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Revision Summary

Revision Number	Date	Comments
R000	2024-11-13	Initial Issue.
R001	2025-06-20	Editorial changes throughout Re-classified R001 report to 'Internal Use Only' Updated with Risk Reliability & SAMG, Fuel & Reactor Physics, and Design Stakeholder Reviews • Clarified bolted joint and seismic brace design changes in Section 2.3.1 • In Section 6.2, defined Plant Damage States (PDS) in detail. • Wording changes in Section 8.0 and subsections. • Added Reference [27] that documents changes to SORO and SORO Utilities to account for TDS

Executive Summary

Ontario Power Generation (OPG) has a Target Delivery System (TDS) installed at Darlington Nuclear Generating Station (DNGS) for the purpose of transporting target capsules to produce isotopes in the reactor for medical treatments. This review focuses on the applicability of current analysis and assessments to installation and operation of additional systems on other DNGS units. The need for additional TDS installations is based not only on the need for expanded isotope demand but also the ability to produce isotopes in a manner that ensures reliability of supply. With only one TDS installed on Unit 2, there is a risk to production of isotopes due to both planned and unplanned outages, TDS reliability and normal planning activities which may conflict with TDS operation.

The review focuses on key documents completed in support of the installation and operation of the existing TDS, as well as the introduction of Cobalt Adjusters to Darlington reactors. While the current TDS installation is on Unit 2, which currently has Stainless Steel Adjuster Absorber rods, separate reports were prepared to account for Cobalt Adjuster rods.

The following reports formed the basis for this review:

- Event Identification and Classification Report,
- Assessment of Target Delivery System for Molybdenum Irradiation on the Darlington Internal and External Hazard Screening Assessment,
- Assessment of Target Delivery System for Molybdenum on the Darlington Probabilistic Safety Assessment (PSA),
- Integrated Nuclear Safety and Operational Assessment of the Target Delivery System in Darlington,
- Nuclear Safety Assessment for the Production of Yttrium-90 (Y-90) and Lutetium-177 (Lu-177) at Darlington Nuclear Generating Station
- Operational Assessment of the Target Delivery System Installation in Darlington,
- Cobalt Adjuster and Molybdenum Target Delivery System Interaction

As part of the original design and installation of the TDS at DNGS a detailed Failure Mode and Effects analysis was completed and formed the basis for the subsequent planning and analysis of the associated safety cases. The event identification and classification exercise identified a number of new initiating events. In addition to those initiating events considered in safety analysis, additional initiating events were screened for impact on the PSA.

Detailed impact analysis was performed, not just for safety analysis implications but the overall impact on Plant Operations. Review of all Darlington Safety Report Accident Analysis Appendices was completed and are detailed in the integrated safety and operational assessment as well as the Cobalt interactions report. Impact on the ability to comply with key safety parameters was assessed and documented in both the operational and the integrated safety and operational assessment reports.

The detailed assessments concluded the TDS system did not introduce any new initiating events or hazards that would impact the conclusions of the current safety analysis or PSAs. Further, the operational assessments confirmed that the introduction of the TDS is well within the capability of current systems and process to ensure plant operation remains consistent with the defined Safety Operating Envelope (SOE).

Based on this review, there are no additional safety analysis requirements necessary to support the installation of a TDS on other DNGS units. There is a need to complete the necessary updates of the associated PSA models to incorporate the TDS design, and these will be completed according to the required update frequency. Systems, structures, and components will continue to provide the required safety, protective and mitigating functions necessary to ensure the original design objectives are met. Further, current operating practices and processes will ensure continued operation within the defined SOE.

1.0 INTRODUCTION AND BACKGROUND

Ontario Power Generation (OPG) Darlington Nuclear Generating Station (DNGS) has installed a Target Delivery System (TDS) on Unit 2 to irradiate medical isotopes that are contained inside a target capsule. The design and installation of the TDS was performed using the Engineering Change Control (ECC) process. The TDS utilizes a combination of mechanical, hydraulic and pneumatic transfer systems designed to transfer the target capsules to specified locations within the reactor core for a defined period to irradiate and produce medical isotopes. A comprehensive description of the design and operation of the TDS is available in Reference [1] and is based on the TDS Failure Modes and Effects Analysis (FMEA) Reference [3]. A brief system description is provided in the next Section. In addition, there is a summary of the planned TDS changes for the installation of the next TDS.

This Nuclear Safety Review will focus on the installation of additional Target Delivery Systems that will utilize the same fundamental design and irradiate the same target capsules in the same manner to produce medical isotopes. The basis of the review is the Nuclear Safety Impact Assessment documented in Reference [4]. There has been a significant effort in the development of both the nuclear safety case and operational assessments for the introduction of the TDS and original production of Mo-99. Previous assessments have demonstrated the very small impact on the complete safety case and operation at DNGS and the analysis was completed based on the analysis for any DNGS unit, as deterministic analysis is performed at the single unit level. While there are common mode events as well, these are considered based on a single event unit. Further the probabilistic safety assessments also consider event analysis primarily at the Unit level with contributions from common mode events assessed based on a common unit design. In the case of installing additional TDSs on multiple units, a summary review of the analysis and operational assessments, based on a qualitative review to confirm these analyses and assessment remain valid is completed.

2.0 TARGET DELIVERY SYSTEM OVERVIEW

2.1 TDS System Overview

The TDS utilizes a combination of mechanical, pneumatic, and hydraulic methods of propulsion to transfer target capsules into and out of the reactor core for the purpose of irradiating the target capsules to produce medical isotopes. Strings of eight target capsules are inserted into the reactor in four out-of-service Adjuster Assembly (AA) locations, specifically AA1, AA8, AA17, and AA24 (renamed as Target Elevators (TEL) 1-4), as depicted in Figure 1. TDS equipment is in each of the modified AA ports on the Reactivity Mechanism Deck (RMD).

Target capsules containing target isotope materials are received and then, using pneumatic flight tubes, connected to the New Target Loader. The target capsules are then transferred through the Target Airlock (TAL), and from the TAL into a basket in a TEL using a hydraulic propulsion system. The target capsules are transferred into a locked basket in a “home” position. Target capsules are lowered in a target basket into the reactor core inside of a TEL. The drive mechanism at the top of the modified AA port moves the target basket using a winch and cable. The cable is unwound relying on the motor settings, weight of the basket and targets to lower them to the proper location in the reactor core. The target basket and the

guide tube are perforated so that the targets are in direct contact with the moderator, resulting in effective heat removal from target capsules caused by thermal heating during irradiation and activation of the isotopes.

The targets will remain in-core, at approximately the reactor vertical centre line[1], during the irradiation period. The targets are harvested after a specified duration (up to seven days) of irradiation at or near full power. After the necessary irradiation period, the targets are harvested by raising the target basket from the core with the drive mechanism. The target basket is initially raised to a dwell position in the guide tube extension below the RMD but out of the reactor core (out of the neutron flux) to allow short-lived activation products to decay. The dwell period is determined based on the isotope being irradiated but cannot be less than two hours due to procedural and associated dwell time requirements. Once the irradiated targets have completed the dwell period the targets are returned to the home position in the TEL. They are then transferred out of the basket to the TAL and then to the flask loader and finally into the shipping flask using both hydraulic and pneumatic systems.

The TDS will operate based on the need to produce medical isotopes with the reactor operating at high power. The target strings will reside in the core for durations up to approximately one week before being harvested and replaced. The time to harvest is variable depending on the isotope and required time that the targets must sit in a dwell position outside of the reactor flux. The reactivity worth of each target string is approximately 0.062 mk for an all-molybdenum string or less, depending on the target string isotope mix (Reference [1], [2]), which corresponds to approximately 1% average liquid zone controller level. The reactivity effects from associated seeding and harvesting of Mo-99 were confirmed acceptable during commissioning of the TDS during reactor start-up Phase 4A and 4B, Reference [5], as well as commissioning at high power Phase 4C, Reference [6].

A more detailed description of the TDS seeding, harvesting, flask process, and transport can be found in Reference [1].

2.2 Target Capsule Design Features

The following description is obtained from Reference [7]. The target capsule is a streamlined container designed to operate within the TDS to allow the transport of a defined quantity of material for irradiation inside the TEL to produce the required isotopes. Target capsules are constructed of Zirconium with welded end caps and an aerodynamic shape to maximize flow performance through the transfer tubing. The general dimensions and overview of the target capsules is shown in Figure 2. The general dimensions are consistent for all isotopes irradiated. Bulges added to each end of the target capsules increase the cross-sectional area, improving the propulsion characteristic and reduce the contact area responsible for generating friction as indicated in Figure 3. The target capsules are helium filled, and leak tested prior to being shipped to site for isotope production through irradiation. Joints, ends and the tubular section are designed to not loosen, stretch, or jam due to internal system pressures, forces encountered during transfer and planned impacts.

[1] The string of 8 target capsules is located approximately between rows M and N, columns 5 and 6 for TELs 1 and 3, and columns 19 and 20 for TELs 2 and 4

The target capsules for production of Mo-99 contain a series of natural molybdenum washers secured by a molybdenum pin encased in a Zirconium alloy (Zircaloy-4). The design for the target capsules to produce Lu-177 and Y-90 contain both molybdenum metal and zirconium as a ballast material to ensure weight requirements are met to properly function with the existing TDS.

Target capsules within the system are subject to travel through tubes with multiple bends (up to 90°) and vertical elevations. The target capsule design emphasizes the reliance on aerodynamic and hydrodynamic principles to achieve adequate propulsion and to optimize vertical travel (during harvesting) to overcome the gravitational forces. The bulges as seen in Figure 3 improve the ability of the Target Capsule to navigate bends in the flight tubes as illustrated in Figure 4. During corner navigation of a R6.00", 90° bend, interference can be seen from the simple cylinder.

Each target design has different thermal characteristics due to the nature of the isotope being irradiated and its unique features. Each capsule will produce heat energy during irradiation and will undergo a steady and stable boiling heat transfer to the surrounding moderator water. The added heat to the moderator for Mo-99 production with all sites seeded is in the range of $1.4x10^{-4}$ of the heat to the moderator due to thermalization of neutrons to sustain the fission reaction, Reference [1]. The target capsule is held in the dwell position in the guide tube extension until the neutron and gamma heating is reduced to < 0.2% of that present during irradiation, at which point the heating is dominated by decay heat.

2.3 Planned Design Changes for Future TDS

As part of the planning and design of the new TDS, there are three design changes accompanied by minor design enhancements which are being implemented primarily for interferences and obsolescence. While, improvements are part of any new design, these changes do not introduce any new failure modes or change the assumptions or factors used in the development of the Nuclear Safety Analysis both deterministic and probabilistic. A summary of the planned changes is provided with a rationale of impact on the completed analyses for the current TDS design.

2.3.1 Bolted Joint and Seismic Brace

The TDS airlock platform and seismic braces have a slightly different design. During the supply and installation of Unit 2 airlock platform and seismic braces, it was identified that some of the connections involved using bolts into threaded holes. While it was shown that this was acceptable from a strength and seismic perspective, the second TDS will utilize bolt and nut connections where applicable. While changing the pin connections on the West seismic braces at platform side, the design was modified to accommodate a design which would be more suitable for installation and fit-up at site.

These changes remain in compliance with the design requirements and comply with CSA S16-14, Design of Steel Structures including connection design requirement and CSA N291-19, Requirements for Nuclear Safety-Related Structures. These changes do not impact on the operations or maintenance of the TDS and are consistent with design requirements. As such they do not impact on the overall assumptions or analysis completed in support of the Nuclear Safety Deterministic or Probabilistic analyses and assessments. However, it should be noted

that the TDS has been identified as part of the scope for the update of the Seismic Probabilistic Safety Assessment (PSA).

2.3.2 Vertical Alignment

Due to differences in the location of the Reactivity Mechanism Decks (RMDs) on all units, it is necessary to measure and compensate for small elevation differences in some of the support surfaces of the frame assembly. This will allow the flight tubes and shielding to remain in the same location which limits the changes to the rest of the transfer system and associated piping.

The change does not impact on the operations or maintenance of the TDS and is consistent with design requirements. The modification is made to ensure that changes to other operational aspects of the system remain unchanged. The change does not impact on the overall assumptions or analysis completed in support of the Nuclear Safety Deterministic or Probabilistic analyses and assessments

2.3.3 Target Elevator Cladding

Target Elevator Cladding is changed to a stainless-steel inner sleeve to isolate all tungsten from potentially wearing components. The change in the target elevator cladding is at the top of the elevator and does not impact on the operation of the reactor in any way.

The change does not impact on the operations or maintenance of the TDS and is consistent with design requirements. Further, the change is in a location that does not impact on reactor operation as it is at the top of the elevator and not part of the devices explicitly modelled as part of the TDS installation in any of the analyses. Therefore, the change does not impact the overall assumptions or analysis completed in support of the Nuclear Safety Deterministic or Probabilistic analyses and assessments.

2.4 Other Enhancements

These changes do not impact on the operations or maintenance of the TDS and are consistent with design requirements. These are in support of personnel safety, access control, easier installation of the TDS, and easier maintenance on other station equipment. None of theses changes impact on the overall assumptions or analysis completed in support of the Nuclear Safety Deterministic or Probabilistic analyses and assessments. These changes are noted as follows:

- Target Transfer Deck Plate Optimization - The design has been changed to a split plate design that will allow for the installation and removal without affecting target transfer assembly components.

- Contaminated Exhaust Ducting – The Contaminated Exhaust System is modified to avoid a positioner interference while allowing the TDS to vent to this station system.

- Stairs and Handrails – The stairs and handrails are different to accommodate the presence of Cobalt-60 related components in the same physical location. Also, an additional barrier is introduced on a hoist way gate.

