ESTIMATE OF DETECTOR FLUX DECREASE DUE TO THE PRESENCE OF AN ABSORBER IN BRUCE REACTOR

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Abstract

This paper presents the investigation supporting a possible method for measuring detectors prompt fraction, without the need for a reactor shutdown. A rapid flux depression can be induced in a detector by inserting an absorber in the same detector assembly. This paper calculates the static flux depression that would occur. Several configurations of absorber placed beside the detector are investigated with both DRAGON and MCNP.

1. Introduction

In-core self powered flux detectors (ICFD) produce an electric current in the presence of a neutron flux. Such detectors are characterized by a flux sensitivity (electric current vs neutron flux) as well a dynamic characteristic (response to a fast perturbation) [1]. These characteristics are dependent on the active material composition. The detectors currently used in CANDU reactors can be underprompt (i.e the ratio of detector response to a flux increase is less than unity) or overprompt (i.e. ratio is greater than unity). These characteristics are affected by aging as discussed in various detector design documents [1]. Sensitivity degradation with aging can lead to operational constraints as the amplifier units have a limited range. Aging makes dynamic response slower than the nominal values. In safety analysis, maximum deviations of the dynamic response are established; additional degradations can lead to operational penalties.

In order to confirm that the detectors are within their safety limits, the main indicator of detector dynamic response, the prompt fraction (PF), is confirmed using fast rundowns from high power, typically induced by SDS2 rundowns from approximately 60% FP. The ICFD effective prompt fraction is determined by the ratio between the normalized signal drop of the reference ion chamber and that of the ICFD signal, measured three seconds after trip initiation (for further discussion see [3]). It was estimated that at least a 50% reduction in the flux seen by a detector would be required in order to obtain reasonable estimates.. It would be beneficial if alternate methods of testing detectors PF's could be established such that measurements can be obtained more often or more accurately.

This paper looks at one such idea. Inducing a fast and significant flux drop in one detector would allow, in principle, to establish the PF of the affected detector. Insertion of a strong neutron absorber in proximity of a detector could in principle provide a means to reduce the neutron flux and ultimately allow determination of its dynamic characteristic. This could be provided by a thin absorbent rod travelling in an empty well of the HESIR assembly that would be quickly moved in position to provide a shutter effect on the detector of the interest. There are additional requirements, such as minimal perturbation of the core as result of such a test. However the main focus here is to establish the typical reduction in the detector signal when a strong absorber is introduced in an available well of a Hybrid Encapsulated Straight Individually Replaceable (HESIR) detector assembly, in the immediate vicinity of an in-core detector. The methodology for analyzing such a test has not been developed yet, however in principle it would be similar to the analysis of SDS1 rundowns and would have to rely on detector measured signal analysis using on an off-line MATLAB methodology [4] and on the estimates of flux reduction as calculated here

More precisely we will provide in this paper an estimate of the decrement of the flux inside of a detector assembly when the center well is occupied by a 3mm Outer Diameter (OD) Cadmium rod compared to the nominal case. The detector assembly can be located on the line demarcating two fuel cells similarly to a reactivity device or closest to one of the cells.

2. Traveling Flux Detector (TFD) Layout

The general arrangement of Vertical Flux Detector (VFD) units has been studied from design drawings as well as the other drawings available. A general discussion on the design of detector assembly can be found in other papers such as [1] and [2].

Figure 1 shows the layout of the HESIR assembly. There are 12 small tubes (well tubes) for individual detectors, strapped around the shield plug (Section 3-3 and 4-4 on Figure 1). At the lower portion, inside the core, below the shield plug end, there are only the tubes strapped together (Sections 5-5 and 6-6 on Figure 1). One of the tubes, marked as T.F.D. is for a Traveling Flux Detector, which is used for calibration. That tube goes through the centre of the shield plug upper portion and the centre of the housing (see Section 2-2). That T.F.D. tube has access from the top of the housing, after removing the screw plug on top of the housing, so there is no need to open the housing. The actual view 6-6 represents the detector layout as inside the reactor. The locations of the actual detectors depend on each VFD unit.

