHT before Vacuum Dry
2. Rx Face Supplemental Shielding
3. Install Shielding in the SDS2 Bunker
4. Airlock 2 Walkway Shielding
5. Reduce D2O Currie Content
6. Reduce CP Leakage: HTS Depressurize & Drain in 1 Shift
7. Reduce CP Leakage: Retorque Leaking Closure Plugs
8. Create Low Dose Environment for Power Track Work
9. Install Munters before Reactor Defuel
10. Human Performance (HU) Improvement

Clean up PHT before Vacuum Dry

- PHT was drained to the header and the remaining 115 Mg (113 tons) of D_2O were vacuum dried causing radionuclide deposition on the PHT pipework.
- Clean up of PHT before vacuum dry minimized contamination spread during PT and feeder removal series. A new resin (Lanxess) was proposed to be utilized.
- A dose estimate based on radioactivity concentrations in Unit 2 PHT shows that implementation of Lanxess resin could save 10 person-rem of dose and significantly reduce contamination spread when feeder pipes are cut and severed.
- Exceptional teamwork between RP, Chemistry, Operations, Engineering, Supply Chain and Project Office was mainly responsible for the success in addressing a multitude of procurement, scheduling and technical issues.
- The Lanxess resin was successfully installed in IX-1 on December 23, 2016, prior to PHT drain.

Clean up PHT before Vacuum Dry

- Based on preliminary Chemistry grab sample results,
  - A factor of 3 reduction in major radionuclides such as Sb-124, Zr-95 and Nb-95 was observed between samples taken 5 days apart
  - When compared to historic values from 2010-2015, a factor of up to 10 times reduction was achieved for these major radionuclides.
  - These are preliminary results, but show great promise.
- Successful implementation of Lanxess resin in Unit 2 and improvements from lessons learned will greatly benefit implementation for other Darlington units and fleet wide.

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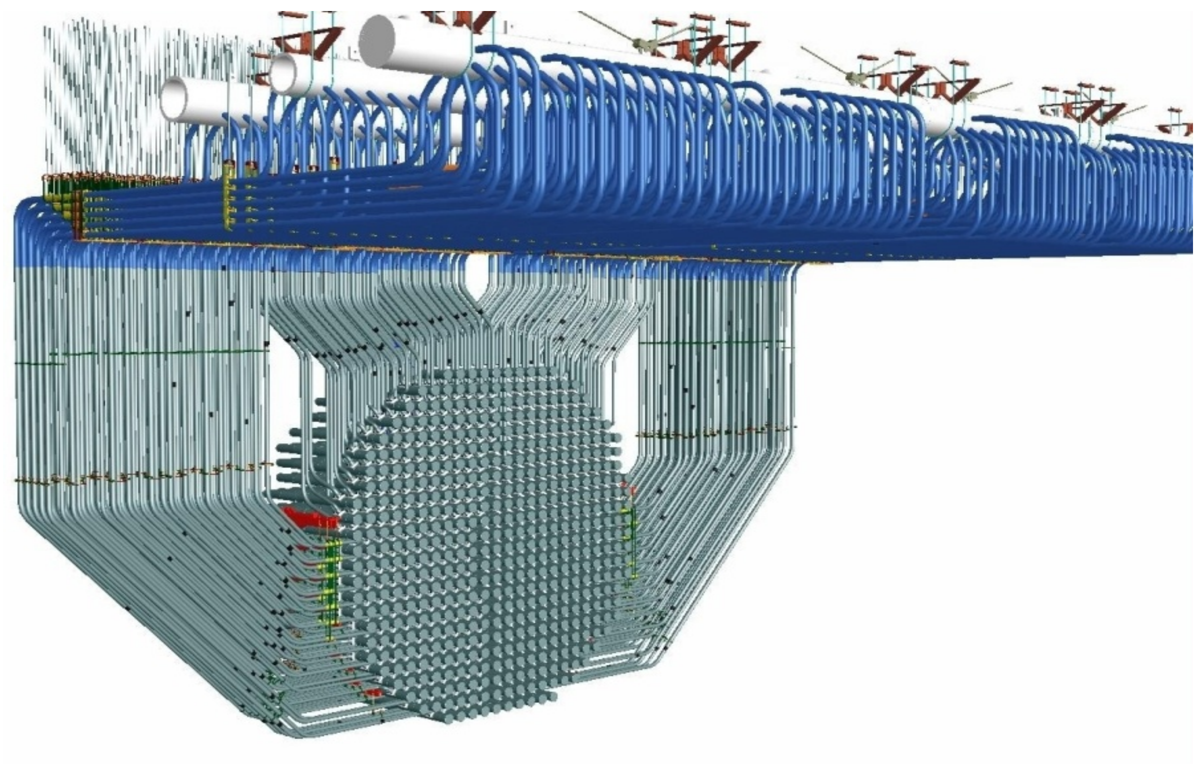
Reactor Face Supplemental Shielding