- Obsolescence of Electrical Components - Many electrical parts were replaced due to obsolescence. The new parts are similar form, fit and function and will not impact other aspects of the system design including software.

- Shut-off Rod Assembly (SAs) - 3-31810-SA2, 7, 16, 17, 28 permanent rotations are being considered to facilitate maintenance of these SAs. These rotations could impact the TDS piping geometry.

- An electrical junction box will be added to the End Sheild Cooling System that will facilitate installation of TDS. This change has no connection to the TDS.

The remainder of the changes are at a lower level of detail, none of which impact on operations of the TDS. Different components installed due to obsolescence are being procured following appropriate engineering processes and are consistent with design requirements. None of the planned changes impact on the overall assumptions or analysis completed in support of the Nuclear Safety Deterministic or Probabilistic analyses and assessments. All changes will be managed in accordance with the Engineering Change Control Process, N-PROC-MP-0090, with all the necessary provisions to ensure that all aspects of safety and regulatory requirements are considered accordingly.

3.0 OBJECTIVES

The objective of this summary is to review essential documentation to confirm that the installation of additional TDSs on other DNGS units is acceptable and does not impact the current safety basis. As the safety analysis and assessments are conducted based on a single unit, the general arrangement does not cater to individual unit designs, rather the generic unit. From the perspective of safety significant work completed for the TDS installation the following reports and assessments will be included in this review:

- Integrated Nuclear Safety and Operational Assessment of the Target Delivery System in Darlington, Reference [1].

- Nuclear Safety Assessment for the Production of Yttrium-90 (Y-90) and Lutetium-177 (Lu-177) at Darlington Nuclear Generating Station [2].

- Event Identification and Classification Report, Reference [10].

- Assessment of Target Delivery System for Molybdenum Irradiation on the Darlington Internal and External Hazard Screening Assessment, Reference [12].

- Assessment of Target Delivery System for Molybdenum on the Darlington Probabilistic Safety Assessment (PSA), Reference [13].

- Operational Assessment of the TDS Installation in Darlington, Reference [14][15].

- Cobalt Adjuster and Molybdenum Target Delivery System Interaction, Reference [17].

The intent is not to revisit each of the subject reports and references, as the focus is on the general applicability of the analysis to multiple units.

4.0 EVENT IDENTIFICATION AND CLASSIFICATION

The process of installation and operation of the TDS at Darlington necessitated a detailed review of nuclear safety initiating events (IEs). The scope included both identification and classification of new IEs and impact on IE categories covered in the Current Safety Report Part 3, Accident Analysis, Reference [18]. The scope included both the installation and operation of the TDS and associated interactions with other plant systems, structures and components.

The TDS FMEA report (Reference [3]) is based on a functional process analysis of the equipment which addresses failure modes related to the processes involved in the seeding, irradiation, and harvesting of the product isotopes. The approach utilizes Severity Classification to assess the worst-case effect of a failure regarding its Nuclear Safety, System Functionality and Design Intent, Employee Safety, Economic Impact, and Environmental Impact. As the overall process is completed on a single unit, the FMEA is applicable to each individual unit at DNGS where a TDS is installed.

The assessment completed [10] identified eleven new initiating events which are detailed along with their associated frequencies which were subsequently updated as a result of introducing different isotopes [2] in Table 1. Of the eleven new initiating events, all are specific to unit operations required to fulfill the design intent of the TDS. As the assessment was done with a generic unit, the events are applicable to all units with a TDS installed.

In terms of event classification of IEs [11], the following are the associated frequency limits.

• Abnormal Operation Occurrence (AOO): frequency ≥ 10-2 occurrences per year (occ/yr)

• Design Basis Accident (DBA): frequency <10-2 occ/yr and ≥ 10-5 occ/yr

• Beyond Design Basis Accident (BDBA): frequency < 10-5 occ/yr

Normally event identification and classification are performed for plant states such as normal operation, shutdown, etc. The conditions that are pertinent for the safety analysis are taken from those which are likely during the plant operating state. The approach taken needs to account for the potential for numerous normal operating conditions which may be relevant to the analysis.

Further, as previously identified, the normal process of seeding and harvesting results in an operating reactivity effect or perturbation in the reactor core in which the operation occurs. Harvesting introduces positive reactivity due to removal of the target capsules. It is possible that an event occurs during harvesting where additional reactivity would be introduced during the target string withdrawal. From a safety analysis perspective, the rate of reactivity insertion in terms of assessing the impact on operation and accident analysis is most important. In general, the effect of introducing the new IEs in accident space would require the accident

categorization to be assessed based on the concurrent event frequencies. Thus, a current AOO may become a DBA based on the IE frequency.

In addition, the introduction of other target isotopes has been completed and detailed in Reference [2] which identified that some of the event frequencies change as a result of more frequent seed and harvest activities. The conclusion remained that the impact of having a TDS with multiple isotopes with differing irradiation durations and seed and harvest frequencies did not have any impact on overall plant risk.

While concurrent event probabilities and irradiation of multiple isotopes have the potential to change risk factors, they remain specific to a single operating unit. This is a correct and customary practice as the operation of any unit with a TDS is independent of other operating units.

A summary of the Darlington Safety Report – Part 3 (Reference [18]) appendices associated with relevant event categories is contained Table 2. Based on the review completed, the assessment of IEs and the impact on safety analysis of multiple TDSs do not change the conclusions of Reference [2] and [10]. PSA elements will be updated as part of the ongoing update strategy, however it is recognized that the impact on PSA and therefore severe core damage frequency (SCDF) and large release frequency (LRF) is insignificant.

5.0 INTERNAL AND EXTERNAL HAZARD SCREENING

The completed hazard assessment [12] focused on the impact of installation and operation of the TDS equipment on the Darlington hazard screening analysis (Reference [19]) and the identification of any new initiating events that needed to be added to the PSA. Subsequent assessment [2] for irradiation of new isotopes resulted in some changes in classification of two of the new IEs as a result of the more frequent harvest and seed intervals that could occur due to different irradiation requirement. There were no additional IEs identified and the original conclusions remain valid.

5.1 Internal Hazards

The focus of the screening assessment was only those items required to establish the safety analysis basis and to provide support for operations. This resulted in specific exclusions from the assessment that remain valid based on the installation of a TDS on multiple units and multiple approved isotopes. The specific exclusions were covered by other areas of the TDS project and are summarily addressed as part of the overall PSA update strategy where qualitative assessments are utilized to disposition the impact of the TDS on the various PSA models. In the case of the Darlington Level 1 At-Power, Internal Events, Unit 2 is the reference unit for the internal events PSA model. Therefore, the modelling implications of the TDS will be assumed for the reference unit regardless of where the TDS is installed.

Table 3 identifies the hazards identified during the screening process. The initial 11 hazards were taken from the IEs developed in Reference [10]. In addition to the IEs, an additional 21 hazards were identified during reviews of the FMEA (Reference [3]) as well as information relating to the transfer flask, craning and transportation logistics.

The combined hazards include not only event-based hazards but also radiation hazards, which will only impact Nuclear Safety under specific conditions. Namely, habitability of the Main and Secondary Control Room/Areas, access to critical staffed areas (e.g. EPS building) and areas of the station that must remain accessible for operator field actions.

Most of the radiation hazards identified for the TDS primarily impact Rooms 301 and 302. The installed fixed area gamma monitor installed would ensure that if staff needed to be present the dose received would be less than 1 Rem, ensuring worker safety. Access to these areas would occur after decay of the hazard or a change in the location of the hazard, potentially back to an in-core position. A similar arrangement would be implemented on any unit where a TDS is installed to protect staff from radiation dose.

Further, Table 3 provides an event classification and all of the identified hazards, with the exception of two, are specific to the unit in which the TDS is installed. The two station related hazards are related to transportation and would be equally applicable to other units where a TDS is installed.

5.2 External Hazards

The list of external hazards from Reference [20] was reviewed for those hazards that may be impacted by the TDS with the full listing of external hazards and the results of the pre-screening available in Appendix A of Reference [12]. The TDS installation was determined to potentially impact the assessment of seismic and high wind hazards. These hazards were assessed qualitatively for impact of the TDS on the PSAs in Reference [13].

Further, the qualitative assessment did not identify any aspects of the TDS that could contribute to the evolution and consequences of a common mode failure. As such the introduction of TDSs on multiple units is equally inconsequential.

6.0 PROBABILISTIC SAFETY ASSESSMENT

A qualitative review of the impact of the TDS and production of Mo-99 isotopes in the target capsules on the Darlington PSAs was completed. The goal of the qualitative analysis was to determine the impacts of the TDS on SCDF and LRF. The assessment reviewed each task of each PSA element. As part of this review, limited quantitative analysis was done, as described further below and in detail in Reference [13]. Noteworthy, SCDF and LRF were not re-quantified for any PSA element. The required model changes are described, and this information can inform any future update of the PSAs. Full details of the assessment of the impact of the TDS on the Darlington probabilistic safety assessments can be found in Reference [1].

The Darlington PSA consists of the following elements:

- Darlington Level 1 At-Power Internal Events PSA
- Darlington Level 2 At-Power Internal Events PSA
- Darlington Level 1 and 2 Outage Internal Events PSA

- Darlington Internal Flood PSA
- Darlington High Wind PSA
- Darlington Internal Fire PSA
- Darlington Seismic PSA
- Darlington Non-Reactor Source PSA[2]

The overall impacts from the TDS on the quantification of SCDF and LRF in the various PSA elements are low. This is the expected result as the TDS has very few interfaces with other station systems, consists of a small number of components, and complies with OPG design, manufacture, and installation standards. Based on the findings of Reference [13], the addition of the TDS does not constitute a “major change” and PSA model updating outside of the normal five-year PSA update cycle is not warranted.

6.1 Level 1 At-Power Internal Events

The Level 1 at-power Internal Events PSA (referred to as Level 1 at-power PSA) is an assessment of at-power accident sequences leading to reactor fuel damage arising from failures within the plant. Introduction of the TDS was assessed based on the potential to increase the frequency of some of the initiating events modelled in the Level 1 at-power PRA. These changes are minor, and the overall impact on the SCDF quantified in the Level 1 at-power PSA is low. It should be noted that the Level 1 at-power PSA default unit is Unit 2, for which required PSA updates are currently being completed.

The initiating events considered were primarily those failures that could lead directly, or in combination with other failures, to damage to fuel in the reactor. New hazards associated with the TDS were screened and no new internal initiating events were identified in Reference [12]. The hazard assessment in Reference [12], identified that the following existing initiating events bounded the consequences of the new hazards arising from the TDS:

- Forced shutdown
- Loss of moderator cooling
- Loss of regulation

In addition to the potential increase in the probability of interfacing system failure, there is a potential for the TDS to increase the frequency of the initiating events representing failure of these interfacing systems. The potential for a small increase in frequency to be observed over time with this assessed in Reference [13]:

- Forced Shutdown: Small increase to event frequency, negligible impact on SCDF.

[2] This is not affected by TDS installation and was not considered in TDS reference analysis or assessments

• Loss of Moderator Cooling: Low increase to event frequency, potential for low impact on SCDF.

• Loss of Regulation: Small increase to event frequency, negligible impact on SCDF.

• Loss of Class III: Small increase to event frequency, negligible impact on SCDF.

• Loss of Class II: Negligible impact on event frequency or SCDF.

• Loss of Class I: Negligible impact on event frequency or SCDF.

• Total Loss of Instrument Air: Small increase to event frequency, negligible impact on SCDF.

The assessments are on a unit basis and therefore apply equally to any new TDS installed on another unit, provided the installation is consistent with the original design and assumptions. Details of design changes planned for the next TDS are included in Section 2.3

6.1.1 Moderator Impacts

In most of the Level 1 at-power PSA sequences involving limited fuel damage, the moderator is credited as the ultimate heat sink if the steam generator and SDC heat sinks fail. The TDS has a direct interface with the moderator, as the target basket with the target capsules is in the moderator in the modified guide tube. There is a potential of debris entering the moderator pump suction if the target were to break apart in the basket. The probability of loss of the moderator heat sink due to calandria outlet blockage in the post-initiating event mission is a highly unlikely event, bounded by consequences of in-core Loss of Coolant Accident (LOCA). The additional impact of damaged targets in this scenario is insignificant, no new moderator blockage events need to be added to the moderator fault tree, and the existing event therefore does not need to be re-quantified.

Progression of the accident scenarios and consequences are based on the single reference unit and are independent as there is no linkage of these systems between units. Installing a TDS on multiple units has no impact or implications for the assessment.

6.1.2 Loss of Regulation Impacts

The TDS adds a small source of reactivity to the reactor core; each string is assessed to have a reactivity worth of ~-0.062 mk, for a total reactivity worth (all in-core components) of -0.247 mk when all 4 in-core locations are seeded with molybdenum targets. Harvesting has the opposite effect, adding positive reactivity as a result of absorber removal. The reactivity worth of the TDS components is small compared to the negative reactivity inserted from other control and safety systems.

The operational assessment [14] shows that the Reactor Regulating System (RRS) Setback ability would not be affected by the approximately 1% liquid zone controller level change associated with TDS operation. Based on a 60 second withdrawal time for a target string, the reactivity change associated with target removal is approximately 0.001 mk/s. For context the RRS bulk control can change power by 0.115 mk/s based on current bulk gain values.

The assessment in Reference [14] also confirmed that Stepback was effective if both RRS and Setback fail. The only other failure mode to be added to the fault tree models is related to transients (e.g., Setback or Stepback) when a target is being harvested (travelling from In-Core position to DWELL position).

Progression of the accident scenarios and consequences are based on the single reference unit and are independent as there is no linkage of these systems between units. Installing a TDS on multiple units has no impact or implications for the assessment.