The TFD tube is the tube in which the Cd wire can be inserted. Inside each detector capsule, Helium gas is modelled by CO2. The dimensions of the well tubes are

Small well tubes:	0.135” ID x 0.008” wall thickness	material: Zircaloy
Capsule tube:	0.650” ID x 0.020” wall thickness	material: Zircaloy
Guide tube:	0.820” OD x 0.040” wall thickness	material: Zircaloy

3. DRAGON and MCNP Models

Several configurations of absorber placed beside the detector are investigated with both DRAGON [5] and MCNP [6]. The models are described below.

3.1 DRAGON Model

The DRAGON model is based on the standard supercell 3-D model, where the device is replaced by the detector layout described above. Local conditions for the fuel bundles were taken as equilibrium core with 2.72% PT crept and full power conditions based on the standard Bruce A model. The supercell models used in DRAGON to compute Shutoff Rod incremental cross sections are the basis of the current modelling. The fuel and pressure tube (PT) conditions have a limited impact on the detector fluxes. Since we are calculating a flux ratio, we expect the results to be similar for any fuel and PT conditions.

The model in DRAGON is representative of the detector unit layouts as shown in Figure 2 and Figure 3. The two layouts are chosen to represent when the detector is either on the line demarcating the 2 cells or when the detector is closer to one of the cells. Two calculations are performed on each supercell model, with and without the Cd wire inserted. The Cd wire is 0.3 cm O. D. with a density of 1.07g/cc containing only Cd113. The fluxes inside all detector capsule tubes are condensed to two energy groups.

DRAGON version 3.06 [5] on Linux has been used, because the NXT module was required to model the actual detector layout. The All-DRAGON approach is selected. In DRAGON, tracking options of 12 angle directions and 100 lines/cm^2 have been used.

The size of the detector guide tube and well tubes is very small compared to the supercell size : 1.04 cm of outer radius for guide tube and 0.2 cm outer radius for well tubes, compared to 57.15 cm × 28.575 cm × 49.53 cm for the supercell.

3.2 MCNP Model

MCNP [6] models have also been built using the DRAGON 3-D models for the 2 detector layouts as a comparison. The library XS68MT based on library ENDF-B/VI release 8 has been used and all DRAGON mixtures are reproduced in MCNP.

4. Results

Only neutron thermal fluxes are reported; depending on the type of detectors, gamma response may be important (e.g., inconel detectors are less impacted, however the platinum based detectors include a non-negligible gamma component) and would somewhat increase the signal, however this is ignored for the purpose of this work. There is not much impact on the fast flux from the Cd wire and detectors are sensitive to thermal flux only. DRAGON calculations are reported, MCNP results are used as confirmation. The fluxes for the layout (1) in DRAGON are shown in Table 1. The fluxes are flat across the detector locations when there is no Cd wire.

The results for the two layouts in DRAGON are shown in Table 2. For any layout, the 12 detector depression factors show no symmetry around the Cd wire. Although layout 1 is not symmetrical, layout 2 is. The results for both layouts are very similar when using DRAGON. After further investigation, it appears that the tracking errors in the small regions representing the well tubes are not the same in each tube and the resulting fluxes are then in error.

Two approaches were followed to establish the flux decrement. MCNP models of the 3D supercell have been built for the 2 detector layouts. The DRAGON 3D model was simplified as a 2D model in which the detector layout is fully represented but the fuel channels are simplified by a homogeneous region as shown in Figure 4. Moderator only is defined around the detector guide tube. The overall 2D geometry is a quarter of the original 3D one. The MCNP models will provide the expected decrement of fluxes and the DRAGON 2D models will show if DRAGON really fails to model the detector or if the accuracy required of the 3D model was out of reach for DRAGON.