Feeders are major source of radiation in the vault.

1. Reactor Face – 100 merm/h
2. Vertical feeder cabinet – 80 merm/h
3. Horizontal feeder cabinet – 150 mrem/h feeders, 32 merm/h headers



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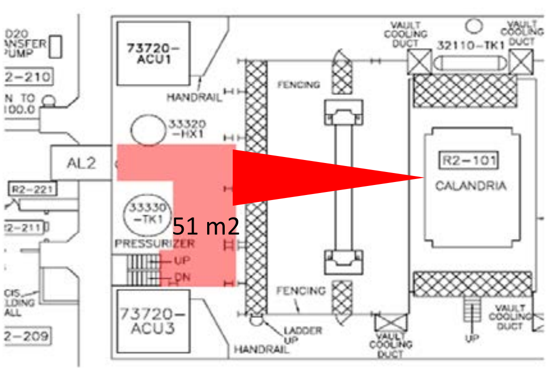
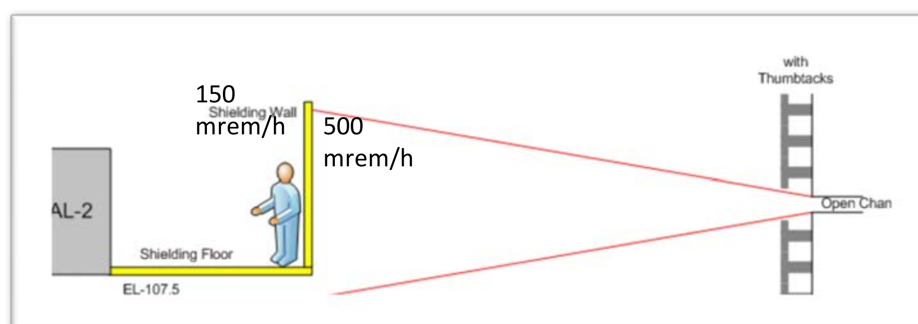
Reactor Face Supplemental Shielding

- The Unit 2 reactor was shielded with 1" Silflex, providing 25% dose rate reduction in the vault
- Magnetic Silflex was used for header shielding for quick installation and removal
- Total dose savings for Unit 2 estimated to be 61 person-rem
- Reusable for U3/U1/U4

Airlock 2 Walkway Shielding

- The Unit 2 vault will be under controlled access due to open beams from RFR work resulting in 111 elevation being stranded most of the time. This will restrict execution windows for Balance of Plant and Steam Generator work creating situations where work may have to be done in high dose
- RP has proposed and implemented a project to shield the walkway with 1” of steel (or equivalent) to reduce dose rates below EPD alarm set point
- Remote monitor with local display and sign posting will warn people of higher dose rate and the need to transit the area expeditiously
- The shielding wall was declared available for service before the first open channel work in September of 2017.