6.2 Level 2 At-Power Internal Events

The Level 2 at-power internal events PSA is an assessment of at-power accident sequences leading to external plant releases of radionuclides arising from failures within the plant, assessed in Reference [13]. The Level 2 PSA is quantified by building on the results of the Level 1 At-Power PSA, as the Level 1 fuel damage categories are inputs into the plant damage states (PDS) analysis. The minor changes in the quantification of SCDF associated with the installation of the TDS on Unit 2 as discussed above resulted in very minor changes in the quantification of the release categories. Like the Level 1 at-power PSA, the impact of the changes was anticipated to be very low and did not necessitate any immediate action as the PSA will be updated according to the normal planned frequency.

The PDSs form the interface from the Fuel Damage Categories (FDCs) that are the end states of the Level 1 event tree analysis and various possible states of the plant in terms of degree of core damage and availability of reactor and containment systems to mitigate the challenges arising from accident progression. Representative PDS sequences are then linked to a Containment Event Tree (CET). The CETs, model the challenges to containment integrity that can arise due to the subsequent accident progression and estimate the frequency and magnitude of any significant releases of radioactivity to the environment. Based on the review of the Level 1 PSA, the TDS installed on any specific unit results in only minor changes to the FDC2 frequency, and negligible impact to the FDC1 frequency, and does not require any changes to the plant damage state definitions. FDC2 is impacted by Deuterium build up in the guide tube extensions, which is mitigated with the introduction of the Deuterium Recombination System (DRS). The largest contribution to FDC1 is associated with human error of simultaneous harvesting of two strings from two separate sites. The quantification of the human error event is considered very conservative, and thus the impact on FDC1 will be very small, and the impact on SCDF (FDC1 + FDC2) will be negligible.

For CET analysis, the in-core components of the TDS are of primary importance, as they can affect the accident dynamics in a severe accident scenario due to mixing with corium. The introduction of a TDS on multiple units will not impact the CET, provided no new materials are introduced beyond the current in-core components and associated isotopes. None of the planned upgrades or minor changes for the new TDS involve in-core components. Therefore, from a CET perspective, as there are no new materials there is no impact, beyond that of the original TDS and isotope targets. Consistent with the original TDS, the branch point probabilities associated with the accident pathways as captured in the CET remain unchanged. No new phenomenology is necessary to be added to the CET as a result of the failure of the TDS, regardless of unit of installation.

From the perspective of source term and impact, the combined addition of ~14 kg of Zircalloy, small amounts of molybdenum, Ytterbium, and Yttria AluminoSilicate (YAS) glass from the TDS components and target capsules in a severe accident core melt-down scenario is insignificant when compared to the Darlington core mass (194 Mg). Given that neither the magnitude or timing of releases of Cs-137 or I-131 will be impacted directly by the TDS, it can be concluded that the TDS regardless of which unit it is installed in will continue to have no impact on the release categories assigned to different PDS. Overall, the impact of TDS being added to any unit has negligible impact on the severe accidents source term.

6.3 Level 1 and 2 Outage Internal Events

The Level 1 Outage internal events PSA assesses outage accident sequences leading to reactor fuel damage arising from failures within the plant (e.g., equipment malfunctions, operator errors). The outage PSA scope is for the reactor in a guaranteed shutdown state (GSS) for a minimum of 24 hours with the HTS cold. The Darlington Level 2 Outage PSA is a limited scope consequence assessment for select internal events that establishes a technical basis for arguing that the consequences arising from IEs during outage are bounded by those encountered at power and documented in the Level 2 At-Power PSA. Consistent with current TDS assumptions any other unit with a TDS installed will assume that the targets are withdrawn from the core during a planned outage.

The currently installed TDS may potentially increase the frequency of some of the initiating events modelled in the Level 1 Outage internal events PSA and will require revision of the quantification of some of the failure probabilities in instrument air model when the model is being updated according to the required frequency. The changes associated with the TDS will be incorporated in the next update, however, none of the planned design changes should impact on the models beyond the currently installed TDS design. No impacts were identified in the Level 2 Outage PSA assessment related to the TDS, and the limited design changes should not impact these conclusions.

6.4 Other PSAs

The following PSA assessments and associated models were identified as not being impacted by the installation of the TDS. It follows that introduction of a TDS to other units will not change this conclusion.

6.4.1 Internal Flood PSA

The Internal Flood PSA is an assessment of the potential for fuel damage and potential radionuclide release resulting from an internal flooding event and subsequent failure of fuel cooling/containment functions. Based on the results of the qualitative assessment, no impact on the Internal Flood PSA analysis is identified because of the addition of the TDS, which can be inferred as being on multiple units. There would be a low to negligible impact on the quantification of SCDF or estimate of LRF in Internal Flood PSA due to the TDS modifications and associated changes in the PSA model.

6.4.2 High Wind PSA

The High Wind PSA is an assessment of the potential for fuel damage and potential radionuclide release resulting from a high wind event and subsequent failure of fuel cooling/containment functions. Based on the results of the qualitative assessments, the addition of the containment extension piping associated with the TDS results in a modification of existing model representing the reactivity mechanism deck; however, this change does not impact the quantification of the missile fragilities for this model. Any impact of quantification of the SCDF in the High Wind PSA due to addition of the TDS is negligible: Which then supports no impact on the estimate of LRF because of the TDS installation and associated changes in the PSA model.

6.4.3 Internal Fire PSA

The TDS has been reviewed against all major elements of the Internal Fire PSA to assess the potential impacts. Most elements have been found to be unaffected by the installation. Physical Analysis Units (PAUs) are used to evaluate the impacts of fires on the plant and are related to plant partitioning. Plant partitioning forms the basis for the development of discrete PAUs impacted by fires inside the plant. The identified impacts related to the TDS are limited to a small set of new fire scenarios for fixed ignition sources in two PAUs, modification to the ignition frequencies of transient fire scenarios in two PAUs, and minor changes to the mitigating system fault tree modelling in the fire-induced risk model increase in fire risk from these changes. The associated review of PAUs transient weighting factors only impacted Rm 302 and Rm 304. The assessment conservatively estimated the impact to be only 0.08% of the DNGS Fire SCDF and 0.09% of the LRF. This impact would be applicable to each unit with a TDS installed, but overall, the impact remains negligible.

The potential for deuterium fires has been evaluated and does not result in fire scenarios that could credibly impact the ability to shut down the reactor or impact post-shutdown mitigating functions. The impact on SCDF in Internal Fire PSA will be negligible.

6.4.4 Seismic PSA

The TDS has been reviewed against all major elements of the Seismic PSA to assess the potential impacts in Reference [13][3]. Assumptions were made regarding the seismic capacity of the installed TDS based on OPG seismic design requirements and form the basis for the conclusions drawn in this assessment. While the TDS installation was only assumed to include Unit 2, differences in design between the Darlington units were not considered. However, while the qualitative assessment concluded that the impact on SCDF, LRF and containment robustness was negligible, meeting specific assumptions as the seismic evaluations of the final system design were not complete; it was deemed a specific Alternate Unit analysis would be unaffected should TDS installation occur in a different unit. While this implies that the differences among the units are not significant enough to warrant treating them as different unit installations, it does not explicitly account for the impact of multiple unit installations.

[3] The DNGS seismic hazard characterization (PSHA, UHRS) have changed for the 2020 and 2025 Seismic PSA updates. The changes may require a re-evaluation of TDS installation on seismic PSA results

The qualitative assessment concluded that the TDS does not impact the results, conclusions, or insights of Seismic PSA. The TDS installation completed on Unit 2 will be evaluated as part of the DARA-Seismic update, however, the assessment conclusions should remain valid and be unaffected by the addition of TDSs on other units.

7.0 NUCLEAR SAFETY ASSESSMENTS

7.1 Overview of Analyses Impacts

In general, event identification and classification are performed for plant operating states such as normal operation, shutdown, etc. The conditions that are pertinent for the safety analysis are taken from those which are likely during the plant operating state. The approach takes into account the potential for numerous normal operating conditions which may be relevant to the analysis. Additionally, the impact of the installation and operation of the TDS on the currently identified initiating events was determined according to Reference [1].

As shown in Table 1, eleven (11) new IEs were identified based on estimating their frequencies. Following a reassessment as part of introducing new isotopes for irradiation in the TDS four IEs are classified as AOOs, and seven IEs as DBAs. The events of Table 1 and their associated appendices in the Safety Report Part 3 [18] are discussed in detail in Reference [1] and [2].

Based on the identified new initiating events, their impacts, the location and type of initiating event are identified for each event. The impacted analyses include:

• Out of core events

• Loss of Reactor Power Regulation

• Loss of Moderator Cooling

• Chemistry Impacts

• Operational dose

• Potential for deflagration during normal operation

• Operational Analyses

The overall impact of installing and operating a TDS is well understood and documented. The impact on safety analyses has been assessed and while differences between operating units is known to exist, in general safety analysis is assessed and completed based on a generic unit. At Darlington, both the introduction of the TDS and production of Cobalt-60 have been assessed based on the known design and making appropriate assumptions. As a result, the TDS can be installed and operated on any unit, including those with Cobalt Adjuster Absorbers used in the production of Cobalt-60.

7.2 Detailed Review of Safety Analysis

In the following sections, each Appendix from the Darlington Safety Analysis Report Part 3 [18] is revisited along with the interactions associated with the introduction of Cobalt Adjuster rods previously assessed in Reference [17]. The combined effect of the TDS and the Cobalt adjusters were assessed with respect to the evolution and consequences of the events analyzed in each Safety Report Appendix. The primary initial conditions, such as channel and bundle power limits that serve as input to various safety analyses, were demonstrated to remain unchanged as a result of fuel management practices that will account for the presence of both Cobalt adjusters alone or in combination with the TDS. The introduction of TDS components into the reactor along with isotope target capsules has a very small impact with the results documented in References [1], [2], [14] and [17].

The assessments are based on a review of the limiting events for each accident category and the key parameters and phenomena important to safety to identify whether there is any potential impact of the TDS on event progression. As well considering the consequence of event progression on the TDS, and the combined impact with the introduction of Cobalt Adjuster rods in operating units. The parameters that are key in determining the outcome of the design basis accidents are given in Table 1-13 of Section 1 of the Darlington Safety Report Part 3 [18] and reproduced in this document as Table 4. Existing SOE limits and conditions remain unchanged following the installation of the TDS.

The TDS interfaces directly with the moderator and forms part of the containment boundary, necessitating reviews to assess the impact on accidents involving releases from the calandria. It also interfaces with reactor core in the areas of the modified AA ports used for target transfer and irradiation, necessitating reviews to assess the impact on accidents affected by changing fluxes and powers.

The following sections provide very brief descriptions of the Safety Report accidents and the rationale. In general, the overall impact of the TDS, target capsules and Cobalt Adjuster Absorber rods is deemed to be none or negligible on the submitted Safety Analysis and Analysis of Record.

7.3 Appendix 1 – Fuel Handling System Failures

Fuel handling accidents are those that can affect fuel bundles in some phase of the fuelling and storage process. The detailed analyses are documented in Appendix 1 of the Safety Report, Part 3 [18] except for fuelling machine induced loss of coolant accidents, which are covered in Appendix 4.7 Fuelling Machine Induced LOCA. The fuel handling accidents cover a set of accidents in which fuel failures and subsequent fission product release could potentially occur due to either physical damage or overheating.

The analysis of fuel handling events covers the following scenarios:

• Fuelling Machine Incidents Off-Reactor

• Fuelling Machine Incidents On-Reactor

• Fuelling Handling Incidents at the Irradiated Fuel Port (IFP)

• Incidents in the Irradiated Fuel Bay (IFB)

The TDS does not require operation of the fuel handling system and is not operated during fuelling operations. The TDS components have no interface with the irradiated fuel bay (IFB), the irradiated fuel port (IFP) or the Fuelling Machine (FM); hence, there is no impact of the TDS on the progressions or consequences of fuel handling system failures. Similarly, there is no impact on fuel handling accidents on TDS operation. Subsequently the introduction of new isotopes has no impact on fuel handling accidents.

Further, Reference [17] concludes the design basis accidents analyzed in Appendix 1 of the Safety Report will not be affected by the presence and operation of the TDS. The only impact would be from the Cobalt adjusters. Further, if both the TDS and Cobalt Adjusters are installed on the same unit, the impact would be limited to the Cobalt Adjuster Change. Further details of these events are discussed in References [14] and [21].

7.4 Appendix 2 – Electrical System Failures

Analysis in this Safety Report Appendix covers failures of electrical power systems that are important to reactor safety. The objective is to demonstrate that the reactor can be shut down prior to any fuel failures occurring and that effective long-term heat sinks remain available to ensure the required dose limits are met.

The analysis presented in Appendix 2 of the Safety Report includes the following scenarios:

• Loss of Unit Class IV Power

• Single Heat Transport Pump Trips

• Loss of Unit Class IV and Unit Class III Power

• Loss of Unit Class II Power

• Loss of Unit Class I Power

• Loss of Unit Emergency Power System (EPS) Power

• Loss of Common Electrical Power

• Heat Transport Pump Seizure

In all the associated scenarios, the TDS system was found to have no impact on analysis or no impact on long term plant safety.

When considering the temporal and spatial separation in routine operations, the effects of the TDS and the Cobalt adjusters on design basis accidents is primarily due to their effect on the core physics as determined in the corresponding reactor physics assessments, fuelling studies and supporting operational assessments (References [14], [15], [22], [23] and [24]). Local effects on individual channels in the core, small variations in the axial flux distribution in channels which are near each of the neutron absorbing devices (target capsules and Cobalt

adjusters) may change the axial distribution or power profile in those channels. The changes associated with each system have been accounted for in terms of accident analysis and compliance parameters. There will be no discernible combined effect of the two systems on the axial power distribution of the impacted fuel channels. In addition, the comparison of average core conditions with and without the TDS, and/or with the Cobalt adjusters demonstrates that the installation of these two new neutron absorbers has no effect on the core average thermal-hydraulic parameters.