The results of the MCNP models are shown in Table 3. The flux ratios are fully symmetrical around the Cd wire. Moreover the layout has no impact on the flux ratios. Table 4 shows the results on the DRAGON 2 D models. It has been verified that the keff eigenvalue was similar for the case without Cd wire in both 2D and 3D models in DRAGON, providing a verification of the homogenization process and dimensions. MCNP and DRAGON eigenvalues without the Cd wire are close as well. Results of the 2D DRAGON models show that DRAGON can handle the detector models, but the results are under-estimating the cadmium impact. In a 3D DRAGON supercell geometry, the accuracy required to get the flux depression in each of the 12 wells is too demanding for the tracking capabilities in 3D.

5. Conclusion

A model for detector layout has been developed and the impact of a nearby absorber has been assessed. The results show that the flux depression will reduce the static detector response of about 20%. Future work could be undertaken to investigate if this effect can be employed to determine dynamic detector behaviour although the initial judgment was that 50% would be needed. The 20% flux reduction is judged to be of the same order of magnitude as the typical detector noise hence this would also suggest un-feasibility of such a flux-drop method.

With respect to the methodology employed it is to be noted that to compute such flux depression in very small regions compared to the fuel channels dimensions, great attention has to be paid to the model convergence and its representation (2D or 3D). A 2D model in DRAGON is an acceptable compromise to estimate the flux depression in regions of interest much smaller than the fission source, or far away from it. It is recommended to use a simplified 2D DRAGON model before using directly a MCNP model. Expectations based on geometry and symmetry configuration are primary expectations that should always be considered.

6. References

[1] C. J. Allan, “Recommendation Concerning the Choice of Detector Designs for Future (Bruce B and Beyond) CANDU Power Reactors”, CRNL-1977, Oct. 1979.

[2] J. Cuttler, N. Medak, “New Flux Detector for CANDU 6 Reactors”, Proceedings of 13th Annual CNS/CNA conference, St John, NB, June 1992.

[3] O. Glöckler et al, « TESTING THE DYNAMICS OF SHUTDOWN SYSTEMS INSTRUMENTATION IN REACTOR TRIP MEASUREMENTS », paper presented at 8th Symposium on Nuclear Reactor Surveillance and Diagnostics, Göteborg, Sweden, May 27-31, 2002

[4] O. Nainer, C. Banica, “Analysis of September 2007, Bruce A Unit 3 SDS1 Rundown to Assess the Impact of Empty Channels on Detector Responses”, Proceedings of 23rd Simulation Symposium, Ottawa, ON, October 2008.

[5] G. Marleau, A. Hébert, R. Roy, “A User Guide for DRAGON 3.06”, École Polytechnique, Technical Report IGE-174, 2009.

[6] Applied Physics Division, "MCNP – A General Monte Carlo N-Particle Transport Code, Version 5 – Volume II: User's Guide", Los Alamos National Laboratory Report No. LA-CP-03-0245, April 2003.

Table 1 Fine Mesh: Average Thermal Flux – Layout (1) [dimensionless]

Detector Location	No wire	Cd Wire	Ratio
1	2.44690E-03	2.211E-03	90%
2	2.44530E-03	1.685E-03	69%
3	2.44540E-03	1.936E-03	79%
4	2.44480E-03	1.948E-03	80%
5	2.44610E-03	2.127E-03	87%
6	2.44600E-03	2.257E-03	92%
7	2.44620E-03	2.262E-03	92%
8	2.44470E-03	2.200E-03	90%
9	2.44520E-03	2.102E-03	86%
10	2.44540E-03	1.673E-03	68%
11	2.44700E-03	1.965E-03	80%
12 (TFD)	2.44520E-03	-	

