**Fuel Defect Localization Using Delayed Neutron Monitoring System
Bruce A 2011 to 2013**

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Abstract

The delayed neutron monitoring system (DNMS) is the primary system used to locate defective fuel bundles in reactors on the Bruce site. Recent system upgrades at Bruce A and the refurbishment and restart of two reactor units have created minor challenges. The data analysis methods used for Units 3 to 8 could not be directly applied to the scan data from the refurbished units due to lack of historical data and initial scans being performed after fuel defects were present in the cores. Work continues to better utilize the DNMS data to locate channels containing defect fuel.

1. Introduction

Fuel defects have been at the forefront of many nuclear power discussions in recent years due to the lasting impact on radiation dose to workers. Many initiatives to improve prevention, detection, location, and removal of fuel defects have been undertaken.

At Bruce Power, the primary method of locating fuel defects is by analysis of data from the delayed neutron monitoring system (DNMS). Historically on Bruce Units 1 to 4, DNMS data trends have been analysed in conjunction with chemistry grab samples [depressurized samples taken from the primary heat transport system (PHTS) and analysed by the chemistry lab] and unit fuelling history to narrow down potential candidate channels. Bruce Units 5-8 also have a gaseous fission product system in service to continuously monitor fission product concentrations in the PHTS which aids in the use of other defect characterization tools. The refurbishment and restart of Bruce Units 1 and 2 presented a unique challenge in that the first DN scans were performed after fuel defects were present in the core and well before the onset of routine refuelling.

Upgrades to the DNMS on Bruce A units have also presented challenges in how to treat data from the upgraded system and trend it in conjunction with data from the old system.

2. DNMS Background

2.1 Basic System Design

A sample line from each fuel channel's outlet feeder is run to the designated DN room (east or west depending on the flow direction of the channel). Within each room, the coolant from each channel passes through sample coils which are arranged in 8 rows of 30 to form a matrix. The system utilizes restrictors in the piping that returns the coolant to the PHT circuit to provide a uniform transit time from the feeder to the sample coil [1].

To perform a scan, a carriage with eight BF_3 detectors mounted on it travels along the rows stopping at each of the 30 positions. The measured count rate for each channel is currently exported to an Excel spreadsheet and saved for analysis in a directory accessible by Fuel Handling, Station Engineering, and Fuel & Physics.

2.2 Data Analysis History

Multiple studies have been undertaken to determine an optimal way of normalizing the raw data from the DNMS [2, 3]. Normalization of the data is required due to each detector having a characteristic profile and each channel having a unique background count rate (See Figure 1: Unit 1 Detectors 1E & 3E).

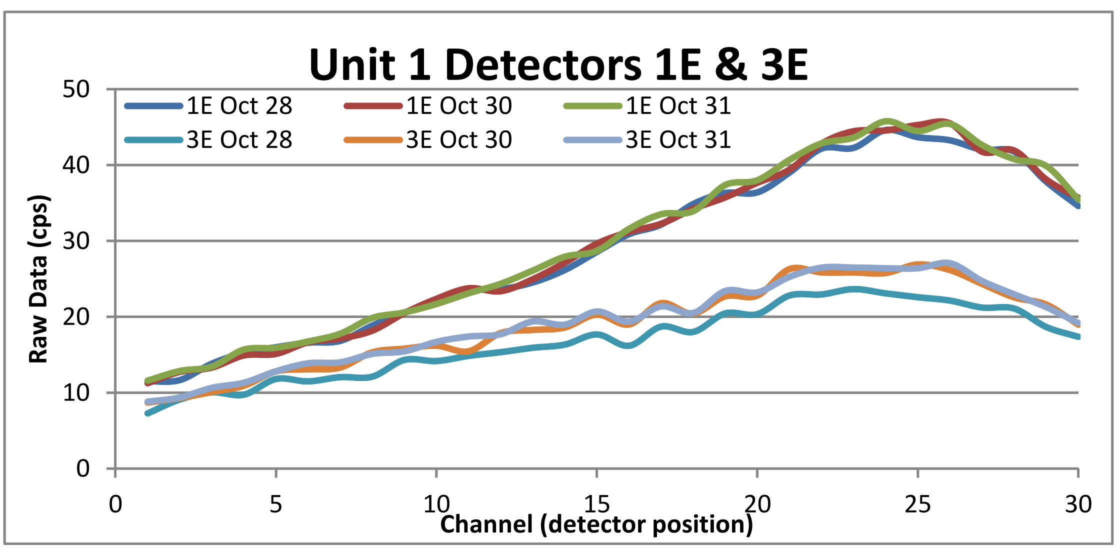

Figure 1: Raw data from two Unit 1 Detectors (1E and 3E) taken from three scans showing the typical shape of a detector's readings (with the lowest points between positions 1 and 8 and the highest readings between positions 20 and 28 [2]).