Therefore, the design basis accidents analyzed in Appendix 2 of the Safety Report will not be affected by the presence of, only the TDS with any isotope target capsule design, only the Cobalt adjusters, or if both systems are installed in a Darlington unit. Due to the spatial separation of the two systems, there are no further effects of the combination of the two systems that could be impacted as a result of electrical failures. Further details of these events are discussed in References [1] and [21]. The main conclusion being that a TDS, Cobalt Adjusters or both can exist on any unit with no impact.

7.5 Appendix 3 – Control Failures

Failures of individual control functions can occur due to equipment failures, program malfunctions or digital computer control system failures. The loss of regulation events considered include loss of reactivity control, loss of reactor power regulation, and failures of the various digitally controlled process control functions. The key parameters important in determining the systems response are provided in Table 4 - Important Parameters for Accidents (Table 1-13 of [18]).

The TDS has no direct impact on the global thermal hydraulic characteristics of the primary heat transport system. The flow resistance and fuel heat transfer areas are unchanged by the new system (Reference [1]). The TDS will result in a small variation in neutron flux distribution near target elevators, which may marginally change the axial power distribution and Critical Channel Power (CCP). CCP assessments in channels near the location of in-core TDS components were performed using nominal steady state flux shapes corresponding to operation prior to and after installation and operation of the TDS system. The largest (negative) impact on the maximum bundle power is in channels adjacent to the targets (M20, M05, etc.). The results of the assessment are shown in Table 7. The inclusion of F21 and V15 in the assessment is because these channels experience the earliest onset of dryout in aged reactor analyses for SBLOCA and LOF. It is noted that the CCP with No TDS is marginally lower but essentially unaffected. This conclusion remains valid for all types of isotopes used in the TDS.

Small variations in the distribution of power to coolant in the core may have local effects but will have no significant effect on the global thermal-hydraulic response of the primary heat transport system during steady state and accident conditions. This was demonstrated in the thermal-hydraulic assessment, which showed negligible impact on the system parameters (Reference [1]).

Of all the important parameters listed in Table 4, the conclusion of the assessments was that the current TDS has no impact or very limited impact which was assessed in terms of the CCP and in the next section on NOP. As a result of the minimal impact on the key parameters, none of the events associated with control failures were impacted by installation of the TDS.

With respect to cobalt adjusters, they are designed to have very similar reactivity worth to the current stainless steel. Therefore, reactor control during such events will be very similar and would have negligible effect on the margin to derived acceptance criteria as determined in Reference [17].

Therefore, the design basis accidents analyzed in Appendix 3 of the Safety Report, Part 3 [18] will not be affected by the presence of only the TDS, only the Cobalt adjusters, or if both of the systems are installed in a Darlington unit. As a result of the spatial separation of the two systems, there are no further effects of the combination of the two systems. The implicit assumption being that normal fuel management practices are maintained to ensure compliance with all key safety analysis parameters that will ensure the mitigation of the effects of the presence of each system individually. Further details of these events are discussed in References [1], [2] and [21].

7.5.1 Assessment of Impact on NOP Analysis

The Event Identification and Classification, Reference [10], identified additional flux shapes that could result either from normal operation (i.e., harvesting) or through new initiating events (i.e., targets stuck partially in core).

In support of the Slow Loss of Regulation (SLOR) impact assessment, a representative subset of flux shapes was required for evaluation of the sensitivity of the NOP Required Trip Set Point (RTSP) associated with the implementation and operation of the TDS. The flux shape categories analyzed are those that meet one or more of the following criteria:

• Flux shape category is representative of steady-state operation;

• Flux shape category that produces the limiting NOP RTSP for either shutdown system for the Normal or Abnormal Handswitch Position (HSP) in the current NOP licensing analysis (Reference [26]); or

• Flux shape category is representative of an SLOR initiating event, with which simultaneous occurrence of target harvesting is classified as a DBA per Reference [10] (e.g., single zone drain or single adjuster withdrawal).

To represent normal operation of the TDS, each flux shape selected per the above criteria was regenerated three times, once each from Reactor Fuelling Simulation Program (RFSP) steady states corresponding to (1) all four targets in-core, and (2) harvesting of a single target (from four target sites nominally occupied), and (3) one target harvested from three target sites nominally occupied. These are reflected as Standard TDS Configurations and are shown in Table 5. In addition, to represent non-standard operation of the TDS, the nominal steady-state flux shape was also regenerated using the RFSP steady states corresponding to a number of non-standard configurations and are shown in Table 6.

NOP analyses classify flux shapes as being either normal or abnormal based on both the calculated RTSP as well as whether an operator can detect that the reactor is in a specific core state or flux shape. The additional flux shapes for the TDS, including the non-standard flux shapes, are included in the normal category. The analysis also includes the currently

limiting abnormal flux shapes to confirm that the TDS has no impact on their calculated RTSPs.

The introduction of the TDS on any unit will not impact on any of the conclusions related to the effectiveness of NOP trip setpoints. Further, part of NOP analysis uses channel ripple (calculated channel power divided by NOP reference channel power) sets from all operating units to ensure that all units are correctly represented. Future NOP analysis may need to consider unit specific differences with unit designs being slightly different with the introduction of the TDS and Cobalt Adjusters. Given the small localized differences in the case of the TDS absorbers and the larger time dependent changes from Cobalt Adjusters, both have been confirmed to not affect the installed NOP trip setpoint, References [1], [2] and [21].

7.6 Appendix 4 – Small Break Loss of Coolant Accidents

Loss of coolant accidents are classified in terms of their initial coolant discharge rate from the piping. Small LOCAs are defined to extend from a very small leak up to a break of the largest inlet feeder pipe near the Reactor Inlet Header.

The key objective of the small break Loss of Coolant Accident (LOCA) safety analysis is to demonstrate that public dose limits are not exceeded. In and effort to simultaneously limit economic consequences demonstrating fuel and fuel channel integrity is maintained by demonstrating that fuel temperature excursions remain below fuel failure levels following the event are adopted as additional safety design criteria. In order to meet those criteria, it is sufficient to ensure that:

• Reactor power is reduced in time to prevent failure of the fuel or significant pressure tube heat-up; and

• No significant fuel temperature excursions occur thereafter by providing coolant makeup by D2O feed and or emergency coolant injection to prevent onset of steam cooling and to ensure adequate fuel heat removal throughout the event and thereafter.

Of all the important parameters listed in Table 4, the conclusion of the assessments was that the TDS has no impact or very limited impact. The negligible impact on the system parameters for the current TDS is demonstrated in the thermal-hydraulic assessment discussed in Section 7.5 and in detail in Appendix B of Reference [1]. As a result of the minimal impact on the key parameters, none of the events associated with SBLOCA were impacted by installation of the TDS. The potential minor effect impact on NOP margin to trip due the slight variation in the flux distribution in close proximity of the TDS targets (for units with TDS installed) was dispositioned, consistent with the discussion in Section 7.5.1. Small variations in the distribution of power to coolant in the core may have local effects but will have no significant effect on the bundle and channel power safety margins, or the global thermal-hydraulic response of the primary heat transport system during steady state and accident conditions.

The design of the cobalt adjusters is such that their reactivity worth at end of life (maximum 3.5 EFPY) is approximately the same as the current aged stainless steel adjusters in Darlington [21]. Similarly, the reactivity worth of the fresh cobalt adjusters is slightly higher than the fresh stainless steel adjuster worth. Channel and bundle power distributions will be

minimally affected by the design change, and the long-term power distributions can be maintained using the current fuelling practices. It was judged that the conclusion in the Safety Report for small break loss of coolant events during power maneuvering are unaffected by the implementation of cobalt adjusters.

References [1] and [21] present more detail and further discussion on the full range of small break LOCAs (in-core and out of core) and the effects that the presence of the TDS alone and the Cobalt adjusters alone will have on the evolution and consequences of such an event. As the two systems are physically separated, and the vastly different time scales of reactivity changes resulting from the two systems, their combined presence will have a negligible effect on the evolution and the consequences of a small break LOCA.

7.7 Appendix 5 – Large Break Loss of Coolant Accidents

A large break is defined as a break in a pipe that would result in an initial break discharge in excess of 2000 kg/s. These failures in large diameter pipes have a very low probability of occurrence and are analyzed to demonstrate the large capability provided by the process and special safety systems to protect the public for the entire spectrum of possible break sizes and locations. The primary objective of the large break LOCA analysis is to demonstrate that:

• The reactor shutdown capability is such that fuel channel integrity is not compromised by excessive energy deposition into the fuel due to the initial overpower transient;

• Adequate heat removal capability is maintained to ensure fuel channel integrity, which in turn ensures that the fuel remains in a coolable geometry; and

• The overall containment system is effective in limiting radiological consequences to the public.

The reactor physics assessment in support of TDS installation, contained in References [1] and [2] concludes that no material impact on reactor physics parameters will result due to the TDS installation and operation. The fuelling rates, power distribution, and RRS response are all within acceptable operational variations. Therefore, the impacts of these events on the TDS operation are judged to be negligible from a reactor physics perspective.

The TDS as well as the Cobalt adjusters would result in small variations in the neutron flux near the new systems, which may marginally change the power distribution. The reactor physics assessment showed that after the TDS installation, the coolant void reactivity will increase by 0.001 mk which is considered negligible. The other important reactor parameters listed in Table 4 important in a large break LOCA are not affected by the TDS.

One of the design objectives for the cobalt adjusters is that channel and bundle power distributions should not be significantly affected. At the beginning of the Cobalt adjuster irradiation, a slightly higher fuelling rate will be required to compensate for higher reactivity worth of Cobalt adjusters, slightly reducing in-core burnup and average exit burnup of the fuel. Overall, fuel burnup or average exit burnup will not be significantly affected by the Cobalt adjuster design as documented in Reference [17]. As such, core average exit irradiation should be insignificantly affected. Further, there were no important parameters listed in Table 4, impacted by the TDS.

These moderator system parameters are related to the required moderator subcooling to ensure PT integrity under PT ballooning contact with the CT for critical break Large LOCA. The impact of TDS is judged negligible based on:

• Moderator outlet temperature is negligibly impacted by the very small additional heat load of the new system. The heat load from the system is expected to be less than ~20-22 kW which is negligible compared to the reference moderator heat load of 142 MW used in accident analysis.

• TDS operation is expected to be associated with localized moderator boiling at the surface of the target capsules. However, the small amount of heat input would have a negligible impact on moderator subcooling, so the bubbles are extremely unlikely to migrate to neighbouring calandria tube surfaces.

• The cover-gas pressure contributes to moderator subcooling, and it is assumed to be a constant 24 kPa(g) in the analysis which can be credited during the LBLOCA as there is no large break location that could result in a threat to the cover gas piping due to pipe whip. The cover gas pressure may increase during the accident but will remain controlled by the system. There are no additional factors introduced as a result of installing the TDS. The cover gas balance lines which will ensure that the target site guide tubes remain at the cover gas pressure.

With respect to important parameters specific to shutdown systems, the TDS may result in a small variation in axial flux in channels which are near the new system, which may marginally change the axial power distribution, as previously discussed. The local margin to the NOP trip setpoint might be slightly changed but there will be no adverse impact on NOP trip coverage for Large LOCA events because the NOP trip time is based on the bulk reactor response to the event and not on localized effects. From the point of view of shutoff rod worth, the Cobalt adjusters are designed such that the impact on the effectiveness (reactivity worth) of Shutdown System one (SDS1) shutoff rods will be minimal. Large break LOCA results are more dependent upon the speed of the shutdown system response than the depth, and implementation of Cobalt adjusters would not affect the speed of the SDS1 response. After reactor shutdown, the adjusters have no direct effect on fuel cooling or refilling of the HTS, nor do they have any direct effect on establishing long term quasi-steady state conditions.

The remaining important parameters listed in Table 4, were identified as having no impact as a result of the installation of the TDS. Therefore, the TDS and Cobalt adjusters will not have any significant effect on the evolution and consequences of a large break LOCA, either individually or in combination. Part of the justification being a result of the spatial separation and vastly different time scales of reactivity change. References [1] and [21] present more detail and further discussion on the full range of large break LOCAs and the effects that the presence of the TDS and the Cobalt adjusters will have on the evolution and consequences of the event. Regardless, the conclusion remains that either or both may be installed on any unit.

7.8 Appendix 6 – LOCAs Outside Containment

Failures of HT auxiliary systems outside containment represent a class of accident also known as by-pass breaks. The potential radiological consequences following these failures occur as

tritiated D2O and radioiodines contained in these systems are released into the powerhouse and subsequently escape to the atmosphere in the form of steam or water droplets.

The TDS has no interface with the auxiliary systems, its components are physically isolated from, and do not require operation of these systems; hence there is no effect or impact of the TDS on breaks outside containment. Since the TDS has no connection to powerhouse, these events will have no effect on the TDS. The TDS and its equipment will be environmentally qualified; hence the effect of the harsh environmental conditions will not affect the system for such an event. The installation is unit specific and can reside on any unit.

The implementation of cobalt adjusters is not expected to have any effect on the consequences of LOCAs outside of containment. In-core burnup, average exit burnup and bundle and channel power distributions are not expected to change significantly through the use of Cobalt adjusters, and accordingly the initial conditions prior to a LOCA outside of containment would not differ appreciably from what was assessed in the Safety Report with the current stainless steel and Titanium adjusters. As such, the implementation of cobalt adjusters was judged to be negligible for the consequences of these events.