Table 2 Flux Depression in 3D DRAGON Model – Both Layouts

Layout 1

	7	9	
6	8	10	
5	4	12 (TFD)	11
3	2	1	

	92%	86%	
92%	90%	68%	
87%	80%	12 (TFD)	80%
79%	69%	90%	

Layout 2

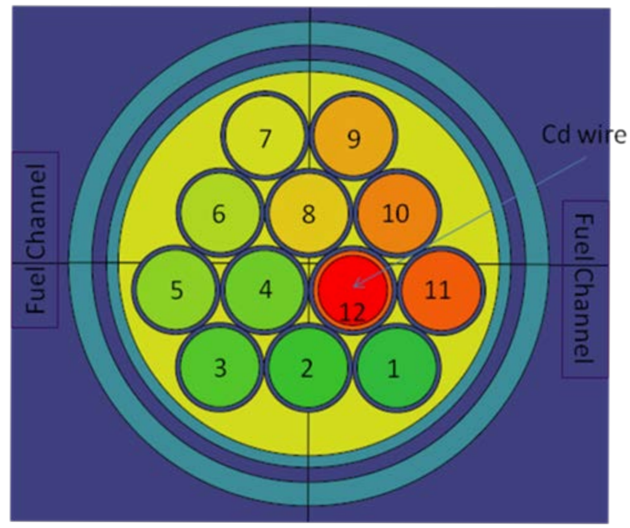
	11	1	
10	12	2	
9	8	4	3
7	6	5	

	91%	69%	
80%	12 (TFD)	80%	
80%	70%	90%	92%
81%	86%	93%	

Table 3 Flux Depression in 3D MCNP Model – Both Layouts