The most common normalization method applied to data from all eight Bruce units for over six years in attempting to locate fuel defects has been referred to as a Double Normalization or a Double Discrimination Ratio[1] (DR). The first normalization is relative to the average count rate over the detector. An initial average of the 30 data points is calculated and any outliers (points more than 2 standard deviations from the average) are removed before a revised average is calculated. The count rate from each position is then divided by this revised average, resulting in a ratio referred to as the single normalized value.

This ratio is the basis of the second normalization. The single normalized values for up to 100 previous points for the specific channel (or matrix position) are averaged. This average is again calculated using data values that are within +/- 2 standard deviations of the original channel average. The single normalized value for each channel from each scan is divided by this average. This is referred to and the doubled normalized value.

The primary purpose of this approach is to compensate for fluctuations in the scan data due to the electronics and other factors that uniformly change the scan data results for a specific row. Other special groupings of the data are currently limited to viewing all channels in the same row of the DN matrix within the same graph and having each position of each row denoted by the same colour of line in the trends. For example, each position '1' channel is denoted by the same colour within the graph of their row. So, if the carriage position during one scan is slightly incorrect and results in the counts for all channels in the same column of the matrix being skewed, this is more transparent to the user.

Historically, regardless of the method used to calculate discrimination ratio, DR $\geq$ 1.3 indicated a channel containing a failed fuel bundle. A defined threshold value was especially useful before the regular use and availability of computers made data trends readily and easily possible. It continues to be useful when comparing the effectiveness of different data analysis methods in locating fuel defects. However, in practice, no DR threshold is required to identify a "suspect defect" channel. Figure 2 shows an example of a channel identified (and later confirmed) as containing defect fuel based on the double normalized trend while the DR was less than 1.15. The channel was refuelled on June 9, 2011 and the double normalized data corresponding to the channel in question is denoted by the thicker teal coloured line in Figure 2.

Following the first normalization currently in use at Bruce Power, the DR for each channel is typically between 0.3 and 1.7 (see Figure 3 for example). Logically, about half of the data points should be greater than one and half of them less than 1.

[1] The term Discrimination Ratio has been used in the past to mean any normalization of the data intended to highlight a significant increase in the DN signal for a given channel from its background count rate.