Therefore, the TDS and Cobalt adjusters will not have any significant effect on the evolution and consequences of a LOCA outside containment. References [1] and [21] present more detail and further discussion on the various LOCAs outside containment and the effects that the presence of the TDS and the Cobalt adjusters will have on the evolution and consequences of the event. Given there is no interaction of either the TDS including target capsules and Cobalt adjusters, either system installed independently or together will have no effect on the evolution and consequences of the LOCA outside containment events.

7.9 Appendix 7 – Feedwater System Failures

Feedwater system failures may lead to the degradation and potential loss of the steam generators as heat sinks to the HTS. Breaks in feedwater system piping, or failure of the feedwater pumps or control valves, can result in either the reduction or loss of feedwater to the steam generators, thereby reducing their heat removal capability. The effectiveness of the secondary side system as a heat sink is dependent upon the liquid inventory remaining in the steam generators following the reactor shut down relative to the energy generation rate in the HT system.

The TDS and its components have no interface with the feedwater system. While the feedwater system is required for the plant to operate at higher powers, none of the important parameters listed in Table 4 associated with feedwater failures are impacted by the TDS. Given there is no impact on the key parameters it follows that the TDS will not impact on the conclusions of the Safety Analysis associated with this series of events.

Given that the cobalt adjusters are to be designed and operated with very similar reactivity worth values as the stainless-steel adjusters and the insensitivity of the steam generator trip parameters to adjusters-withdrawn scenarios, the implementation of cobalt adjusters will have no effect on the Safety Report conclusions for this series of events.

Therefore, the TDS and Cobalt adjusters will not have any significant effect on the evolution and consequences of feedwater system failures. References [1] and [21] present more detail

and further discussion on the various feedwater events and the effects that the presence of the TDS and the Cobalt adjusters will have on the evolution and consequences of the event.

7.10 Appendix 8 – Steam Supply System Failures

Failures in the steam supply system can result in major perturbations to operating conditions in the feedwater and steam supply systems, which can result in a degradation or loss of the steam generators as a heat sink to the HT system. These perturbations in operating conditions are classified into two groups: depressurization of the SGs, as in the case of steam piping ruptures, and pressurization of the SGs, as in the case of a turbine trip.

The primary criterion for analysis of steam supply system failures is to demonstrate that a reactor trip is initiated sufficiently early that the remaining inventory in the steam generators provides an adequate heat sink until such time as an alternative, long-term heat sink can be brought into service. The required duration is 15 minutes if operator action from the main control room can establish the alternative heat sink, or 30 minutes if field action is required. Additional considerations are confirming that HT system integrity is maintained, and that fuel failures are avoided.

The TDS and its components have no interface with the steam supply system. While the steam supply system is required for the plant to operate at higher powers, none of the important parameters listed in Table 4 associated with steam supply system failures are impacted by the TDS.

On the basis of the similarity between steam supply system failure events and feedwater system failure events discussed in the previous section, and the similar safety concerns, the use of Cobalt adjusters in place of stainless-steel adjusters will have no effect on the Safety Report conclusions for this series of events.

Therefore, the TDS and Cobalt adjusters will not have any significant effect on the evolution and consequences of steam supply system failures and can reside in any unit alone or in combination.

7.11 Appendix 9 – Shutdown Cooling, Shield Cooling and Moderator System Failures

The SDC system is designed to cool the HT system from 149°C following a normal reactor shut down and to hold the system temperature at 54°C or lower to facilitate maintenance on components of the HT system and its auxiliary systems. In general, shutdown modes of operation are not relevant to TDS operation since the targets will not normally be present in the core as they will be harvested at power prior to a planned unit shutdown and not re-seeded until after a return to full power. The shutdown state becomes relevant only if a target string becomes stuck and cannot be removed until the next planned outage, or if there is an unplanned outage while targets are in-core. However, the TDS has no effect on the safety case for shutdown cooling failures. There are no new initiating events identified as relevant to shutdown cooling failures.

The main functions of the shield cooling system are to maintain the end shields and shield tank full of water to provide biological shielding during normal operation and shutdown conditions, and to remove heat which accumulates in the end shields and shield tank due to

nuclear radiation from the reactor core and heat transfer from the fuel channels and HT system feeders. The TDS and its components have no interface and do not require the operation of this system; hence there is no impact of the TDS on the shield cooling system failures. While the TDS piping between the airlocks and the transfer location pass near the shield expansion tank, any failure of the tubing is highly unlikely to cause any damage to the tank or associated piping.

Moderator system failures considered include loss of moderator inventory (LOMI), moderator heat sink failures due to loss of service water or loss of moderator circulation and overcooling of the moderator due to loss of temperature control low. The three safety concerns associated with moderator system failures are:

• Public doses from tritium contained in the moderator fluid released through various pipework, rupture disks or valves,

• The possibility of reactor structure thermal deformations sufficient to jeopardize the integrity of the HT system or the operability of the shutdown systems, and

• The possibility of a deuterium deflagration in the cover gas space in the emergency discharge pipes above the moderator level, or inside the calandria if the moderator level has fallen.

Trip coverage for moderator system failures is provided by moderator low level and moderator high level trips on both SDS1 and SDS2. The low-level trips provide protection for loss of moderator inventory events, and the high-level trips for loss of heat sink events. The NOP trips also provide protection for loss of inventory events, for cases in which the moderator low-level trips are not credited, and the moderator level drops slowly enough that the reactor regulating system maintains reactor power at its initial level.

Failures of the shutdown cooling system are relevant after reactor shutdown and the Cobalt adjusters have no role during these events. The safety concern associated with shield cooling events is the potential for deformation of the shield tank and end shield structure that could challenge the integrity of the heat transport system. Similarly, the adjusters have no direct role in events affecting the shield cooling system.

As both the TDS and the Cobalt adjusters are in the moderator, there is a direct interaction with the moderator system, and internal heat generation due to the activation of isotope targets and Cobalt. As result, a re-analysis of the loss of moderator inventory (LOMI) events (References [24] and [25]) was performed for each system separately. The analyses showed that there is ample margin to the acceptance criterion of surface ignition temperature of 685°C for the Cobalt adjuster rods. The peak reference temperature for the TDS Molybdenum target capsules was calculated to be 498°C. This represents a margin of 179°C to the surface ignition temperature of 677°C, documented in Reference [1]. Different isotopes have been assessed to have adequate margin even with conservative estimates of target material masses.

An identical analysis was performed for the Cobalt adjusters and the peak reference temperature was calculated to be 609°C, as documented in Reference [23]. As both TDS targets and Cobalt adjusters would remain in-core during such an event, this scenario is

where there is some potential for the two systems to interact. It should be noted that the target capsules use identical outer layers, with the decay heat impacted by the isotope being produced or irradiated. It was determined that there will be no significant difference in the results as there are inherent similarities in design and material content combined with the expected low energy yield (heat) from the new isotopes [2]. Further, as the TDS targets would be more than 100°C cooler than the Cobalt adjusters, the Cobalt adjusters are more limiting from the surface ignition perspective. Since the physical distance separating the two systems is large enough, any thermal interactions between the two systems would be insignificant. That is, the hotter Cobalt adjusters would not be able to significantly heat up the TDS capsules, nor would the TDS capsules act as a significant heat sink for the Cobalt adjusters.

Further details of these results and events can be found in References [21] and [1]. For the specific analysis of the loss of moderator inventory event, References [23] and [24] provide details of those analyses. The TDS, target capsules, and Cobalt adjusters will not have any significant effect on the evolution and consequences of shutdown and shield cooling system failures. Part of the justification being a result of the spatial separation and vastly different time scales of reactivity change. These results are not unit specific and both systems can exist in any unit.

Additional discussion of LOMI and aging impacts is further examined in Section 7.14.

7.12 Appendix 10 – Support System Failures

Analysis presented in this appendix covers failures of service water and instrument air systems which are important to safety. This includes the low-pressure service water open system, the powerhouse upper level service water system, the recirculated cooling water system, the emergency service water system, the unit instrument air system and the common instrument air system.

The purpose of this analysis is to show that, in the event of a failure of one of these systems, the applicable dose limit would not be exceeded. With respect to support system failures, the derived objective is to show that the reactor can be shut down prior to any fuel failures, that long-term heat sinks are available and that a LOCA will not result.

The consequences of these events occurring for the TDS operation are covered by the Safety Report. The TDS and its components have no interface and while the systems are required for the plant to operate at high power when the TDS is being utilized, none of the important parameters listed in Table 4 associated with any of the support water systems failures are impacted by the TDS or target capsules.

Loss of instrument air would result in leaving Targets stalled in the Elevator or out-of-core transfer lines; therefore, there is potential for a radiation hazard during harvesting. As this is an out of core event, it is not relevant to the interactions occurring in-core or accident analysis.

The operation of the TDS does not require connection to or use of common instrument air. Therefore, there will be no impact of the TDS on loss of common instrument air accident, and no impact of this accident on the TDS.

Implementation of Cobalt adjusters would have no effect on these series of events as they are not connected to any of the associated systems. A loss of common instrument air does not require a reactor shutdown in the short term and no fuel cooling problems or radioactive releases occur, and therefore Cobalt adjusters would have no effect on this conclusion.

As neither the TDS, associated target capsules nor the Cobalt adjuster systems individually influence the evolution or consequences of support system failures, the combination of both systems will also have no effect on the evolution or consequences of support system failures.

7.13 Appendix 11 – Common Mode Failures

The TDS has no effect on the identification and classification of the common mode external events [10]. There is a potential effect on the identification and classification of internal fires due to the presence of D2 gas in the TDS. The Safety Report (Internal Fires section) identifies an external release of moderator cover gas (MCG) and subsequent fire as a result of a MCG pressure boundary failure. The two possible mechanisms for deuterium fire/deflagration are identified in the event that a failure of the deuterium recombination system could result in the accumulation of deuterium in the guide tube extensions. The possible mechanisms were a pressure boundary failure in the target propulsion system resulting in release of deuterium out into Rm-301 (RMD), and ignition inside the guide tube extension by a hot target during harvesting.

For either mechanism, the overall potential for damage from a deuterium fire is limited by the total amount of deuterium available for combustion and the magnitude of the potential energy release if it were all consumed. The two specific risks being a deuterium fire as a result of a TDS pressure boundary failure or ignition inside the guide tube due to a hot target string. The assessment concluded that a deuterium fire resulting from failure of the TDS pressure boundary is unable to impact nuclear mitigating functions and ignition in a guide tube would not impact the ability to safely shutdown. The consequences of the events are assessed in detail in reference [1].

The use of cobalt adjusters instead of stainless-steel adjusters is expected to have no consequence on common mode events. The events that comprise the set of common mode events have no direct connection to the adjusters, and any minor effect the adjusters would have would be as a result of the change of material of the adjuster. The change in the adjuster material would only be seen in the initial fission product distribution within the fuel at the outset of the event. However, as previously discussed, the combination of sound adjuster design and fuelling practices would ensure that the conservative assumptions used in the existing assessments would still be applicable. As such, the implementation of cobalt adjusters has no effect on the common mode events.

Therefore, the TDS, target capsules and Cobalt adjusters will not have any significant effect on the evolution and consequences of common mode failures. As a result of the spatial separation, the combination of the TDS, any target capsule combination and the Cobalt adjusters will also have a non-significant effect on the evolution and consequences of common mode failure events.

7.14 Appendix 15 – Impact of Heat Transport System Aging

The aging of the HTS, among structures, systems and components, is an important consideration with respect to safety margins; however, for analysis of postulated LOMI events it is of lesser concern. HTS aging impacts are addressed in the analysis by establishing and incorporating HTS aging trends into projections of plant conditions up to the aged condition, and application of thermal-hydraulics models reflecting the aged conditions.

The dominant aging mechanisms are those that adversely affect existing safety margins are the following:

• Pressure tube diametral creep (PTDC),

• Feeder corrosion and roughness,

• Steam generator (SG) and preheater tube inner and outer diameter fouling.

PTDC increases the flow area through the outside edges of a channel (flow bypass) which in turn decreases flow through the inner subchannels of the fuel bundles. This leads to accelerated dryout timing and degraded fuel cooling under accident conditions.

Feeder corrosion and roughness leads to feeder degradation resulting in increased flow resistance through the piping below the header. In addition, deposits from the corrosion process are deposited in other components of the system, above and below the headers, introducing additional flow resistance, affecting the header-to-header differential pressure or driving force of channel flow, hence cooling.

Steam Generator fouling occurs due to corrosion of components (e.g., feeders for inner diameter tube fouling) and deposition in the steam generator components which leads to a reduced heat transfer coefficient and increased flow resistance and increased operating temperatures. The increased operating temperature results in a lowered differential temperature across the fuel channels resulting in increased outlet boiling and lower margins to dryout.

Among the moderator system failures, only LOMI and Moderator Cooling Failure would be affected by the impact of HTS aging mechanisms. In a LOMI event, a top-to-bottom flux tilt develops, similar to a Loss Regulation Event. In the Moderator Cooling Failure, pressure tube diametral creep can affect the margin to dryout following the collapse of the moderator level after the rupture discs burst. In general, NOP analysis, which accounts for HTS aging, is expected to bound this scenario thereby ensuring adequate trip coverage and safe operation.

The effect of these changes on the potential TDS component heat-up and deflagration following a postulated LOMI due to the installed TDS is limited to the initial conditions of any transient. Changes in HTS parameters such as the RIH temperature (the parameter most impacted by aging) will have very small impacts on the in-core power distribution and thus very small impact on the subsequent heating of the components following the postulated LOMI. The small break LOCA, Loss of Flow and Slow Loss of Regulation accident scenarios were assessed accounting for the effects of HTS ageing on safety analysis and operational margins (References [25] and [26]). All compliance limits are adhered to without any change

to key initial parameters such as channel and bundle power limits. There is no effect associated with TDS operation or small variation in target capsule design to accommodate the production of new isotopes on the evolution or consequences of any analyzed event due to reactor aging.