	7	9	
6	8	10	
5	4	12 (TFD)	11
3	2	1	

	84%	83%	
84%	78%	78%	
84%	78%	REF	78%
84%	78%	78%	



	11	1	
10	12	2	
9	8	4	3
7	6	5	

	78%	78%	
78%	REF	78%	
84%	78%	78%	84%
84%	84%	84%	

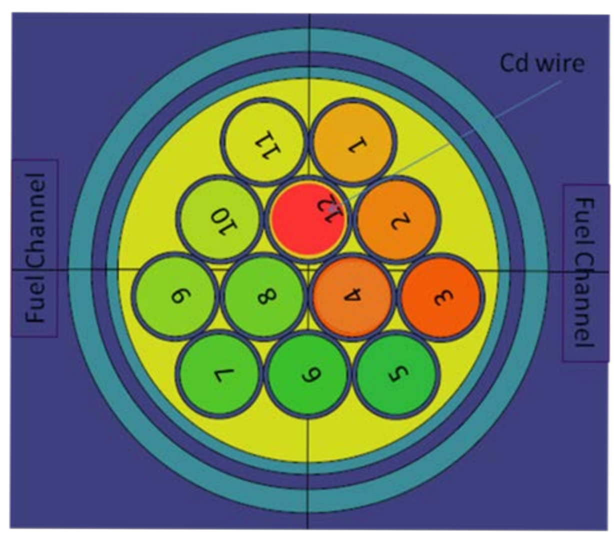


Table 4 Flux Depression in 2D DRAGON Model – Both Layouts

Layout 1

7	9		
6	8	10	
5	4	12 (TFD)	11
3	2	1	