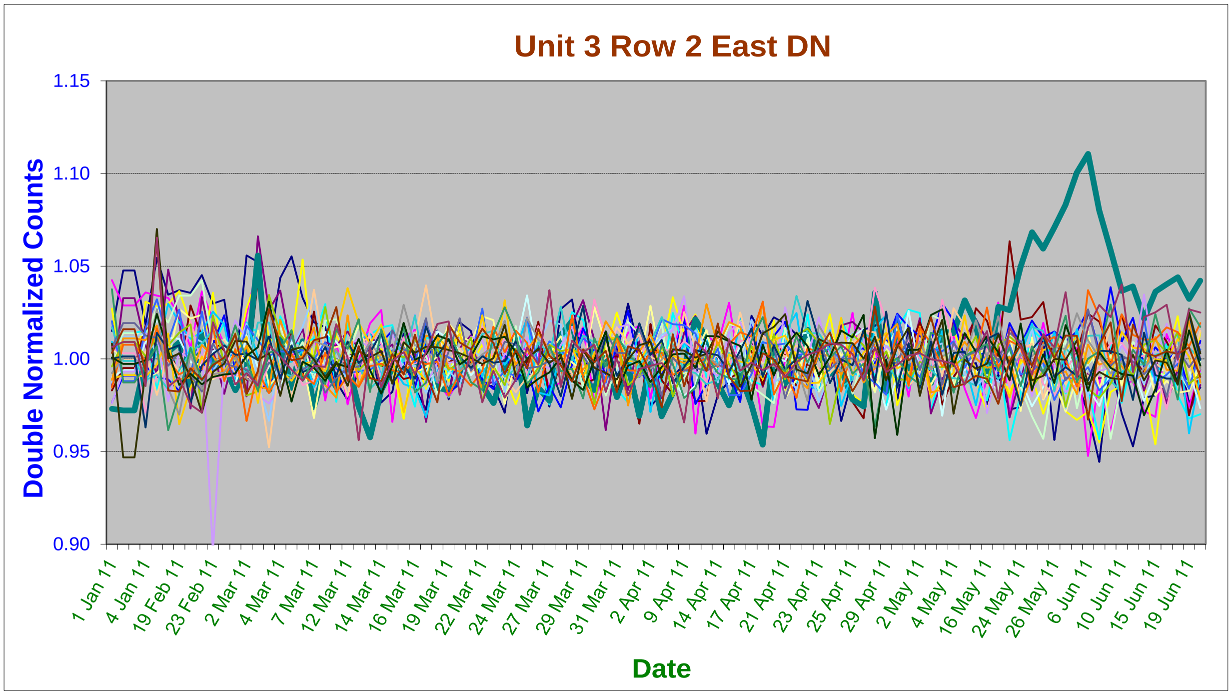

Figure 2: Double normalized data from Unit 3 showing location and removal of defect fuel

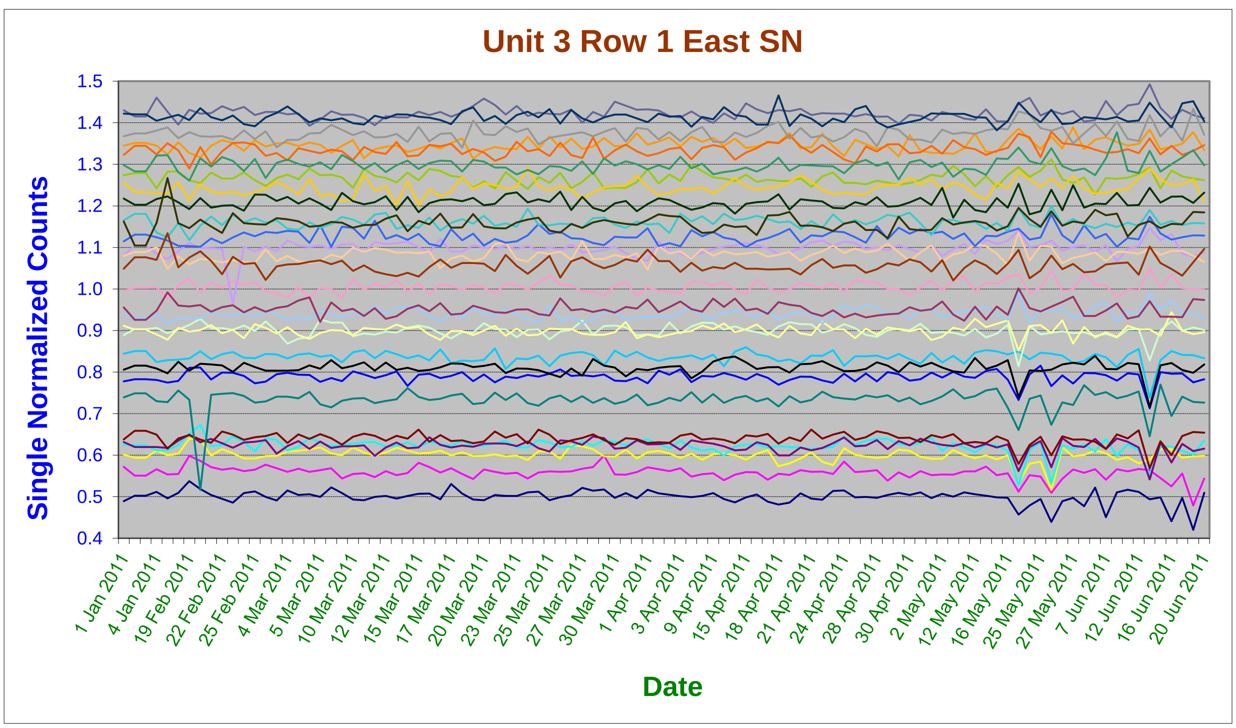

Figure 3: Single normalized data from Unit 3 Row 1 East.

