Preliminary Core Physics Evaluation of a Small Modular Pressure Tube SCWR

J. Pencer and J. Licht
Atomic Energy of Canada Limited, Chalk River Laboratories, Chalk River, Ontario, Canada
pencerj@aecl.ca, lichtj@aecl.ca

ABSTRACT – The Canadian supercritical water reactor (SCWR) is Canada's contribution to the GEN-IV International Forum (GIF), whose aim is the development of advanced reactor systems with features that support enhanced safety, clean energy, sustainability, economics and non-proliferation. Recently, a scaled down, 300 MW(e) version of the Canadian SCWR was proposed, the SuperSafe© Reactor (SSR). In this work, a preliminary core physics evaluation for the SSR concept is presented.

1. Introduction

The supercritical water-cooled reactor (SCWR) is Canada’s primary contribution to the Generation-IV (GEN-IV) International Forum’s (GIF) research and development effort toward the study and eventual deployment of advanced nuclear energy systems. The Canadian version of the SCWR is a heavy water moderated, pressure tube reactor which uses supercritical light water (SCW) as a coolant [1]. The SuperSafe© Reactor (SSR), a small modular version of the Canadian SCWR, was recently proposed in order to incorporate the advantages of the SCWR, such as enhanced safety and high thermal efficiency (45% as compared to 33% for conventional reactors) in a small modular reactor (SMR) concept [2].

The primary application of both the full scale SCWR and smaller SSR is electricity production, but these reactors could also provide process heat, hydrogen, industrial isotopes and drinking water as supplementary products. While the SCWR is intended to provide power to a large scale energy grid in a densely populated area, the SSR could be deployed to provide electricity to remote mining communities or near oil sand deposits where electricity production could be utilized in combination with co-generated process heat and hydrogen for oil extraction and refining. In addition, SSRs could be deployed across sparsely populated regions, where it is impractical to have a central electricity producer or large centralized energy grid. The reduced core size and number of fuel channels for the SSR compared to the SCWR may require a reduced outlet temperature and will impact the core neutronic performance, specifically core leakage and the resultant maximum achievable fuel exit burnup. Those changes are investigated in this work.

2. The SCWR and SSR Reference Core Configurations

The SCWR and SSR share the same fuel and channel designs. The fuel assembly is based on a 78-element cluster geometry and the fuel channel is based on the high efficiency channel (HEC), both described in [3]. The fuel channel design used in this study has been modified to include re-entrant coolant flow in a channel with a closed end. The fuel used for this study was of uniform composition, containing 13 wt% reactor grade PuO_2 and 87 wt% ThO_2, also described in detail in [3].

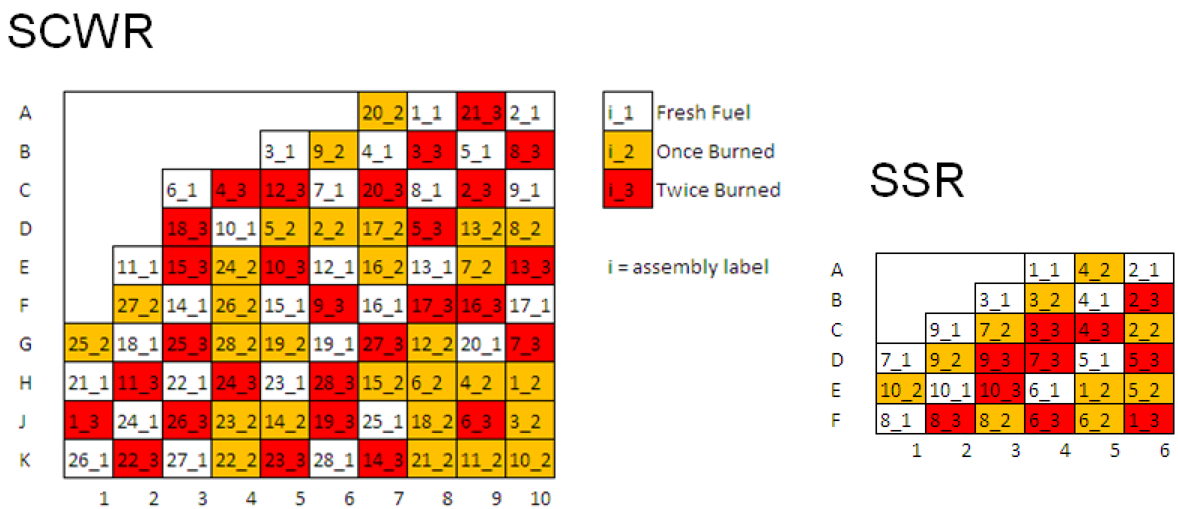

Figure 1 Quarter Core Channel Maps and Fuel Loading Schemes for the SCWR (left) and SSR (right).

Both the SCWR and SSR cores are fuelled in three batches. The SCWR core is described in detail in [3]. The SSR is designed to generate 670 MW of thermal power and about 300 MW of electric power assuming 45% thermodynamic cycle efficiency. The SSR core consists of 120 fuel channels arranged in a 25 cm square pitch lattice. The core diameter is 400 cm (including a 50 cm thick radial reflector); the channel layout and refuelling scheme are shown schematically in Figure 1. Two versions of the SSR are examined, a full length 5 metre core and a 3 metre short core option with reduced exit temperature (555ºC, and estimated thermal efficiency of 42%) for maintaining similar peak clad temperatures. The loading scheme and channel layout here have been modified slightly with respect to those described previously in [2] in order to maintain 8-fold core symmetry.