The effect of Cobalt adjusters on a fresh core and an aged core are limited to the initial conditions of any transient (bundle and channel powers, CCP's, and other key parameters). However, since the initial conditions in the analysis are at their limit of operating envelope, which will not change, there will be no effect on analysis results. As all of the compliance limits are to be adhered to both as the reactor core and the Cobalt adjusters age, there is no effect of the implementation of the Cobalt adjusters on the evolution or consequences of any event as a result of reactor aging beyond what has been analyzed in the Safety Report, and documented in References [25] and [26].

Due to spatial separation and the vastly different time scales of reactivity changes, the combination of the TDS, target capsules and the Cobalt adjusters will also have no significant effect on the evolution and consequences of any events analyzed in an aged core beyond what has been reported in the Darlington Safety Report, Part 3 (Reference [18]) and the updated analyses of record (References [25] and [26]).

8.0 OPERATIONAL ASSESSMENTS

The modifications associated with the installation, and operationalization of the TDS were completed using the OPG Engineering Change Control (ECC) process (i.e. N-PROC-MP-0090). The introduction of new core components combined with dynamic reactivity effects associated with seeding and harvesting were assessed in detail in Reference [14]. Further, the integrated assessment, Reference [1] included some focused summaries from Reference [14] and additional information and impacts. A further reassessment with the introduction of new isotopes was documented in Reference [2]. The overall conclusion from the assessments was that TDS operation would have a minor impact on overall unit operation, with the most significant impacts being associated with planning and execution of seeding and harvesting activities. While it is recognized that the analyses and assessments are independent of unit, there are advantages to installing multiple TDSs as unit outages and other activities may result in conflicts in production of isotopes.

The intent is not to revisit the studies and assessments already completed, rather to confirm they are applicable to all units, and not specific to Unit 2 where a TDS is currently installed and operating.

8.1 Reactivity Worth Comparison

The reactivity worth of the target capsules has been determined through analysis and while the overall amount of absorbing material that has been added to the core is very small, the overall dynamic effect associated with seeding and harvesting represent the reason for performing the associated operational assessment activities. From a fuel impact perspective, the calculated impact from having the new devices and all TELs in operation, seeded nearly continuously with isotopes would require an additional 18 fuel bundles per year to maintain core criticality using the heaviest isotope targets, (Reference [14]). In comparison, the current

fuelling rate due to fuel burn up is approximately 16 bundles per day. The reactivity worth of a target string of molybdenum and basket, which are inserted and removed during seeding and harvesting has a reactivity worth of 0.062 mk/target site (~1% AZL), (Reference [1]). This, combined with the speed of insertion/removal of approximately 60 seconds, results in a reactivity change rate of approximately 0.001 mk/s. In comparison, RRS is capable of adding negative reactivity at a rate of 0.115 mk/s. The reactivity insertion/removal rate associated with TDS operation is a fraction of the value RRS can manage during normal operation. If one compares this to the value AA Bank A removal, the approximate reactivity insertion rate is 0.02 mk/s. During normal operation, AZL is constantly decreasing at a rate of approximately 0.42 mk/FPD (or Full Power Day), which is closely compensated for by the normal fuelling rate, previously noted of approximately 16 fuel bundles per day.

8.2 Fuel Management

A comprehensive fuel management study was conducted as documented in Reference [14] which utilized a lower target threshold for channel selection to compensate for the power changes associated with TDS operation with Mo-99 target capsules. The study was augmented by additional assessments completed in support of irradiating additional isotopes in Reference [15].

The Fuel Management study demonstrated the key fuelling parameters used in compliance with Safety Analyses are not challenged. Given current fuel management practices, there is no concern with the operation of the TDS on any Unit as the power changes associated with isotope targets will not impact future compliance.

The fuelling rates, power distribution, and RRS response are all within acceptable operational variations. Therefore, the impact of TDS operation is judged to be manageable from a reactor physics perspective in terms of fuel selection.

8.3 Core Follow Simulations Impacts

The design, development and implementation of the TDS required that the materials being installed in the reactor be rigorously evaluated and assessed. This required model changes to both RFSP and SORO, documented in in Reference [27]. Incremental cross sections were determined using DRAGON, tested against MCNP, and used in RFSP and SORO. The incremental cross sections for all of the target capsule designs have been completed with the new isotopes documented in Reference [16]. Capsule appropriate cross-sections can be implemented into the model to match the in-use combinations of target string unique to each TEL, as well as allow the baseline evaluation that all targets are conservatively assumed to be the heaviest isotope for any bounding assessments.

In addition to the core follow requirements that are executed by site Nuclear Safety staff, refuelling considerations as well as seed and harvest assessments will be further assessed as additional TDS operations and systems are implemented.

8.4 Impact on Operations

The impact on MCR Operation staff is considered to be minimal. Operating procedures will be the same for each Unit with a TDS installed. The current procedures provide the expected

response to seeding and harvesting with Mo-99 targets, and will be updated to include the response for different isotopes as they are commissioned. Similar responses would be expected on each Unit where a TDS is installed, and the entry conditions would be the same as they are based on reactivity assessments.

The Radiation hazards and the human factors associated for a TDS installed on multiple Units will be assessed as part of the overall ECC process, with their respective strategies implemented as a result.

Tracking of the isotope strings in the different TELs will be necessary to ensure that the Operating staff can adequately assess the planned activities prior to execution based on their procedures.

9.0 CONCLUSIONS

This review in support of installing the TDS on multiple Units to facilitate the regular required production of isotopes includes examination of the main documents completed in support of the installation and operation of the existing TDS on Unit 2 of the Darlington NGS. Review of the TDS initiating events, the potential for impact on the existing safety analyses, impacts on the PSA elements, and operational impacts were part of the review. The conclusions of the review are:

• While the event identification and classification identified 11 new events and potential impact on some existing systems, installation of a TDS on multiple units does not change the conclusions or introduce any new events;

• Parametric assessments indicated the TDS and production of isotopes have no detrimental impact on the safe and reliable operation of the reactor and adding a TDS on multiple units does not change the conclusions;

• The introduction of a TDS on other units does not impact the conclusion that its overall impact on the quantification of SCDF and LRF in various PSA elements is expected to be low;

• Operational assessments completed for the TDS installed on Unit 2 are applicable to any other unit where a TDS is installed;

• A review of safety analysis appendices and Cobalt Adjuster Rod interactions report did not identify any issues or challenges associated with the existing accident progression or consequences by installing additional systems on other units.

Based on the above, installation of a TDS on other units will have no significant impact on the safe operation of Darlington NGS. Systems, structures and components will continue to provide the required safety, protective and mitigating functions necessary to ensure the original design objectives are met.

10.0 REFERENCES

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[15] OPG Report, “Operational Feasibility Assessment for Production of Yttrium-90 and Lutetium-177 at Darlington Nuclear Generating Station,” NK38-REP-03600-10016-R000, December 20, 2024.

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[18] Ontario Power Generation, "Darlington Nuclear 1-4 Safety Report: Part 3 - Accident Analysis," NK38-SR-03500-10002-R005, October 6, 2017 [SR in use at time of Assessments]

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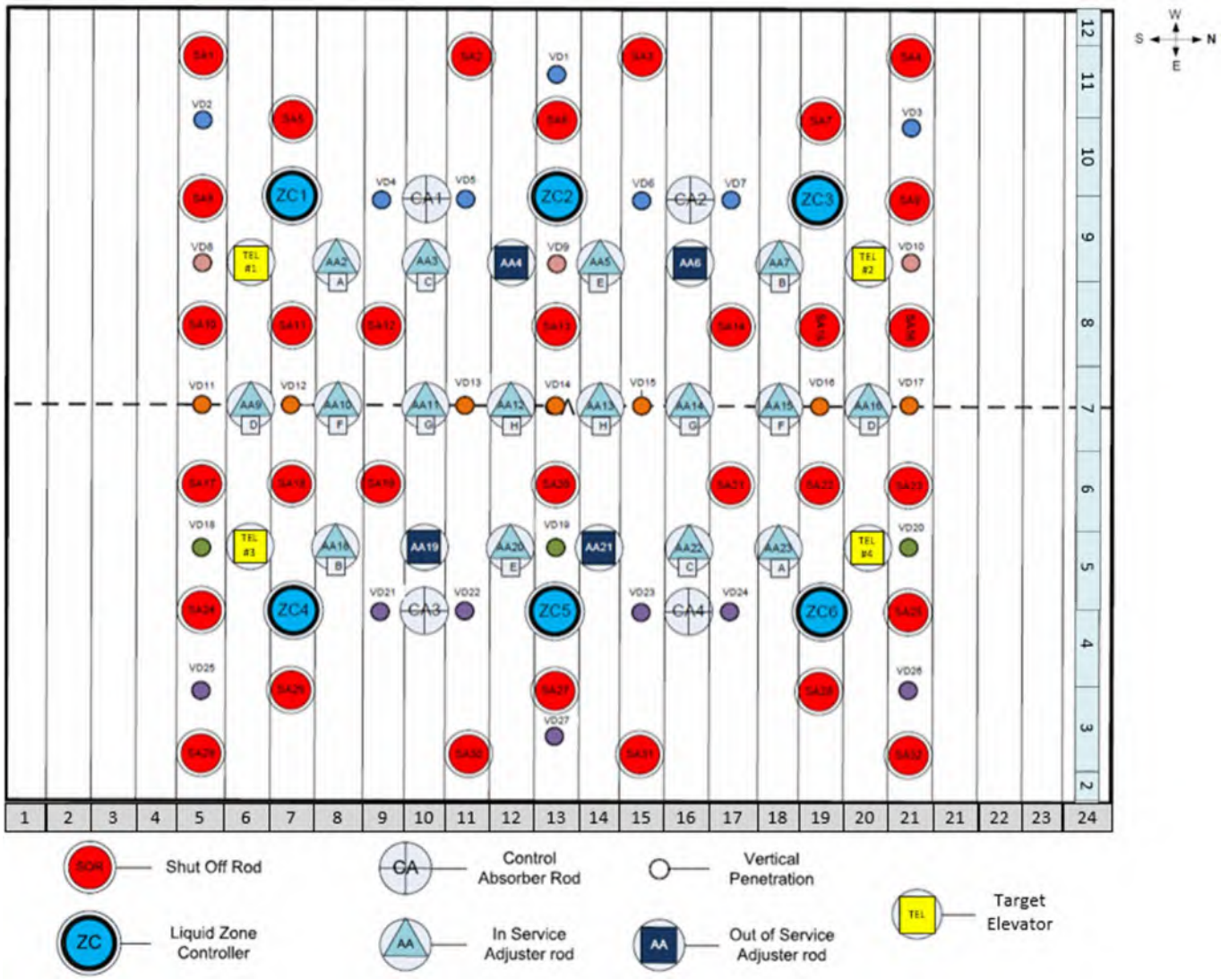