2.3 Data Analysis Program Changes

Modifications to the analysis program continue to be made as opportunities are found to optimize the user's ability to filter the data and identify suspect defect fuel. No major changes have been made to the fundamental method of calculating the discrimination ratio as previously described. Small modifications to the way the program is used and data viewed include presenting the singled normalized values in a graph format; user configurable upper and lower limits to filter input data and eliminate extraneous values; user facility to identify entire files or groups of data in a file that should no longer be used for continued analysis. All of these changes are intended to maximize the use of each scan file in the analysis process.

3. Recent DNMS changes

3.1 2011 / 2012 System Upgrades

A project was undertaken to upgrade the Bruce A Units 1 to 4 DN systems. The scope of this work focused on the modernization of the neutron counting electronics, calibration equipment and replacement of the original computer system used for system control and data collection with a PLC and HMI. Also, a redesign of the mechanical structure of the carriage and drive system was done to improve both access and maintainability. All internal and external cabling to the DN rooms was replaced and a temperature probe was added to allow tracking of room temperature in the scan data. Finally, changes still being implemented include the detector boxes (sampling heads) being re-manufactured with the addition of spring loaded detector retaining clips and a correction to the Unit 1 and 2 waterbox drain lines for improved waterbox venting. Figure 4 shows a general arrangement of the mechanical structure of the upgraded DN monitoring system.

The original system had been designed in a centralized manner which located most of the neutron counting equipment in an equipment room near the Main Control Room. This resulted in long cable runs to each DN system in the field and calibration of the equipment needed to be general enough so as to satisfy the operation of the detectors and other electronics located on each DN carriage. The scope of work of the project changed the design so that the neutron counting equipment was decentralized and located close to each DN room. This was the single most significant design change introduced by the project.

The entire DN monitoring system was not upgraded as part of the recently completed work. The DN room waterboxes were not inspected or changed. Also, the DN sample lines and coils were not altered in any way. There is currently no known process to directly measure the flow through the sample lines and coils. Indirect testing has occurred at Bruce B to confirm flow through a small subset of channels using RTDs. Finally, the DN room cooling was not updated as part of this work, but is currently in the planning phase for replacement.

