Fuel Defect Detection, Localization And Removal In Bruce Power Units 3 Through 8

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Abstract

Fuel element defects are occurring in Bruce 'A' and Bruce 'B' Units. A root-cause investigation is ongoing, however, a solution is not yet in-hand. Fuel defect management efforts have been undertaken, therefore, in the interim.

Fuel defect management tools are in-place for all Bruce Units. These tools can be categorized as analysis-based or operations-based. Analysis-based tools include computer codes used primarily for fuel defect characterization, while operations-based tools include Unit-specific **d**elayed-**n**eutron ('DN') monitoring systems and **g**aseous **f**ission **p**roduct ('GFP') monitoring systems. Operations-based tools are used for fuel defect detection, localization and removal activities.

Fuel and Physics staff use defect detection, localization and removal methodologies and guidelines to disposition fuel defects. Methodologies are 'standardized' or 'routine procedures for implementing analysis-based and operations-based tools to disposition fuel defects during Unit start-up operation and during operation at high steady-state power levels. Guidelines at present serve to supplement fuel defect management methodologies during Unit power raise.

1.0 INTRODUCTION:

Fuel element defects are occurring in Bruce 'A' and Bruce 'B' Units. A root-cause investigation is ongoing, however, a solution is not yet in-hand. Fuel defect management efforts have been undertaken, therefore, in the interim. These efforts (e.g. fuel defect detection, localization and removal) have been underway in Units 3 through 8 from the inception of Bruce Power (2001).

Three groups work together within Bruce Power to optimize defect management efforts:

(1) Analysis: **N**uclear **S**afety **A**nalysis and **S**upport **D**epartment ('NSASD'), Bruce Power, 700 University Ave., Toronto.

(2) Fuel and Physics: At site.

(3) Operations: Shift personnel (fuel handling, etc…), Chemistry Lab personnel, system engineers for detection and localization systems.

Fuel defect detection and localization tools are in-place for all Bruce Power Units. These tools can be categorized as analysis-based and operations-based, specifically:

(1) Analysis-based: Numerical tools developed by or in conjunction with NSASD:

- 'VISUAL-DETECT',
- 'STAR'.

(2) Operations-based: Used by Fuel and Physics staff and Operations staff @ site:

- DN monitoring system,
- GFP monitoring system,
- Station-specific chemistry lab data… timely provision of **P**rimary **H**eat **T**ransport **S**ystem ('PHTS') fission product measured activities (Labs at both Bruce 'A' and Bruce 'B').

This work will describe the analysis-based and operations-based fuel defect detection and localization tools introduced above. This work will then present and discuss implementation 'methodologies' and 'guidelines' developed for these tools.

2.0 FUEL DEFECT MANAGEMENT TOOLS:

2.1 Analysis-Based Tools:

NSASD, in collaboration with the **R**oyal **M**ilitary **C**ollege ('RMC') at Kingston, ON, has developed two numerical tools for characterizing fuel defect behavior. They are:

(1) VISUAL-DETECT:

This computer code can estimate the number of fuel defects/the mass of 'tramp' uranium present in a Unit. The code can also estimate the size of a fuel defect under steady-state operating conditions. Input required includes PHTS measured activities for several radioisotopes, most of which are unavailable on-line (e.g. in 'real-time'). The only input available presently is '16000 second' GFP data which must be collected manually and must be pre-processed prior to being supplied as input to the code. These present limitations related to input data availability hamper the operational implementation of the code.

(2) STAR: '**S**teady-state and **T**ransient **A**ctivity **R**elease.'

This computer code can predict quickly and accurately the fuel-pellet-to-sheath gap inventory of ^{131}I available to be released to the PHTS, should a fuel defect occur. The code can also predict the time history or evolution of PHTS ^{131}I activity for both steady-state and transient operating conditions, once a fuel defect has occurred. Input required by the code includes real-time (or nearly real-time) measured activity values for PHTS ^{131}I, which are available on-line every 1000 seconds from the GFP monitoring system via the **P**lant **I**nformation ('PI') data base. Chemistry lab PHTS manual sampling results can be used as input to the code if PI is unavailable.