Figure 1 – Location of TDS Installed in Out of Service Adjuster Rod Locations

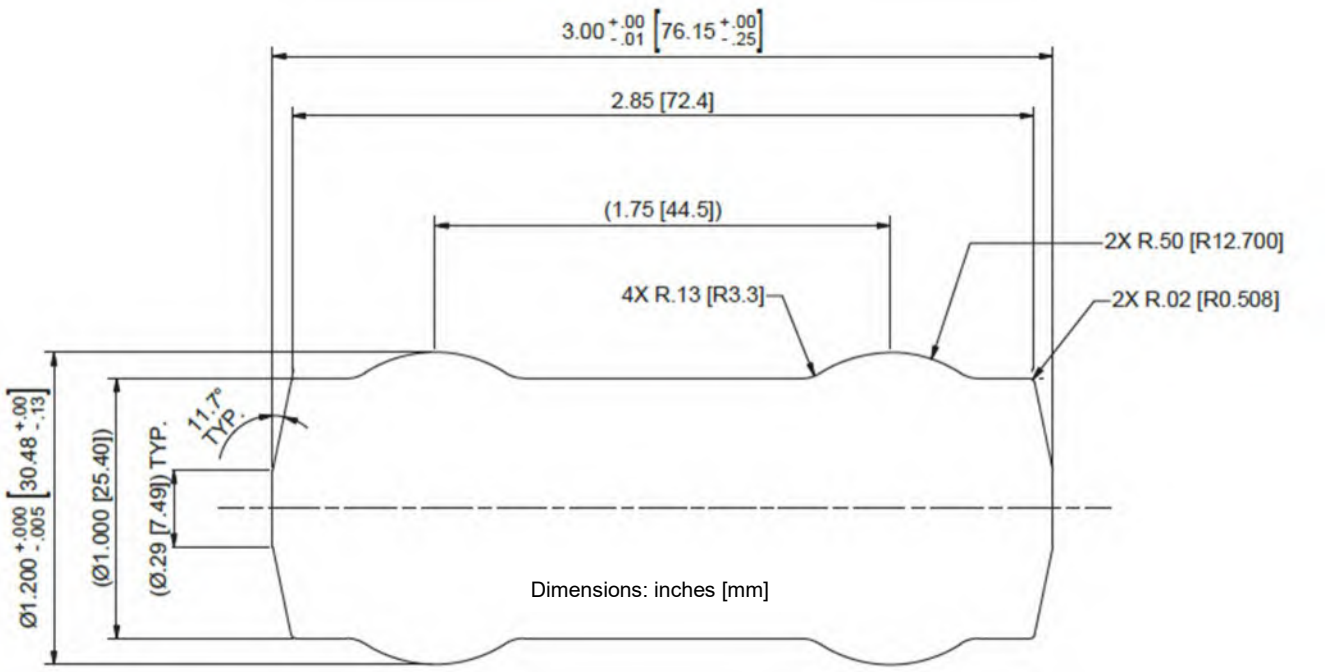

Figure 2 – Dimensional Drawing of Target Capsule

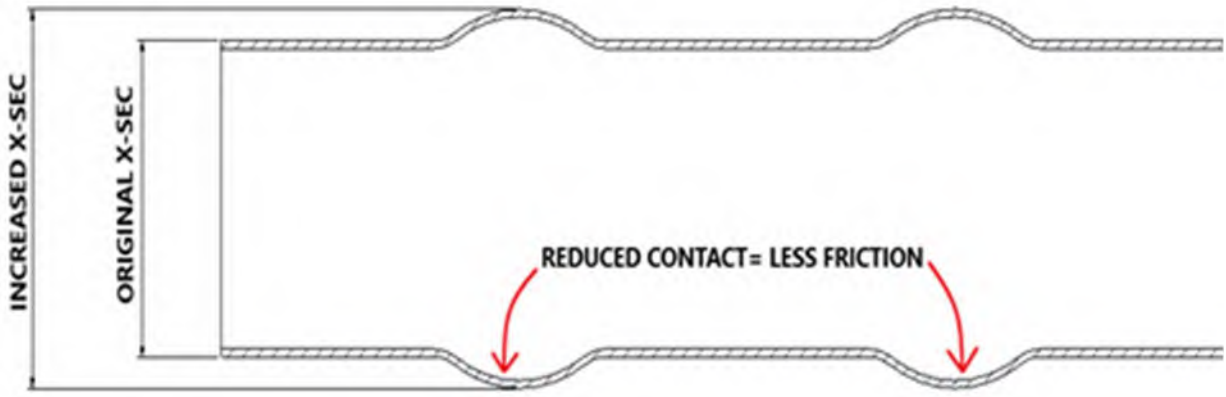

Figure 3 – Simplified Target Cross Section for Reduced Contact

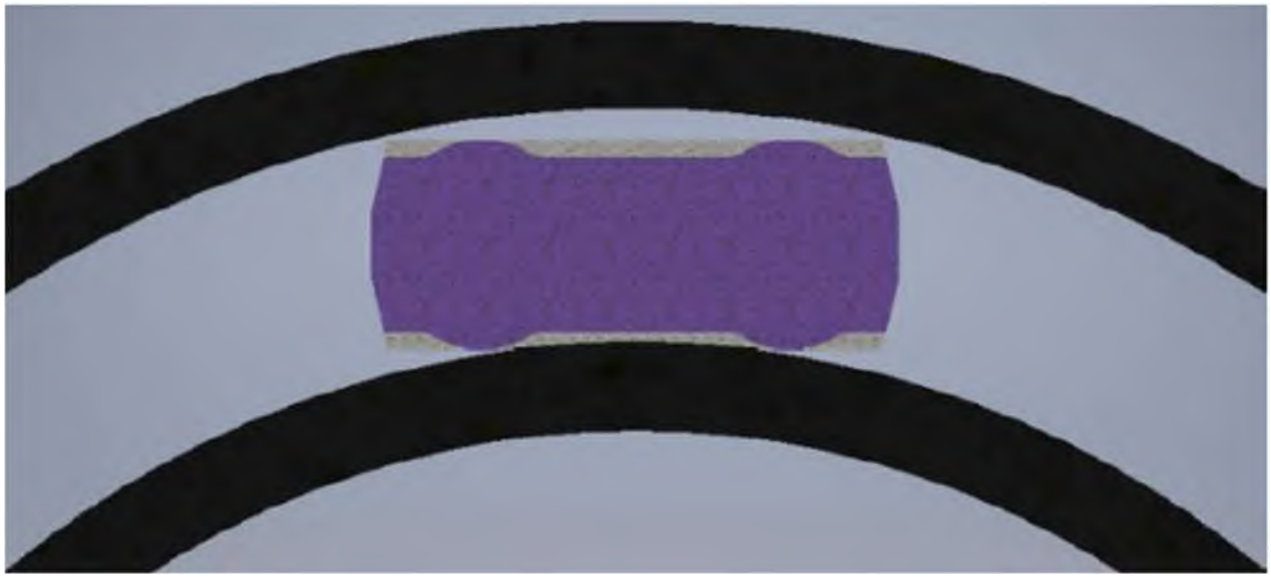

Figure 4 - Illustration of Target Capsule Traversing a Bend in the TDS

Table 1 – TDS Initiating Events and Their Classification

#	Initiating Event	Frequency (occ/yr)	Classification
#1	Target breaks apart during hydraulic transfer with release of its fragments into moderator.	$9.8x10^{-4}$	DBA
#2	Target damage in Target Elevator or in-core with release of its fragments into moderator.	$1.0x10^{-2}$	AOO
#3	Failure of TDS Exhaust System or Contaminated Exhaust System exhaust flow during Target Airlock purging.	$5.5x10^{-2}$	AOO
#4	Failure to purge the Target Airlock during harvesting or re-seeding.	$6.8x10^{-3}$	DBA
#5	Failure of pneumatic tubing between the Target Airlock and the Flask Loader.	$3.0x10^{-5}$	DBA
#6	Failure of containment isolation due to incorrect Target Airlock closing.	$7.1x10^{-4}$	DBA
#7	Failure of Target Propulsion System hydraulic pressure boundary between Target Airlock and Target Elevator.	$1.3x10^{-4}$	DBA
#8	Human error resulting in a simultaneous harvesting of strings from two separate sites.	1.5	AOO
#9	Failure to position Targets at the required in-core location.	$4.9x10^{-1}$	AOO
#10	Human error in proceeding with harvesting without confirming reactor state.	$1.5x10^{-4}$	DBA
#11	Failure to recombine D_2 and O_2 generated in adjuster thimbles during TDS operation.	$2.1x10^{-4}$	DBA[4]

[4] The calculated frequency shows this event as DBA. In the current design, the presence of interlocks which prevent basket movement if concentration of D2 is high, make this event highly unlikely. The interlock will inhibit upward elevator operation if a DRS blower is not running or concentration of D2 > 0.95% and will also inhibit the start of target upward motion if concentration of D2 > 0.8%. Thus, the event may be considered a Beyond Design Basis Accident (BDBA), nonetheless without a more refined calculation it continues to be classified as a DBA.

Table 2 - Impact Summary of IEs for Multiple TDS

Safety Report Event Category	Impact of Single TDS Installation	Impact of Multiple TDS Installations
Fuel Handling System Failures	No impact of TDS on Fuel Handling IEs.	No impact of TDS on Fuel Handling IEs.
Electrical Failures	Identified four AOOs and two DBAs impacted by TDS Installation. Only IE remaining DBA during harvesting would be the single heat transport pump trip AOO which would become a DBA. Remaining IEs would all be classified as BDBA.	No change in impact with system on multiple units.
Control Failures	Identified two DBAs and two BDBAs impacted by IEs. All would be classified as BDBA during harvesting. Important to note that the impact of harvesting on the reactivity insertion rate is very small with RRS capable of mitigation, however during an LORC, RRS would not be functioning correctly. Again, a BDBA due to unlikely nature of LORC and harvesting.	No change in impact with system on multiple units.
Small Break LOCA	An in-Core LOCA can only interact with the TDS system due to coolant discharge into the Calandria vessel that might result in damage to in-core structures including the guide tubes housing the TDS Targets. This is a potential impact on the consequence of In-Core LOCA but there is no impact on In-Core LOCA IEs identification, frequency and classification.	No change in impact with system on multiple units.
Large Break LOCA	No impact of TDS installation on the Large LOCA IEs identification and classification.	No change in impact with system on multiple units.
LOCAs Outside Containment	No impact of TDS installation on the IEs identification and classification of LOCAs outside containment.	No change in impact with system on multiple units.

Safety Report Event Category	Impact of Single TDS Installation	Impact of Multiple TDS Installations
Feedwater System Failures	No impact of TDS installation on the IEs identification and classification of feedwater system failures.	No change in impact with system on multiple units.
Steam Supply System Failures	No impact of TDS installation on the IEs identification and classification of steam supply system failures.	No change in impact with system on multiple units.
Shutdown Cooling, Shield Cooling and Moderator System Failures	The moderator system and its cover gas system have interfaces with the TDS which could have an impact on IEs identification and classification of these systems.	No change in impact with system on multiple units.
Support System Failures	The TDS interfaces with the station IAS. The IAS provides air for pneumatic actuators, pneumatic transfer of the target capsules from the loader to the TAL. The total (global) loss of IAS to the TDS would not increase the severity of the event, so there is no requirement for an IE representing this global failure.	No change in impact with system on multiple units.
Common Mode Failures	The TDS has no impact on the identification and classification of the common mode external events. There are some new IEs associated with the TDS that would impact on some fire safety analysis.	No significant change in impact with system on multiple units.

Table 3 - Hazard Listing from Internal and External Screening

#	Hazard	Safety Concern	Event Type
1	Target breaks apart during hydraulic transfer with release of its fragments into moderator	Debris may be blown into the moderator, with the potential for an upset in moderator chemistry or reactor operation.	Unit Specific
2	Target damage in Target Elevator or in-core with release of its fragments into the moderator	Release of Target fragments into moderator with the potential for an upset in moderator chemistry or reactor operation, possible moderator pump damage; possible radiation hazard from Target if expelled into moderator piping.	Unit Specific
3	Failure of TDS Exhaust System or Contaminated Exhaust System (CES) exhaust flow during Target Airlock purging	Release of contaminated exhaust air to environment. Potential of spreading contamination into other rooms connected to the CES.	Unit Specific
4	Failure to purge the Airlock during harvesting or re-seeding	For failure of purge during harvesting, the safety concern is MCG contaminant release to Flask Loader and consequently to the powerhouse. For failure of purge during re-seeding, the safety concern is injecting air into MCG after the failed purge.	Unit Specific
5	Failure of pneumatic tubing between the Airlock and the Flask Loader	Radiation hazard as a result of Target stalling or being stuck in the impacted transfer tubing. Target acting as a projectile.	Unit Specific
6	Failure of containment isolation due to incorrect Target Airlock closing.	Potential breach of containment with release of radiation to environment	Unit Specific
7	Failure of Target Propulsion System hydraulic pressure boundary between Target Airlock and Target Elevator.	Potential release of radiation to the environment.	Unit Specific
8	Human error resulting in a simultaneous harvesting of strings from two separate sites	RRS and/or shutdown system effectiveness. Possible reactor stepback as larger than expected neutron absorber mass removed from core. One string of targets stuck in transfer tubing; radiation hazard.	Unit Specific
9	Failure to position Targets at the required in-core location	Targets not fully irradiated; this may have an impact on core flux shape, potential for neutron flux tilts.	Unit Specific
10	Human error in proceeding with harvesting without confirming reactor state.	RRS and/or shutdown system effectiveness. Potential for conflict with a reactor control maneuver creating a change in operating conditions that cannot be balanced by reactivity mechanisms.	Unit Specific
11	Failure to recombine D_2 and O_2 generated in adjuster thimbles during TDS operation.	Risk of deflagration of accumulated D_2 if an ignition source is present (e.g., over-heated target).	Unit Specific
12	Target stuck in pneumatic or hydraulic transfer tubing	Radiation hazard	Unit Specific
13	Loss of Class III electrical power supply to the TDS during harvesting or re-seeding	Stalling targets in in-core or out-of-core components. Power loss may increase target parked duration in the gas space. Stalling targets in out-of-core components.	Unit Specific

#	Hazard	Safety Concern	Event Type
14	Loss of instrument air supply to the TDS during harvesting	Stalling of targets in transfer lines. Potential for radiation hazard.	Unit Specific
15	Loss of communication to TDS	Stalling Targets in in-core or out-of-core components. Loss of communication may increase Target parked duration in the gas space which may increase risk of deflagration. Stalling Targets in out-of-core components increases the radiation hazard.	Unit Specific
16	Target withdrawal from the core without dwell time for radioactive decay in the guide tube gas space	Radiation hazard	Unit Specific
17	Shield plug not removed from flask	Flask cannot be loaded, targets remain in pneumatic piping, radiation hazard	Unit Specific
18	Shield plug not replaced	Open flask, radiation hazard	Unit Specific
19	Incorrect magazine loading	Radiation Hazard	Unit Specific
20	Incorrect replacement of shield plug	Radiation Hazard	Unit Specific
21	Incorrect loading leads to targets left in transfer tubing	Radiation Hazard	Unit Specific
22	Winch failure	Damage to basket, targets, and guide tube due to basket free fall, and potential for dry drop in moderator drained state Reactor trip may occur if material enters or exits core at elevated speed.	Unit Specific
23	Diverter failure, two strings sent to same site	Targets stuck in transfer lines. Unable to remove targets from guide tube. Unable to perform normal seeding/harvesting. Targets removed from guide tube may be stuck in transfer lines for extended period. Radiation hazard.	Unit Specific
24	Other combinations of equipment failures leading to a loss of containment	Equipment failures and failure causes could include, but are not limited to: • Valve leaks • Material wear, aging • Contamination	Unit Specific
25	Incorrect positioning of the flask in flask loader	Flask not aligned in shield plug or magazine removal/replacement positions. Radiation hazard. Flask stuck inside flask loader. Radiation hazard.	Unit Specific
26	Loss of D_2O	Loss of D_2O inventory through means other than a pipe break – pump failure, D_2O reservoir leak.	Unit Specific
27	Flask falls from jib crane (freefall or dropped)	Radiation hazard. Load drop. Flask drop from raised height to floor of el 116.4 m. Flask drop in hoistway from max raised height to el 100 m.	Unit Specific
28	Crane stalls during flask lowering (due to loss of power or lack of maintenance)	Radiation hazard	Unit Specific