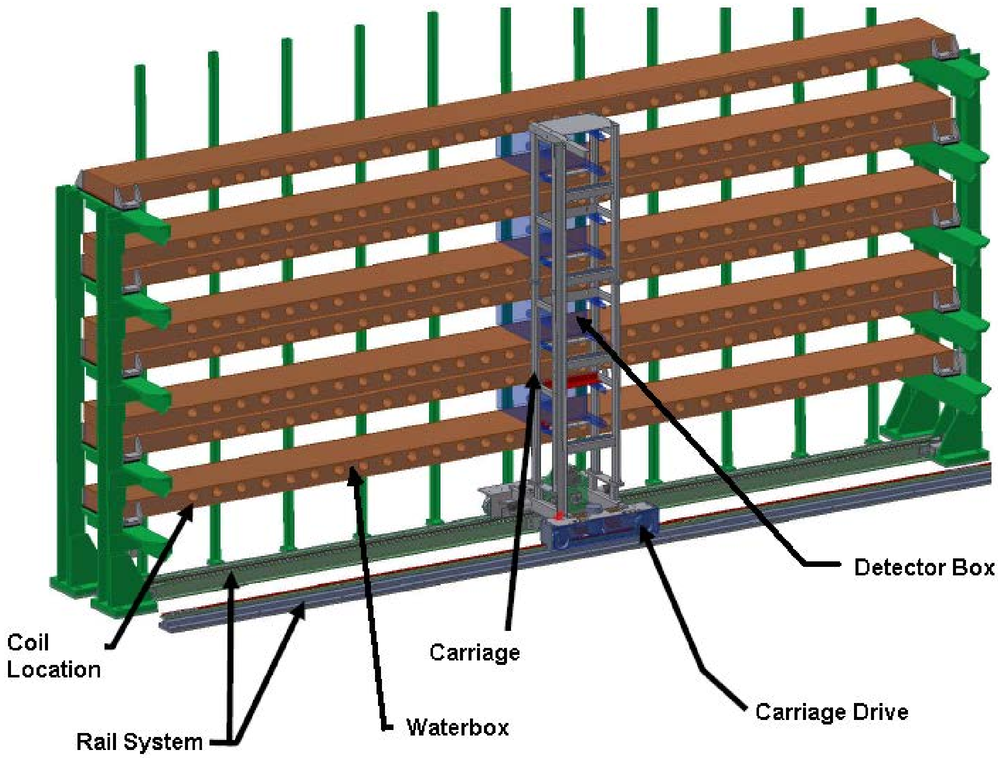

Figure 4: General arrangement of DN carriage, detector boxes and coils surrounded by a waterbox [4].

3.2 2011 / 2012 Units 3 & 4 challenges and OPEX

Following the installation and commissioning of the updated DN monitoring system in Units 3 and 4, it became apparent that the data generated by the old and new systems was not identical in value. The approach used to compare the new and old system data first included a visual check of the characteristic profile of each DN row. A comparison between data gathered from the new and old systems confirmed there are similar DN row profiles as shown in Figure 5. The values in the graph are normalized to the count rate of the DN matrix row 1 position 1 value. This was 10.393 counts per second for the old system and 53.54 counts per second for the new system.

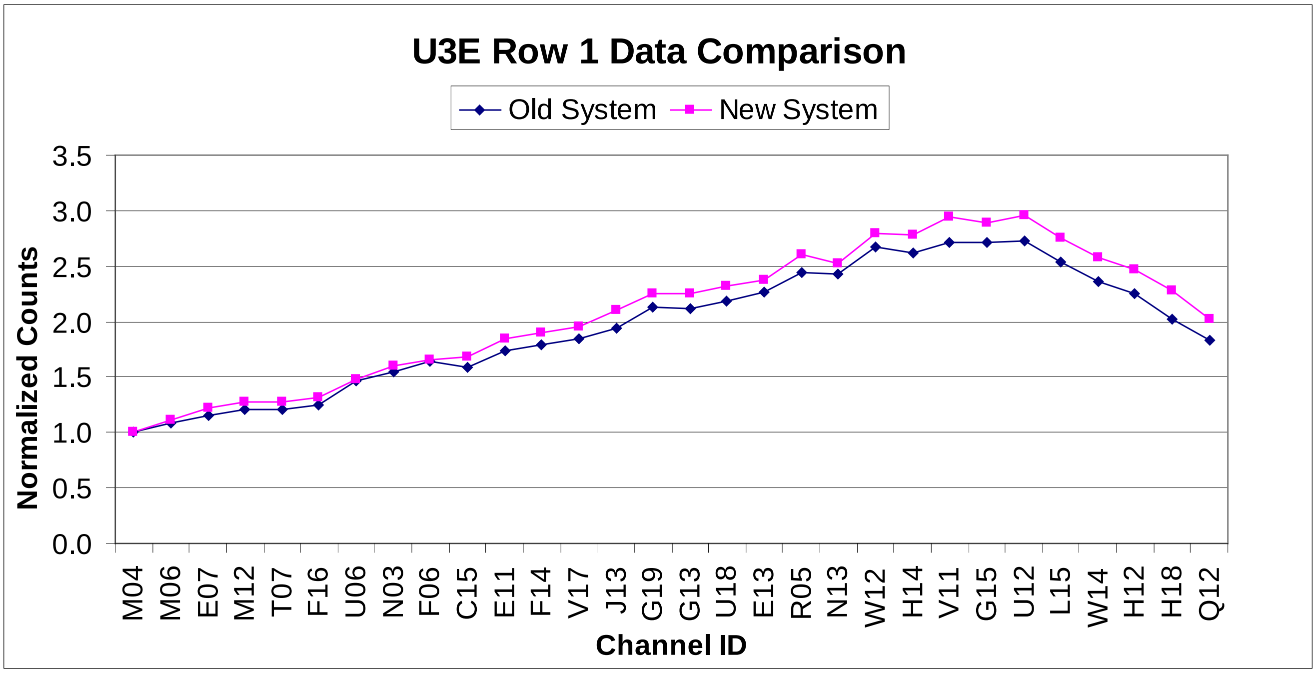

Figure 5: Comparison of data gathered from the new and old DN systems for Unit 3.