STAR has been used at Bruce Power to characterize past ^{131}I releases to PHTS. STAR has also been used successfully to support fuel defect management activities of Fuel and Physics staff and Operations staff during recent defect excursions in Bruce Units. These successes have prompted present efforts to implement STAR operationally at Bruce Power.

2.2 Operations-Based Tools:

Fuel and Physics staff and Operations staff rely primarily upon three tools for detecting and localizing fuel defects:

(1) DN Monitoring System:

Each Unit at Bruce Power possesses a DN monitoring system, used to monitor each fuel channel for the presence of delayed neutrons produced by fission product decay. The system features 480 sampling lines, with one line from each outlet feeder. Sampling lines are distributed between East and West scanning rooms, where in each room 240 lines are arranged into an array of 30 columns by 8 rows. One BF_3 detector is used per row of sampling lines and a reactor scan can be performed in approximately 2 hours.

Bruce Power DN monitoring systems are functioning presently with mechanical and background noise problems. Mechanical and electronics (e.g. signal-to-noise ratio) deficiencies persist due to system maintenance and general aging effects. Localization of fuel defects can be difficult. Delayed removal of failed fuel may impact upon station operation and safety (e.g. pressure tube integrity). **G**eneral **E**lectric, **C**anada ('GEC') has been tasked with replacing the Bruce 'B' DN monitoring systems electronics and cabling, to reduce noise and thereby to improve performance.

(2) GFP Monitoring System:

Each Unit at Bruce Power possesses a GFP monitoring system, used to monitor continuously the PHTS coolant activity by analyzing gamma spectra collected every 1000 seconds. Each system computes automatically PHTS activities for ^{131}Xe, ^{135}Xe, ^{88}Kr and ^{131}I, with threshold of 1 curie per isotope, and results are available on-line via PI. The effectiveness of the GFP systems could be improved greatly if PHTS measured activities for more isotopes were presented and if the storage threshold for PI data was reduced.

Each GFP system also makes available 16000-second data files for further isotopic analysis, but manual collection and processing of these data files is required and is, therefore, labor and time-intensive. Note that non- optimum detectors (e.g. sodium iodide instead of germanium) are installed in the Bruce 'A' GFP monitoring systems, thereby compromising their functionality and effectiveness. Germanium detectors are installed in Bruce 'B' GFP monitoring systems and these systems are fully functional and highly effective.

(3) Chemistry Lab Support:

The Bruce 'A' and Bruce 'B' chemistry labs monitor routinely the PHTS for the presence of several radioisotopes, including ^{131}I and ^{134}I. Activity values are determined via gamma spectroscopy performed upon depressurised PHTS grab samples obtained once per week per Unit. Manual sampling is performed more frequently when ^{131}I activity increases beyond a threshold level (e.g. 'action limit') or when a Unit GFP monitoring system is unavailable.

While chemistry lab sampling for PHTS I^{131} activity is very accurate, this process cannot provide accurate values for PHTS Noble gas activities, since PHTS samples become depressurized upon collection.

3.0 FUEL DEFECT MANAGEMENT METHODOLOGIES AND GUIDELINES:

Fuel element defects are occurring in Bruce 'A' and Bruce 'B' Units. Fuel and Physics staff use fuel defect detection, identification and de-fuelling 'standardized' or 'routine' methodologies to disposition these defects. Additionally, fuel defect management 'guidelines' have been developed in parallel with defect management methodologies. Guidelines serve to supplement methodologies during Unit start-up operation.

3.1 Fuel Defect Management Methodologies:

Two general methodologies used for fuel defect management at Bruce Power. Each of the methodologies is centered upon the life-cycle stage in which a fuel defect is located.