3. Comparison of SSR and SCWR Core Physics Parameters

Core modeling results were obtained using the codes WIMS-AECL 3.1.2.1 and RFSP 3.5.1.1 and are summarized in Table 1. For the SSR, the exit burnup is reduced compared to the full sized SCWR and this difference is most likely the result of the higher degree of neutron leakage from the core. Modifications to the refueling scheme or axial and radial reflector configurations could be incorporated to reduce leakage and increase the exit burnup of the SSR. The normalized radial power distributions within the core at BOC and EOC for the SCWR and both SSR options are shown in Figure 2. Similar results are obtained for the radial and axial power peaking factors (shown in Table 1), despite differences in neutron leakage of the two systems.

Table 1 Comparison of SCWR and SSR Core Physics Parameters

Parameter	SCWR	SSR	Short Core SSR
Average Exit Burnup (MWd/kg)	50.1	44.3	40.1
Excess Reactivity at BOC / EOC (mk)	102.9 / 9.9	96.2 / 11.7	90.4 / 9.6
Radial Peaking Factor BOC / EOC	1.28 / 1.19	1.23 / 1.18	1.19 / 1.18
Axial Peaking Factor BOC / EOC	1.35 / 1.16	1.36 / 1.16	1.41 / 1.21

	1	2	3	4	5	6	7	8	9	10	
A							0.89	1.03	0.84	1.14	BOC
							0.88	0.99	0.83	1.06	EOC
B					1.00	0.94	1.07	0.86	1.12	0.89	
					0.99	0.94	1.05	0.87	1.08	0.89	
C			0.78	0.69	0.74	1.10	0.88	1.15	0.91	1.22	
			0.84	0.76	0.80	1.09	0.91	1.12	0.92	1.16	
D			0.69	0.96	0.93	1.03	1.03	0.93	0.99	1.02	
			0.76	1.01	0.97	1.03	1.02	0.94	1.01	1.02	
E		1.00	0.74	0.93	0.93	1.28	1.11	1.23	1.01	0.87	
		0.99	0.80	0.97	0.95	1.19	1.07	1.17	1.02	0.91	
F		0.94	1.10	1.03	1.28	1.03	1.28	0.93	0.89	1.18	
		0.94	1.09	1.03	1.19	0.99	1.19	0.94	0.92	1.15	
G	0.89	1.07	0.88	1.03	1.11	1.28	0.95	1.02	1.18	0.90	
	0.88	1.05	0.91	1.02	1.07	1.19	0.95	1.02	1.16	0.94	
H	1.03	0.86	1.15	0.93	1.23	0.93	1.02	1.05	1.01	0.97	
	0.99	0.87	1.12	0.94	1.17	0.94	1.02	1.06	1.04	1.03	
J	0.84	1.12	0.91	0.99	1.01	0.89	1.18	1.01	0.87	0.95	
	0.83	1.08	0.92	1.01	1.02	0.92	1.16	1.04	0.94	1.02	
K	1.14	0.89	1.22	1.02	0.87	1.18	0.90	0.97	0.95	0.97	
	1.06	0.89	1.16	1.02	0.91	1.15	0.94	1.03	1.02	1.05	

	1	2	3	4	5	6	
A				1.13	1.01	1.19	BOC
				1.00	0.94	1.07	EOC
B			1.23	0.99	1.15	0.90	
			1.08	0.95	1.10	0.91	
C		1.23	0.99	0.86	0.89	0.95	
		1.08	0.96	0.89	0.94	1.01	
D	1.13	0.99	0.86	0.88	1.13	0.85	
	1.00	0.95	0.89	0.94	1.18	0.95	
E	1.01	1.15	0.89	1.13	0.99	0.92	
	0.94	1.10	0.94	1.18	1.08	1.04	
F	1.19	0.90	0.95	0.85	0.92	0.77	
	1.07	0.91	1.01	0.95	1.04	0.92	

	1	2	3	4	5	6	
A				1.08	0.98	1.15	BOC
				0.98	0.93	1.05	EOC
B			1.19	0.98	1.13	0.90	
			1.07	0.95	1.09	0.91	
C		1.19	0.98	0.88	0.91	0.97	
		1.07	0.96	0.90	0.95	1.02	
D	1.08	0.98	0.88	0.91	1.15	0.88	
	0.98	0.95	0.90	0.96	1.18	0.96	
E	0.98	1.13	0.91	1.15	1.02	0.95	
	0.93	1.09	0.95	1.18	1.09	1.05	
F	1.15	0.90	0.97	0.88	0.95	0.81	
	1.05	0.91	1.02	0.96	1.05	0.94	

Figure 2 Normalized radial power distributions (1/4 core) for the beginning (BOC) and end of cycle (EOC) for the SCWR (left), SSR (top right) and short core SSR (bottom right).

4. Conclusions

The performance of the reference core for the SSR has been compared to the SCWR. Although the cores performed similarly with respect to the axial and radial peak power factors at beginning and end of cycles, the SSR showed a significant reduction in exit burnup due to the increased neutron leakage of the smaller core. Improvements in burnup performance of the SSR may be possible through further optimization of the fueling scheme and axial and radial reflector geometries and will be investigated in future work.

7. References

[1] L.K.H. Leung, M. Yetisir, W. Diamond, D. Martin, J. Pencer, B. Hyland, H. Hamilton, D. Guzonas, and R. Duffey, "A Next Generation Heavy Water Nuclear Reactor with Supercritical Water as Coolant", Proc. of the Int. Conf. Future of HWRs, Canadian Nuclear Society, Ottawa, Ontario, Canada, Oct. 02-05, 2011.

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