#	Hazard	Safety Concern	Event Type
29	Crane boom failure	Radiation hazard. Mechanical rotation hazard	Unit Specific
30	In-plant transportation accident	Collision of in-plant transportation vehicle with a stationary object Collision of in-plant transportation vehicle with another in-plant vehicle Flask falls off vehicle (due to accident or improperly secured) Transportation halted due to event external to vehicle (steam pipe break, etc.) Fire on vehicle	Plant
31	On-site Vehicle Movement (outside of plant)	Collision of off-site transportation truck with a stationary object Collision of off-site transportation vehicle with another vehicle Flask falls off vehicle (due to accident or improperly secured) Transportation halted due to event external to vehicle (steam pipe break, etc.) Fire on vehicle	Plant
32	Failure to load flask magazine	Failure of vertical linear device Attempt to load flask with shield plug in place Target loading operations begin without flask in place	Unit Specific

Table 4 - Important Parameters for Accidents (Table 1-13 of [18])

System / Parameter[5]	FH	CF	EF	SB	LB	FW	SS	MS	AS	Discussion
Reactor										
Bulk Power		✓	✓	✓	✓	✓	✓	✓		Governs HT conditions and initial channel powers
CPPF		✓	✓	✓	✓			✓		Influences maximum channel and bundle powers; Influences NOP trip coverage for in-core LOCA
Flux Tilt		✓	✓	✓	✓			✓		Influences maximum channel power and minimum instrumented channel power
Moderator Poison				✓	✓					Influences in-core LOCA reactivity balance and void reactivity
Moderator Isotopic Purity				✓	✓					Influences in-core LOCA reactivity balance and void reactivity
HT Isotopic Purity				✓	✓					Influences in-core LOCA reactivity balance and void reactivity
Adjuster Rod Withdrawal		✓	✓	✓				✓		Influences maximum channel power and minimum instrumented channel power; For LORC, primarily influences HTHP trip effectiveness
Void Reactivity			✓	✓	✓					Influences reactivity balance; Governing factor for large breaks
MCA Insertion			✓	✓	✓					Influences reactivity balance; (Note: For large breaks, only important for transition break category.)
Zone Level				✓	✓			✓		Influences reactivity balance; For transition break LOCA, zone level dictates the degree of coverage provided by the HTLF trip. For combinations of high initial power and mid-size transition breaks, HTLF is the only other trip, in addition to NOP that provides coverage, and thus, the zone level plays a role in determining whether there is dual parameter coverage on SDS1.
Fuel Channel										
PT Diametral Creep		✓	✓	✓	✓			✓		Influences dryout power and channel flows
Fuel Bundle to Channel End Components					✓					Influences fuel channel integrity due to axial expansion
Maximum Channel Power	✓	✓	✓	✓	✓			✓		Governs margin-to-dryout
Maximum Bundle Power		✓	✓	✓	✓			✓		Influences fuel enthalpy following large break and affects dryout power
Minimum Instrumented Channel Power			✓	✓						Influences effectiveness of HTLF trip
Power/Burnup Envelope	✓			✓	✓					Influences response of sheath (post-dryout conditions) and PT (heatup & ballooning)
Channel Flow		✓	✓	✓						Influences margin-to-dryout (Note: For large breaks, only important for transition break category)
CHF Correlation		✓	✓	✓	✓			✓		Influences void reactivity, time to fuel dryout & trip effectiveness
Post-Dryout Heat Transfer		✓	✓	✓	✓			✓		Governs sheath temperature in post-dryout
Bundle Endplate Coolant Mixing					✓					Influences PT ballooning & fuel/fuel sheath temperatures
Fuel-Sheath Gap Conductance		✓	✓	✓	✓			✓		Influences response of fuel and sheath
Heat Transport System										
Axial Header Pressure		✓	✓	✓				✓		Influences margin-to-dryout and/or margin to HTLF trip
ROH Pressure		✓	✓	✓	✓	✓	✓	✓		Influences trip effectiveness and in FW/SS it influences overpressure protection

[5] See Notes at End of Table

System / Parameter[5]	FH	CF	EF	SB	LB	FW	SS	MS	AS	Discussion
RIH Temperature		✓	✓	✓	✓			✓		Influences margin-to-dryout and depressurization of HT system; (Note: For large breaks, only important for transition break category.)
Pressurizer Level		✓	✓	✓						Influences effectiveness of PLL trip
Liquid Relief Valve Setpoint		✓	✓			✓	✓			Influences overpressure protection and effectiveness of HTHP trip and SS influenced if combined with loss of Class IV power.
Liquid Relief Valve Opening Time		✓	✓			✓	✓			Influences overpressure protection and effectiveness of HTHP trip and SS influenced if combined with loss of Class IV power.
Liquid Relief Valve Capacity		✓	✓			✓	✓			Influences overpressure protection and effectiveness of HTHP trip and SS influenced if combined with loss of Class IV power.
Tritium Concentration	✓			✓	✓				✓	Influences doses for main or auxiliary system breaks
Iodine concentration/ Iodine Spiking									✓	Influences doses for main and auxiliary system breaks outside containment
Moderator System										
Moderator Level								✓		Influences MHL trip effectiveness & conditioning of ECI for in-core LOCA
Tritium Concentration				✓				✓	✓	Influences dose for in-core LOCA and moderator pipe breaks
Calandria Outlet Temperature					✓			✓		Influences MHL trip effectiveness & fuel channel integrity (via moderator subcooling)
Moderator Temperature Distribution					✓			✓		Influences MHL trip effectiveness & fuel channel integrity (via moderator subcooling)
Moderator Cover Gas Pressure					✓			✓		Influences MHL trip effectiveness & fuel channel integrity (via moderator subcooling)
Steam Supply & Turbine										
SG Pressure		✓	✓	✓	✓	✓	✓	✓		Governs HT system temperature
SG Level						✓	✓			Governs SG inventory for post-trip heat sink
ASDV Capacity		✓				✓				Influences SG pressure
CSDV Capacity		✓				✓				Influences steady state for turbine trip/loss of line
SG Tube Fouling		✓	✓	✓				✓		Influences HT system temperature
SG Relief Valve Capacity		✓	✓	✓		✓	✓			Determines upper bound on SG pressure
SG Relief Valve Setpoint		✓		✓		✓				Determines upper bound on SG pressure
Feedwater & Condensate										
Feedwater Flow		✓	✓	✓		✓	✓			Influences HT system temperature & SG liquid inventory
Main Feedwater Pump Capacity						✓	✓			Influences SG inventory net loss rate for secondary side failures
Feedwater Line Pressure						✓	✓			SDS trip parameter
Shutdown Systems										
HTLP Trip Setpoint (SDS1/SDS2)		✓		✓	✓		✓			Influences range over which HTLP trip is effective for small out-of-core & in-core LOCA, and for transition break LOCA
HTHP Trip Setpoint (SDS1/SDS2)		✓	✓			✓	✓			Influences range over which HTHP trip is effective for LORC events and one/two HT pump trip and SS influenced if combined with loss of Class IV power.
HTLF Trip Setpoint (SDS1/SDS2)			✓	✓	✓					Influences range over which HTLF trip is effective for loss of flow events, small out-of-core & in-core LOCA, and transition breaks
RRDP Trip Setpoint (SDS1/SDS2)			✓							Influences range over which RRDP trip is effective for loss of flow events
MHL Trip Setpoint (SDS1/SDS2)				✓				✓		Influences range over which MHL trip is effective for in-core LOCA and moderator system failures

System / Parameter[5]	FH	CF	EF	SB	LB	FW	SS	MS	AS	Discussion
Shutdown Systems- cont.										
MLL Trip Setpoint (SDS1/SDS2)							✓	✓		Influences range over which MLL trip is effective for moderator system failures
NOP Trip Setpoint (SDS1/SDS2)	✓	✓	✓	✓			✓			Influences range over which NOP trip is effective for LORC, in-core LOCA; low moderator flow/circulation; influences net reactivity for large LOCA
HLR Trip Setpoint (SDS1/SDS2)		✓			✓					Influences maximum energy deposition and maximum excess reactivity
PLL Trip Setpoint (SDS1/SDS2)				✓			✓			Influences range over which the PLL trip is effective for small LOCA
SGLL Trip Setpoint (SDS1/SDS2)		✓				✓	✓			Governs range over which SGLL trip is effective for loss of secondary side inventory events
SGFLP Trip Setpoint (SDS1/SDS2)		✓				✓	✓			Governs range over which SGFLP trip is effective for loss of secondary side inventory events
HTHP Time Response (SDS1/SDS2)		✓	✓			✓				Influences range over which HTHP is effective for LOF & LORC events
HTLF Time Response (SDS1/SDS2)			✓							Influences range over which HTLF trip is effective for loss of flow events
NOP Time Response (SDS1/SDS2)		✓	✓		✓			✓		Influences net reactivity for large LOCA, loss of moderator circulation/cooling; EF included for pump seizures
HLR Time Response (SDS1/SDS2)		✓	✓	✓	✓					Influences maximum energy deposition and maximum excess reactivity and HLR effectiveness for in-core LOCA; EF included for pump seizures
ECI System										
Low Pressure Pump Start Setpoint				✓	✓					LP Pumps feed HP pump suction
Injection Valve/High Pressure Pump Start Setpoint				✓	✓					HP delivery of ECI for small LOCA
HPECI Pump Head/Flow Characteristics				✓	✓					Influences flow delivery to HT system
Recovery Sump Water Level				✓	✓					Influences timing of recovery mode
IWST Water Level				✓	✓					Level must be greater than a minimum value for adequate sump level for recovery
Containment System										
Reactor Vault Pressure				✓	✓			✓		Influences blinding break size; ECIS conditioning signal
Reactor Vault Cooler Capacity				✓	✓			✓		Influences repressurization time and hydrogen mixing
Vacuum Building Pressure				✓	✓			✓		Influences containment overpressure and repressurization time
Air In-Leakage Rate				✓	✓			✓		Influences repressurization time, and consequently extent of fission product decay when EFADS operation begins. Also influences FADS flow rate, and hence the rate at which radionuclides are released to the environment
Containment Isolation Setpoints				✓	✓			✓		Influences short-term releases
IPRV Setpoints				✓	✓			✓		Influences repressurization time, and short-term releases
Instrument Air Flowrate				✓	✓			✓		Influences repressurization time, and consequently extent of fission product decay when EFADS operation begins. Also influences EFADS flow rate, and hence the rate at which radionuclides are released to the environment.

Table 4 Notes:

CF - Control Failures (Note that these apply to the Loss of Regulation events)
FH - Fuel Handling Accidents
EF - Electrical Failures
SB - Small Break LOCA
LB - Large Break LOCA
FW - Feedwater Failures
SS - Steam Supply Failures
MS - Moderator System Failures
AS - Auxiliary System Pipe Breaks Outside Containment

Table 5 - Flux Shapes Analyzed for NOP Impact Assessment - Standard Configurations

		Standard TDS Configurations		
Flux Shape Category Flux Shape Numbers	**Reason for Inclusion**	**All targets in-core**	**1 target harvested from 4 in-core**	**1 target harvested from 3 in-core**
Steady State (SS)	Steady State	X	X	
Nominal Steady-State (SS1)	Nominal State			X
Steady State (SS6)	New Initiating Event			
Steady State (SS1)	New Initiating Event			
Axial Pair of Zone Controllers Drain with Bulk and Spatial Control (APZCD1)	Limiting for SDS1 Normal	X	X	
Axial Pair of Zone Controllers Drain without Bulk and Spatial Control (APZCD2)	Limiting for SDS2 Normal	X	X	
Two Axially Adjacent Adjusters ½ Out (TAAHO)	Limiting for SDS1 and SDS2 Abnormal	X	X	
Single Zone Controller Drain with Bulk and Spatial Control (SZCD1)	LORC during harvesting	X	X	
Single Zone Controller Drain without Bulk and Spatial Control (SZCD2)	LORC during harvesting	X	X	
Single Adjuster ½ Out (SAHO)	LORC during harvesting	X	X	
Single Adjuster Fully Out (SAFO)	LORC during harvesting	X	X	

Table 6 - Flux Shapes Analyzed for NOP Impact Assessment - Non-Standard Configurations

Flux Shape Category Flux Shape Numbers	Reason for Inclusion	Non-Standard TDS Configurations					
		2 axially adjacent targets harvested	2 radially adjacent targets harvested	2 diagonally adjacent targets harvested	3 targets harvested	4 targets harvested	1 Target ½ out of core
Steady State (SS)	Steady State						
Nominal Steady-State (SS1)	Nominal State	X	X	X	X	X	
Steady State (SS6)	New Initiating Event						X
Steady State (SS1)	New Initiating Event						X
Axial Pair of Zone Controllers Drain with Bulk and Spatial Control (APZCD1)	Limiting for SDS1 Normal						
Axial Pair of Zone Controllers Drain without Bulk and Spatial Control (APZCD2)	Limiting for SDS2 Normal						
Two Axially Adjacent Adjusters ½ Out (TAAHO)	Limiting for SDS1 and SDS2 Abnormal						
Single Zone Controller Drain with Bulk and Spatial Control (SZCD1)	LORC during harvesting						
Single Zone Controller Drain without Bulk and Spatial Control (SZCD2)	LORC during harvesting						
Single Adjuster ½ Out (SAHO)	LORC during harvesting						
Single Adjuster Fully Out (SAFO)	LORC during harvesting						

Table 7 - Impact of TDS on Dryout Power - Appendix B of Reference [1]

Parameter	M20			F22			V15		
	TDS	No TDS	Diff	TDS	No TDS	Diff	TDS	No TDS	Diff
Initial Power (kW))	6371.5	6377.2		4024.7	4025.0		6146.5	6145.0	
Dryout Power (kW)	8599.1	8559.2	39.9	6066.1	6064.1	2.0	8314.1	8313.8	0.3
Ratio	1.350	1.342		1.508	1.507		1.353	1.353	