90%	89%		
89%	83%	83%	
90%	83%	12 (TFD)	83%
89%	83%	83%	

Layout 2

11	1		
10	12	2	
9	8	4	3
7	6	5	

83%	83%		
83%	12 (TFD)	83%	
89%	83%	83%	89%
90%	89%	90%	

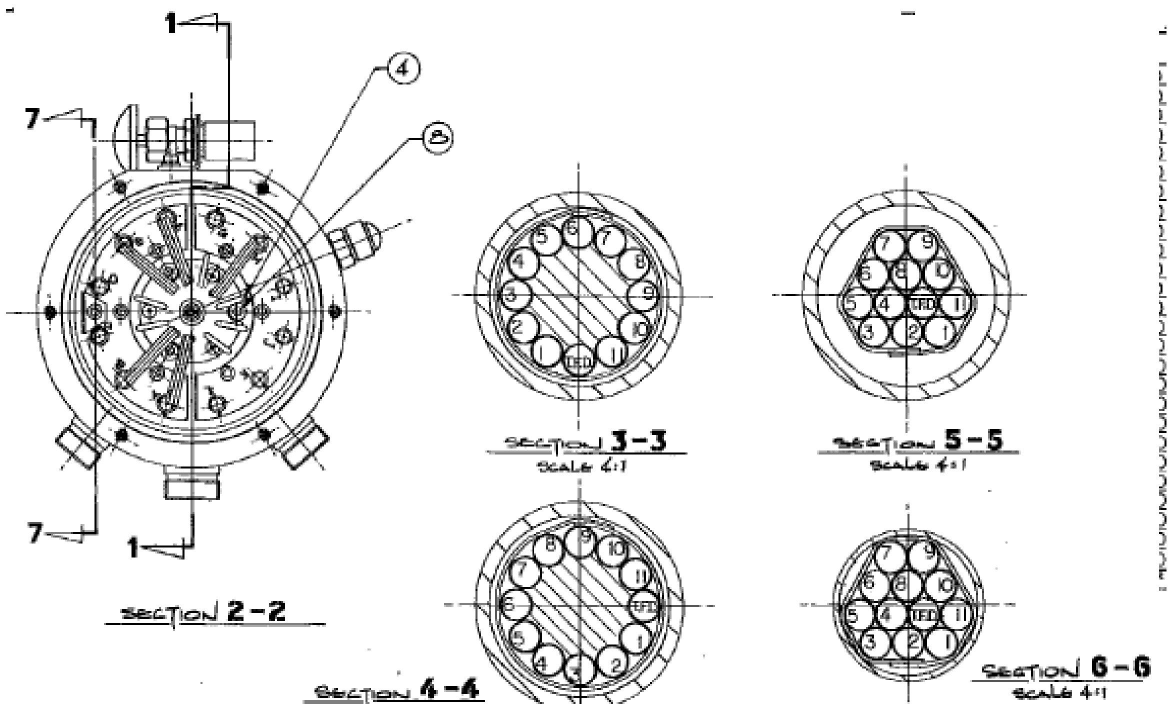


Figure 1 - Vertical Flux Monitor Unit – General Arrangement

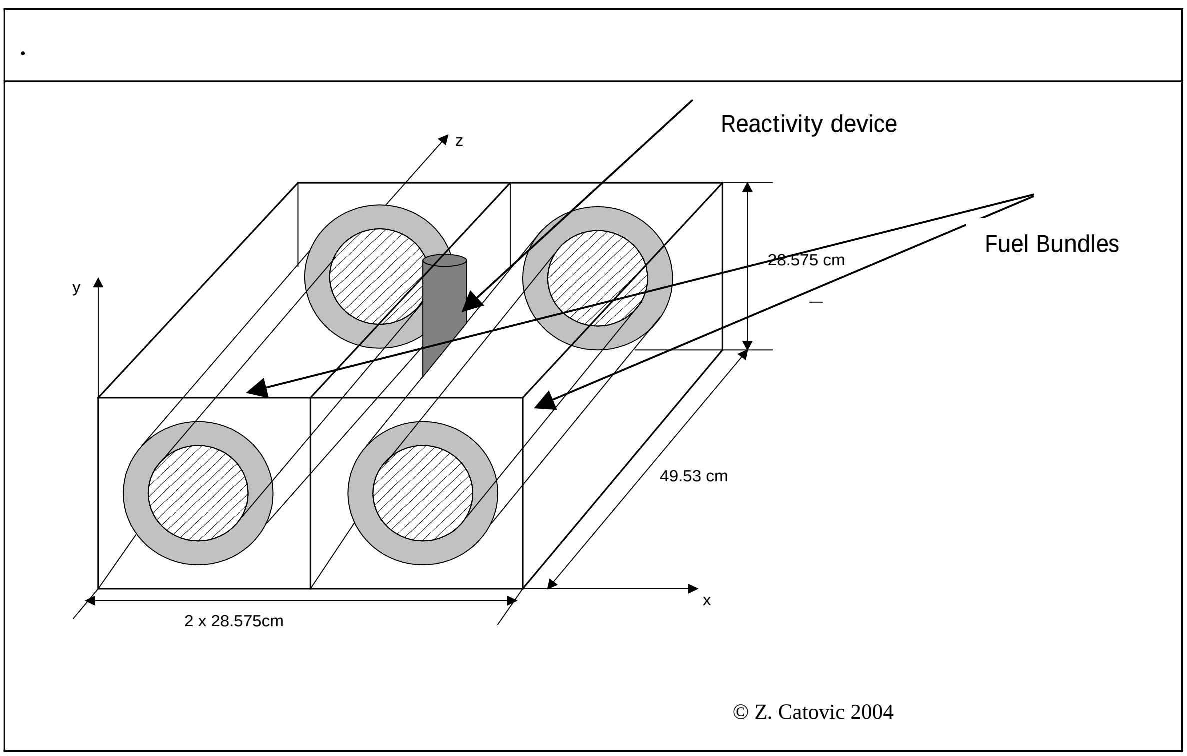
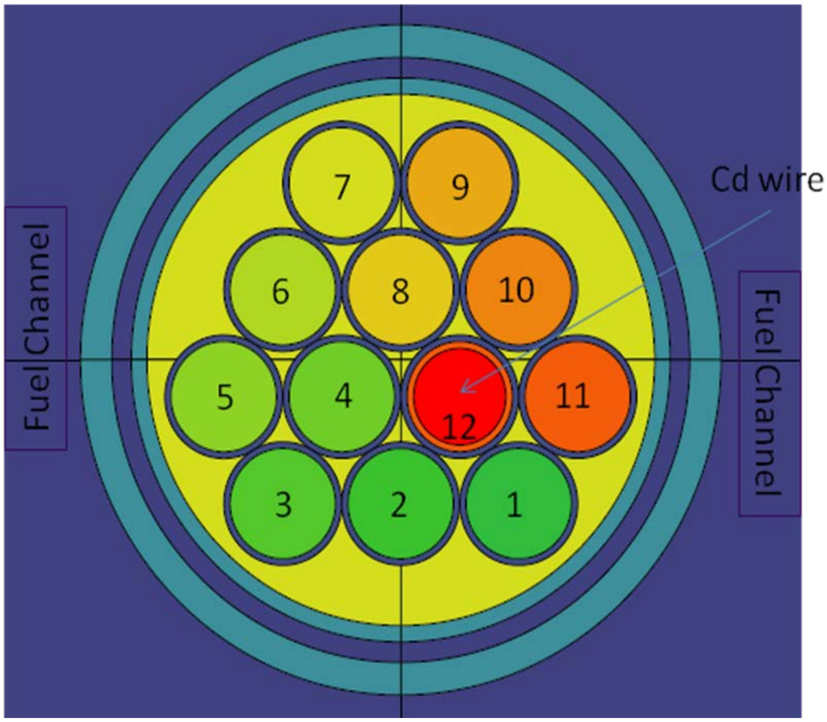