Install Munters

- Munters have been shown to reducing airborne tritium inside containment by a factor of 2.
- Lower PHT pressure (6.5 MPa) during reactor defuel results in isolated Closure Plug leakage which will result in elevated Vault Tritium airborne concentrations
- Early deployment of Munters is critical to reduce tritium during defueling and depressurization. Munters were deployed shortly after the unit was Defuelled.
- The total H-3 Curie content extracted from vault air per day = 77.9 Ci
- On average from Jan 16 to Jan 21, the Munters have been responsible for 70 MPCa (70 DAC) reduction in vault tritium. This translates to approximately 2 person-rem internal dose savings

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Human Performance (HU) Improvement

- Worker and Radiation Technician HU has a large impact on dose performance and is the most cost-effective initiative in dose reduction
- Daily dose monitoring and timely follow-up for lessons learned
- Develop instruction and checklist to assist Radiation Technicians in reinforcing good RP practice and correcting adverse ALARA behaviors and conditions
- Develop timely and targeted communication campaign to reduce unplugged time for jobs involving tritium exposure
- Reduce idle time – Radiation Technician to monitor and remove workers from rad work area if no specific job assignment or not actively engaged in execution
- Radiation Technicians to enforce "clean as you go" to reduce demobilization & clean-up dose.

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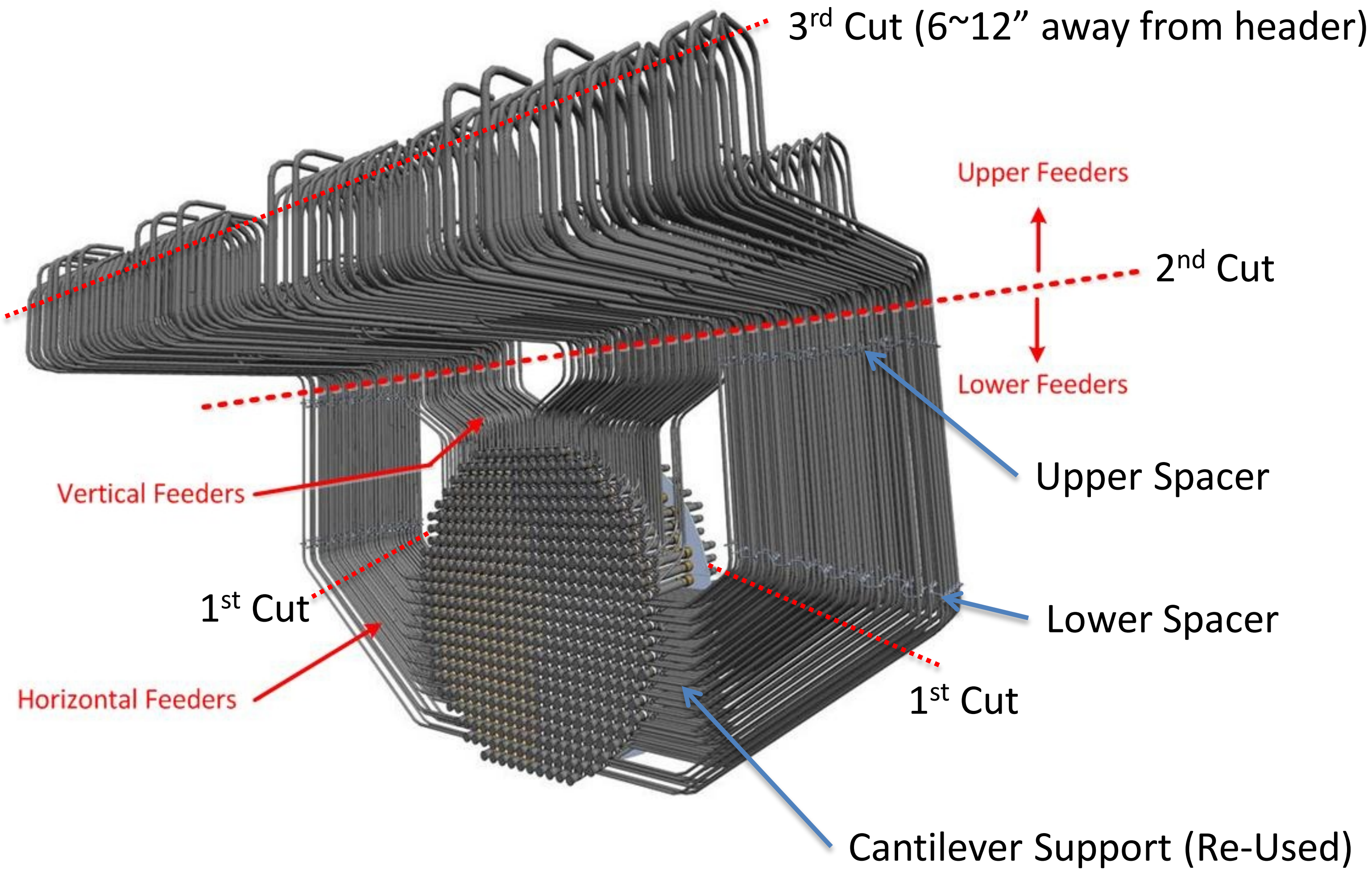
Feeder Removal