A check of the ratio between the new and old system data was also done. The new data showed an increase in counts per second for all DN positions. The factor by which the data increased was generally consistent within each row but different from row to row as shown in Figure 6. Reasons for these changes in acquired neutron counts are suspected to be associated with improved cabling, changes in amplification and threshold limits of the neutron counting equipment and improved sensitivity of the selected detector. Both of the checks done to compare new and old system data were general in nature but showed that the new system was generating data as expected.

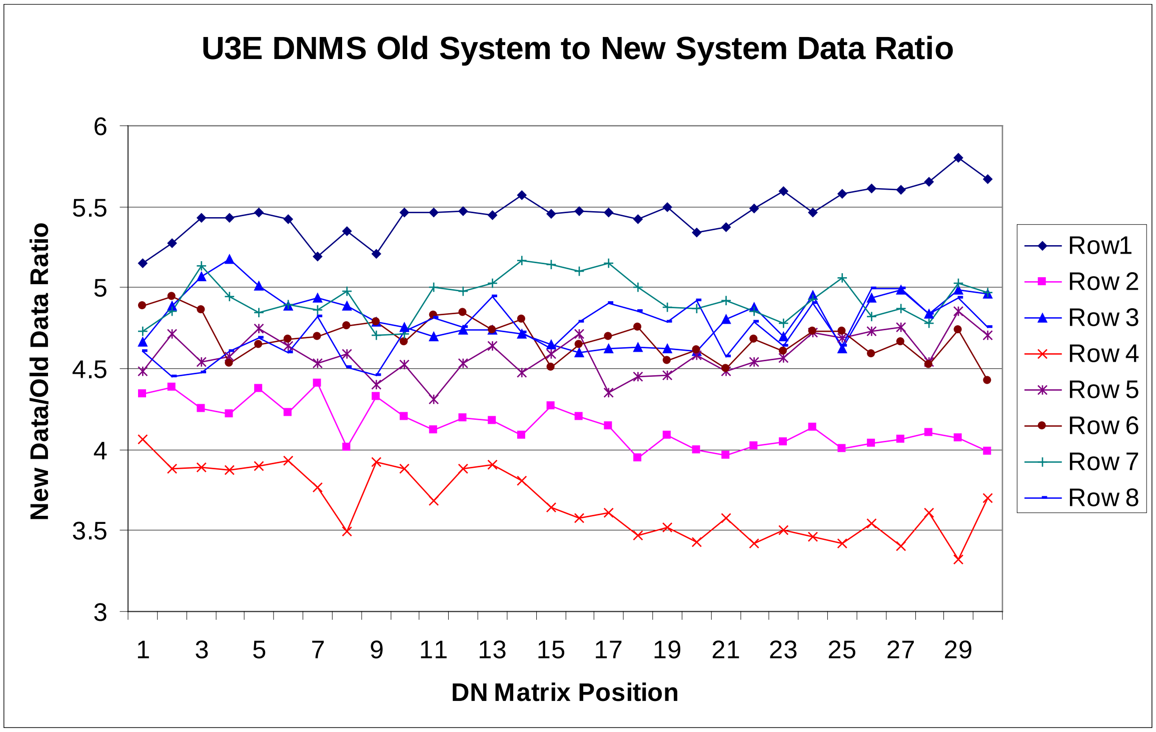

Figure 6: Comparison of data gathered from the new and old DN systems for Unit 3.

3.3 Restart Units 1 & 2 challenges and OPEX

The count rates measured by the new system in Units 1 and 2 are significantly lower than the count rates from Units 3 and 4 (40-100 CPS is typical for Units 3 and 4 while 5-25 CPS is typical for Units 1 and 2) and the low count rates more closely resemble data acquired at Bruce B. However, the Bruce A and B systems are only similar and not identical in design and neutron counting equipment.

Unlike the comparison of patterns from the new and old systems done for Units 3 and 4, there is no recent scan data available to perform a similar comparison for Units 1 and 2. For these units, the general expected shape of the characteristic curve was verified for the data from the new system.