Figure 2 - DRAGON supercell schematic



Detector Layout (1) in DRAGON models

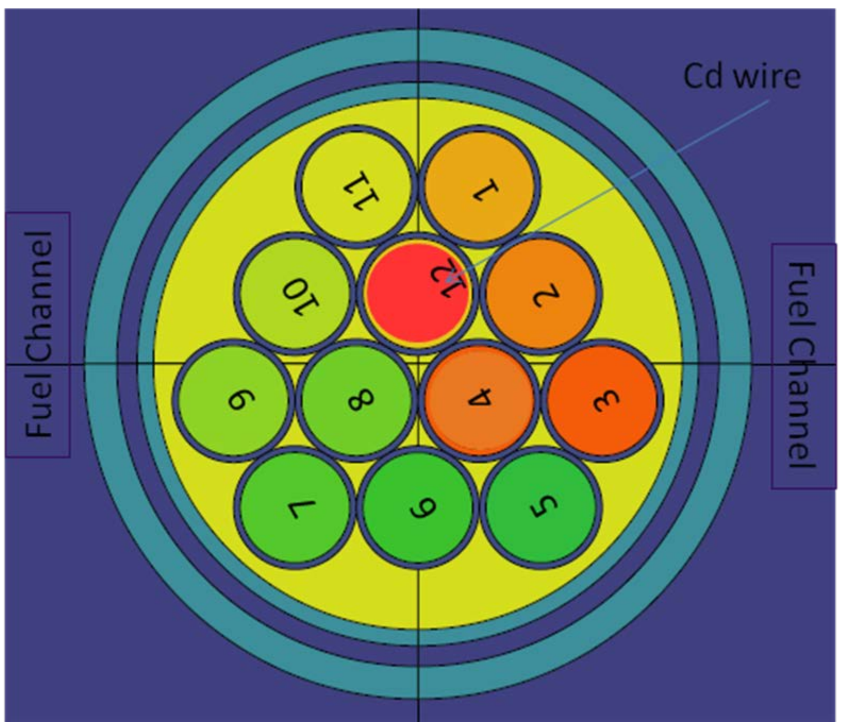


Figure 3 - Detector Layout (2) in DRAGON models

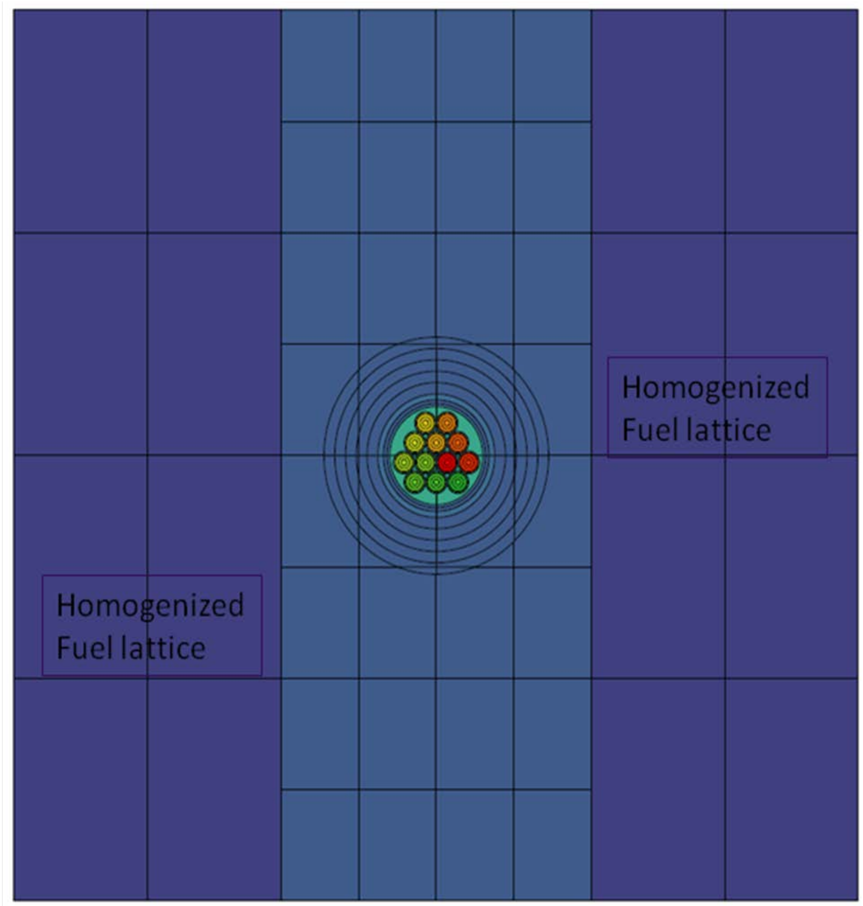


Figure 4 – 2D DRAGON model.