Feeder Removal – Dose Control

- The total dose for the Unit 2 Feeder Removal was 212 person-rem. Comparison with other utilities (taking into account the number of feeders) shows that on a "per-feeder" basis, Unit 2 feeder removal performed well.
  - DNRU2: 0.22 person-rem/feeder
  - PLGS: 0.24 person-rem/feeder
  - Wolsong: 0.26 person-rem/feeder
- The above comparison does not take into account that Darlington's feeders are significantly larger and longer.
- Bruce Power's dose statistics are not included as they only perform partial feeder removal (first bend).
- For Darlington, the total time spent was 27 days.

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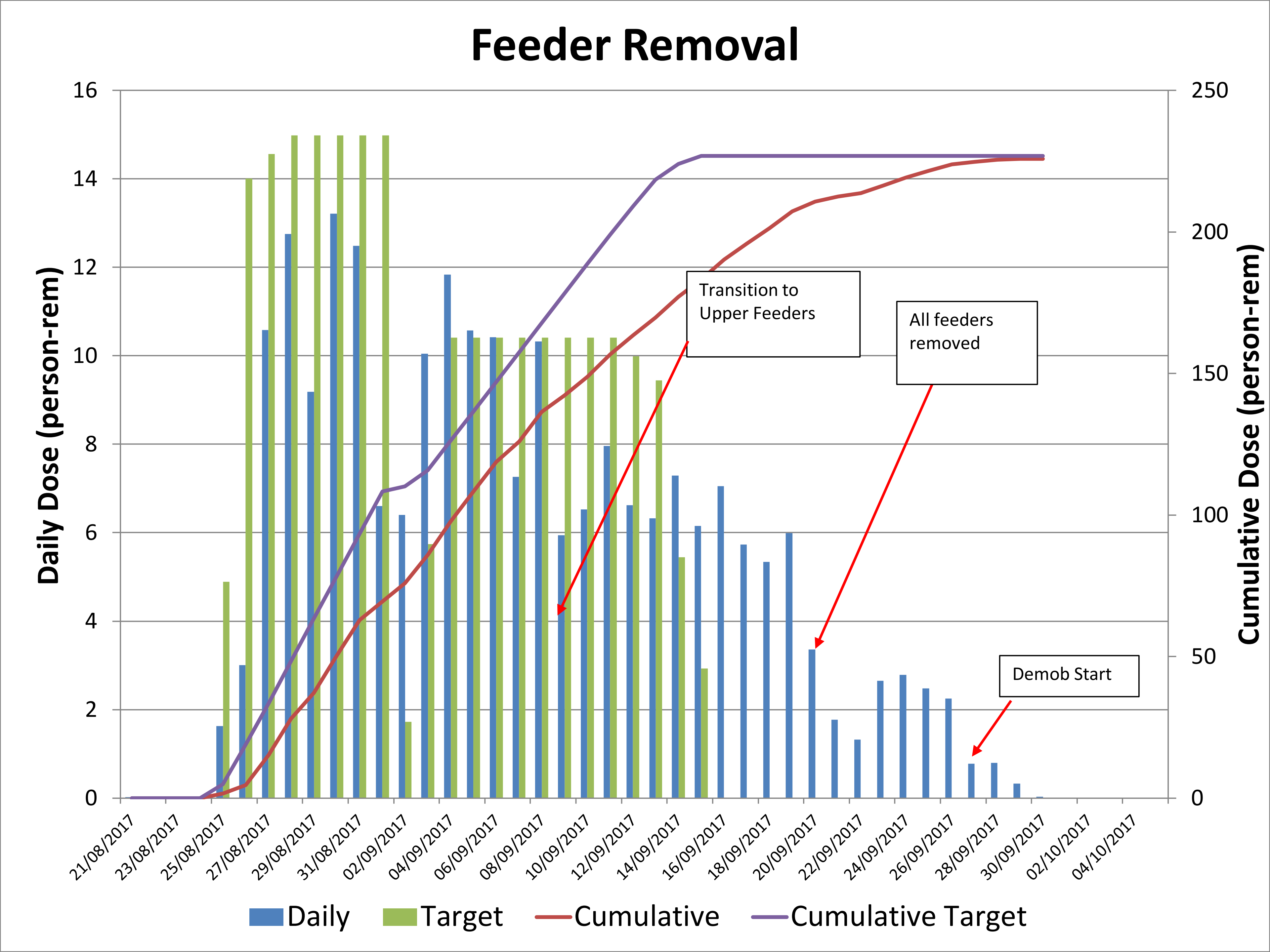