Temperature control issues in the Unit 1 and 2 DN rooms during initial ramp up of the units prevented DN scans from immediately occurring. Following the repair of the rooms cooling system, indications of failed fuel were already present. Therefore, the usual practice of looking for a signal which is increased from its typical baseline value could not be applied. Instead, channels containing defect fuel were identified using raw counts alone. Figure 7 shows the first 12 scans from detector 6 west of the Unit 2 DNMS following the unit return to service after being laid up for approximately 15 years. The channel represented by the bolded orange line was refuelled on February 1.

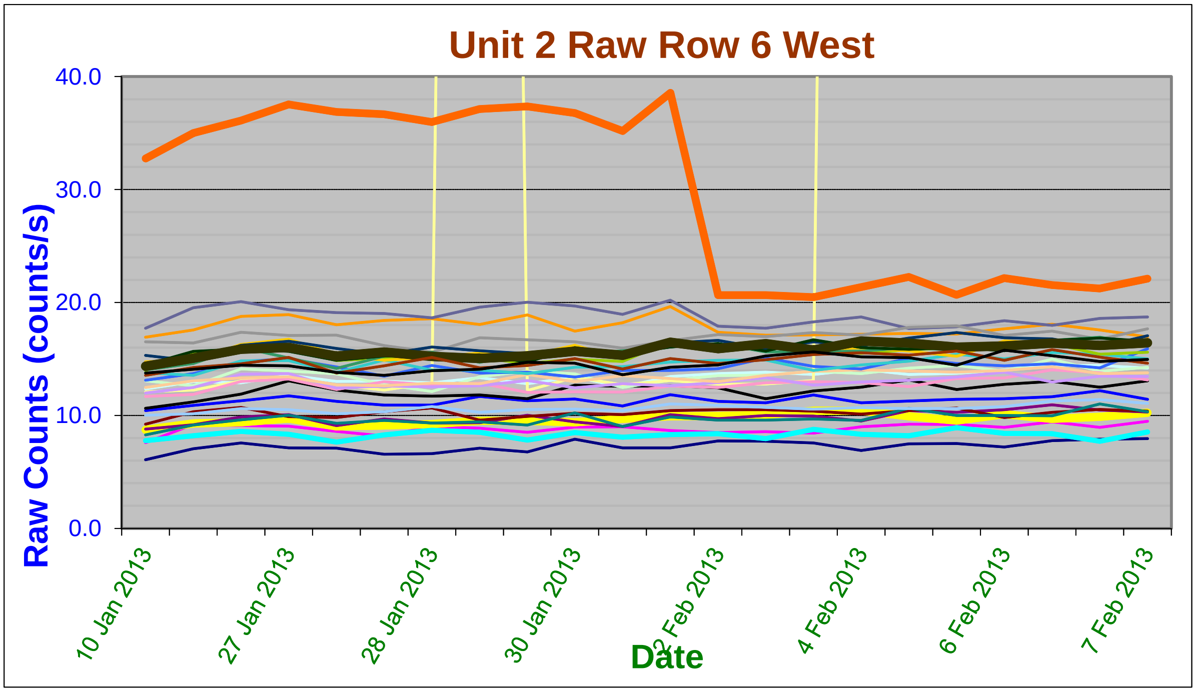

Figure 7: Raw counts from Unit 2 Row 6 west following unit Restart

4. Ongoing Challenges

The original DNMS design included level control of the water in the waterboxes based on tank temperature in one of the waterboxes. As a consequence of this method of control, the flow rate of water into the waterboxes would increase if the temperature increased outside of the set point. This feature is no longer in use at Bruce A and the flow is manually adjusted by operators and, as a result, can be constant for long periods of time until an adjustment is required. It is unclear what, if any, impact this has on the DNMS data.

Other issues that are occasionally encountered include a sudden non uniform step change in the count rate for one or more rows as illustrated in Figure 8. The cause of this change is not well understood and typically applies to several of the DN rows. These changes impact the analysis of the data as long-term trending has typically been instrumental in determining suspect defect channels. This issue is believed to be associated, to some extent, with reactor power levels but further work is required to determine how to compensate for this in order to improve data analysis. In addition, final system upgrades to the DN detector boxes and Unit 1 and Unit 2 drain lines are expected to remove age related and design issues commonly associated with data fluctuations.