The first methodology can be referred to as 'early' localization of a fuel defect. This category of fuel defect presents the minimum risk to an affected Unit. In this scenario a fuel defect is located while the PHTS ^{131}I measured activity values are low. The defect can then be tracked while its sheath-to-fuel pellet gap inventory of fission products builds and while PHTS ^{131}I measured activity values remain well below license limit values. This type of defect is most often removed by regular fuelling, thereby optimizing fuel performance. Note that an 'early' localization defect management strategy can be implemented only if defect detection and localization systems are available and are functioning effectively. Note that stand-alone defect push de-fuelling might be required if PHTS ^{131}I measured activity values increase suddenly.

The second methodology is referred to as 'late' localization of a fuel defect. In this scenario a fuel defect develops without being located in a timely manner (e.g. due perhaps to compromised localization systems) and as a result, much of its sheath-to-fuel pellet gap inventory of fission products is released into the

PHTS. This type of defect is often characterized, therefore, by PHTS ^{131}I measured activity values that are well above the normal operating conditions value for the affected Unit. In this scenario the defect must be located with a degree of confidence and it must be stand-alone defect push de-fuelled expeditiously. Once the PHTS ^{131}I measured activity exceeds the license limit value then only 24 hours are available either for completion of defect identification/location, de-fuelling and confirmation activities or until PHTS ^{131}I measured activity drops below the license limit value.

Fuel defect management methodologies consist of four phases:

(1) detection,
(2) localization (candidate channel selection),
(3) removal, and
(4) confirmation.

Methodologies are station-specific and have been developed therefore in two parts; for Bruce 'A' Units and for Bruce 'B' Units, respectively. The Bruce 'A' 'late' localization defect management general methodology is presented in example, below.

3.1.1 Bruce 'A' (Units 3 and 4) 'Late' Localization:

(1) Defect Detection:

The primary means of fuel defect detection at Bruce 'A' is via Chemistry Lab PHTS ^{131}I measured activity. In the circumstance of 'late' localization, PHTS ^{131}I activity measurements will be requested by the Shift Manager or by Fuel and Physics personnel every 4 hours, typically. The secondary (and substantially less reliable) means of detection is via analyses of DN scan data, but only if a DN scan was performed shortly after the appearance of PHTS fission product elevated levels.

(2) Defect Localization:

The primary means of defect 'late' localization at Bruce 'A' is via analyses of DN scan data. DN scans should be requested routinely from Fuel Handling personnel once per shift, typically, until it is determined either that DN scan results are effective (e.g. the defect is identified confidently) or that DN scan results are inconclusive. Note that two consecutive 'positive' DN scans should be obtained prior to selecting a defect candidate channel. The secondary means of defect 'late' localization at Bruce 'A' is via correlating fuelling history vs. trends observed in PHTS ^{131}I measured activity. Note that if DN scan results prove inconclusive, then the secondary means of defect localization must be used to provide Fuel Handling personnel with defect candidate channels in a timely manner.

(3) Defect De-fuelling:

Fuel defects that are located late are de-fuelled by stand-alone defect de-fuelling. Channel loading (number of bundles required for defect ejection) is determined by correlating fuelling history vs. trends observed in PHTS ^{131}I measured activity. Although time is of the essence in this case, candidate channel(s) de-fuelling should be delayed until PHTS ^{131}I measured activity is shown to be elevated via two consecutive Chemistry Lab measurements.

(4) Defect Confirmation:

PHTS ^{131}I measured activity values are used for short-term confirmation of the presence of a fuel defect in the contents of a de-fuelled candidate channel. Additionally, DN scan results for the de-fuelled channel produced after completion of defect de-fuelling can indicate whether the candidate channel contained defective fuel. Finally, results of ‘dry-sipping’ performed by Fuel Handling personnel can indicate the effectiveness of defect de-fuelling. Note that ultimate confirmation of the presence of a defect in the contents of a de-fuelled channel can be made only after the contents of the channel have been inspected visually.