Feeder Removal
Daily Dose (person-rem)
Cumulative Dose (person-rem)
16
14
12
10
8
6
4
2
0
250
200
150
100
50
0
21/08/2017
23/08/2017
25/08/2017
27/08/2017
29/08/2017
31/08/2017
02/09/2017
04/09/2017
06/09/2017
08/09/2017
10/09/2017
12/09/2017
14/09/2017
16/09/2017
18/09/2017
20/09/2017
22/09/2017
24/09/2017
26/09/2017
28/09/2017
30/09/2017
02/10/2017
04/10/2017
Transition to Upper Feeders
All feeders removed
Demob Start
Daily
Target
Cumulative
Cumulative Target

Feeder Removal – Contamination Control

Throughout the feeder removal campaign, contamination was kept low by applying RP fundamentals:

- Good use of catch containment to intercept cutting debris to keep contamination at the source
- Strict application of "clean as you go" concept using laborers
- Good layout with clear demarcation of Rubber Change Areas and RPPE removal points.
- Classification of areas as Alpha Level 3 sharpened contamination control focus.
- RP application of "monitor, monitor and monitor" principle to detect any early signs of contamination issue and initiate cleanup before it becomes a problem
- Capping of feeder ends immediately after cutting to contain contamination.
- Good rehearsal at the Darlington Energy Centre (DEC) mock-up facility

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Feeder Removal – Contamination Control

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Feeder Removal – Contamination Control

Results of good contamination control are reflected in the following observations:

- Shiftly manual air sampling showed no airborne contamination > 1 MPCa generated
- No iCAM alarms (alpha and beta) throughout the feeder campaign
- Remote radiation monitor attached to the VVRS pre-filter showed no increase in activity
- Contamination was confined to the RTP and feeder removal platform
- Post feeder removal cleanup was not required, as the clean as you go strategy was successfully implemented.

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Feeder Removal – Lessons Learned

Lessons Learned – Cutting Method

- Though the Work Plan called for using the reciprocating saw vacuum attachment, with the success of trapping feeder removal and the reduced mobility associated with the attachment, the decision was made to not use the vacuum attachment. Trials at the mock-up showed up to a 2 fold increase in the amount of time it took to cut a feeder. Also the in-line filter developed by the Joint Venture (JV) was also not utilized. This helped reduce the time required to cut feeders
- The reciprocating saw blade used was the Milwaukee Torch. This bade removed large chunks of material. On average it took about 30 seconds to cut a feeder. Most blades were only good for one or two cuts after which they needed to be replaced.

Feeder Removal – Lessons Learned

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Feeder Removal – Lessons Learned

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Feeder Removal

- Video

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