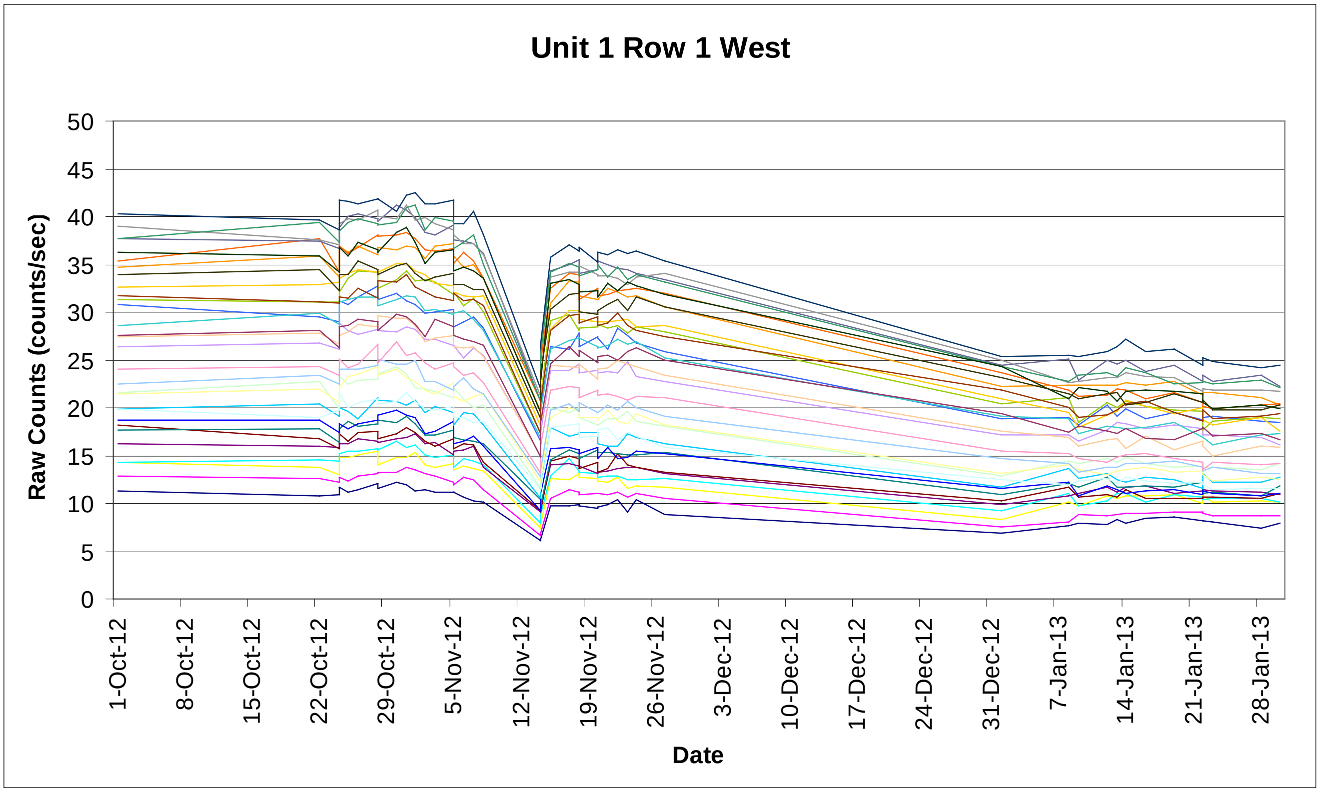

Figure 8: Raw counts from Unit 1 Row West following unit Restart

5. Conclusion

The DNMS is a key tool in the location of fuel defects in Bruce units. Despite a number of challenges, the DNMS data alone has resulted in sixteen suspect defect fuelling operations from the Restart units to date. So far, in bay inspections of the fuel have confirmed defect bundles in all fuel strings inspected.

Following completion of all system upgrade activities at Bruce A, the continuity of the data from scan to scan with respect to operating conditions will be evaluated and the need for further system improvements will be assessed. With data analysis changes being relatively simple to make, when compared to physical system changes, there will be a continued focus in this area with data sorting and filtering as the primary methods to continue to improve identification of channels containing fuel defects.

References

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