Time must be managed effectively during ‘late’ localization defect management if the fission product inventory deposited in the PHTS results in ^{131}I measured activity beyond the License Limit value. Should this occur, then only 24 hours is available for completion of defect identification/localization, de-fuelling and short-term confirmation activities (or until PHTS ^{131}I *measured* activity drops below the License Limit value).

3.2 Fuel Defect Management Guidelines:

Bruce Power has compiled a data base of PHTS ^{131}I measured activity during Unit power raise where the Unit contained either known or unknown fuel defects. These data have been used by NSASD staff and Fuel and Physics staff to characterize analytically and to predict fuel defect behavior during Unit power raise. These characterizations and associated predictive capabilities have been benchmarked successfully. They form the basis for the following fuel defect management guidelines.

Fuel defect management guidelines have been developed for:

(1) Unit start-up after a short-outage (duration less than 30 days).

(2) Unit start-up after a long-outage (duration greater than 30 days).

Guidelines for each of these situations are station-specific and have been developed therefore in two Parts; for Bruce 'A' Units and for Bruce 'B' Units, respectively. Adherence to these guidelines will best ensure that Unit power raise activities can proceed with minimal risk of incurring a significant release of ^{131}I to the PHTS. Bruce 'A' defect management generalized guidelines are presented in example, below.

3.2.1 BRUCE 'A' (Units 3 and 4): Start-up after a short outage:

(1) Chemistry Lab measured PHTS ^{131}I activity must be lower than 3.2 μCi/kg @ 10 kg/s purification flow rate prior to commencing Unit ramp-to-power beyond ZPH. Purification flow rate shall be maximized while the Unit is shut-down. Note that this PHTS ^{131}I activity limit and each activity limit discussed hereafter shall be pro-rated with purification flow rate.
(2) Power shall be raised beyond ZPH in accordance with the Bruce 'A' Operating Manual. Chemistry Lab PHTS ^{131}I activity measurements shall be made each shift beyond ZPH.
(3) Unit power shall be held at or about 80%RP. Three Chemistry Lab PHTS ^{131}I activity measurements shall be made within 12 hours of the Unit attaining this power.
(3) If measured PHTS ^{131}I activities determined in "(3)", above, are *all* less than 8.0 μCi/kg @ 10 kg/s purification flow rate, then power can be raised in accordance with the Bruce 'A' Operating Manual.
(4) If *any* of the measured PHTS ^{131}I activities determined in "(3)", above, are greater than or equal to 8.0 μCi/kg @ 10 kg/s purification flow rate, or if the Unit has been held at or about 80%RP for more than 12 hours, then Fuel and Physics staff shall be consulted for further recommendations.

3.2.2 BRUCE 'A' (Units 3 and 4): Start-up after a long outage:

(1) Chemistry Lab measured PHTS ^{131}I activity must be lower than 3.2 μCi/kg @ 10 kg/s purification flow rate, prior to commencing Unit ramp-to-power beyond ZPH.
(2) Power shall be raised beyond ZPH in accordance with the Bruce 'A' Operating Manual. Three Chemistry Lab PHTS ^{131}I activity measurements shall be made within 24 hours of the Unit attaining full power, and the results of these measurements shall be communicated to Fuel and Physics staff.

4.0 FUTURE WORK:

Fuel defect management efforts must continue for all Bruce Power Units, until a root cause is found for the occurrence of fuel defects. Current defect management tools must be maintained and improved. Current defect management methodologies and guidelines must be updated and revised as experience is acquired. To this end, fuel defect management efforts will be expanded to include:

(1) disposition proactively the maintenance-based deficiencies in Bruce ‘A’ and Bruce ‘B’ GFP and DN monitoring systems,
(2) implement (at-site) the STAR fuel defect characterization computer code in a production environment support capacity,
(3) improve the capabilities of the Bruce ‘A’ GFP monitoring systems,
(4) develop and implement fuel defect management guidelines for high power, steady-state operating conditions, and,
(5) implement the planned upgrades to the Bruce ‘B’ DN monitoring systems.