An Advanced Engineering Test Reactor for Canada

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Abstract

Recent advances in Gen III+ reactors, programs to develop Gen-IV reactors, and more stringent codes and standards have increased the importance of test facilities for future power plants. However, testing in present day nuclear facilities is difficult due to both current safety requirements and the need to focus on operations. Instead of developing a specialized or multi-purpose research reactor, a new approach is suggested. The authors have developed the conceptual design of an Engineering Test Reactor, with the purpose of demonstrating objectively the performance of concept designs, prototypes, and endurance testing for components and subsystems of nuclear power plants.

1. Introduction

Canada's National Research Universal (NRU) reactor [1] has served Canada admirably for 53 years as the primary tool in support research and development. Its role includes testing related to all aspects of power reactor design, provision of neutron beams for materials science, as well as radioisotope production. AECL, the facility operator, recently requested renewal of the NRU operating license until 2016. NRU is already one of the oldest operating research reactors in the world, and cannot be expected to serve indefinitely. Commitment of a new facility needs to be made now. The case for replacing NRU with at least one new research and development facility has been presented forcefully by the members of the Canadian Nuclear Society [2].

The current trend worldwide is toward reactors optimized for specific purposes, for example, the ILL-HFR reactor in France [3] with high flux for neutron science and the proposed MYRRHA facility [4] in Belgium. Aside from NRU there are only two other reactors (in India) currently addressing all three of the above roles. There is conflict between requirements for optimizing the design and operating schedule for each of the three roles. For example, neutron science benefits from the highest possible thermal neutron flux density that is most economically achieved in a small core, while testing of full-scale reactor components and fuel bundles requires a large core.

The fundamental role of the new reactor should be in support of Canada's nuclear industry, both as it exists (assistance for current operating units) and for future development and building of new generations of reactors (including Canada's participation in the Generation IV International Forum (GIF) [5] and the associated Canadian project designated as GenIV [6,7]. This is the role most likely to obtain approval and funding from various sources, such as the governments of Canada and Ontario, the CANDU Owners Group, and the utilities using CANDU reactors including some outside Canada. The focus on CANDU is strategic; Canada has a substantive role (currently about 8%) in the world nuclear market, which is expected to expand rapidly following the current world economic recovery. Already, over sixty “new build” projects are active in the world, with several hundred more in the late and early planning stages. The design of the new research reactor should be judged on its suitability for supporting Canada's expanding nuclear industry. The ETR reactor can be designed to allow for back-up use in neutron science and radioisotope production, as long as this does not interfere with its primary role.

Canada has a pioneering and well-established reputation in the field of neutron science. A special reactor for this purpose, located at the Chalk River site or the Saskatchewan site that is currently being considered, is certainly justified if this country’s strong neutron science research enterprise is to survive.

Canada also has played a pre-eminent role in the development and production of radioisotopes for medical use; the NRU reactor has been the world’s major source of radioisotopes such as ^{99}Mo. However the recent NRU outage has caused a rethinking and diversification of the supply of radioisotopes, and future plans should not be based on assuming a return to such a dominant production role in one reactor. The economics of isotope production are not favorable, since the current price of isotopes like ^{99}Mo is based on marginal costs of production in government-supported reactors such as NRU.

2. Background

A table of research reactors around the world [8] is published by the IAEA. Examination of this table shows that only very few new research reactors are on the books. As might be expected, those countries most heavily involved in “new build” projects (France, Russia, China) already have research/test reactors under construction. Of these, the PIK high flux (1.2 x 10^{15} n/cm$^{2}\cdot$sec) beam reactor [9] is dedicated to neutron physics research. The Jules Horowitz [10] reactor is intended for high flux testing of fuels and materials, in support of present and future reactors. The CFER reactor [11] is a fast-flux test reactor, mainly intended as a prototype for future power plants. MYRRHA is a generic name for a multi-year project in Belgium, aimed at replacement of the old BR-2 machine. PALLAS is a planned research and isotope production facility [12] located on the site of Holland’s Petten reactors.

The Jules Horowitz project (now under construction), the MYRRHA project, and the PALLAS project (both at the planning stage) were formally linked in September 2010. In a press release by the consortium involved [13], it is clearly seen that the European plan calls for three separate facilities to carry out the separate functions previously lumped together under the single heading of “Research Reactors”. Similarly, the Canadian NRU reactor and the now-suspended MAPLE facility were expected to separate materials testing and isotope production functions. The third function, fast spectrum research, is not part of Canada’s plan. The United States has opted for refurbishment of a few of their research/test reactors – both ATR [14] and HFIR [15] have recently been extensively rehabilitated.

In summary, the patterns that emerge are first, the establishment of single purpose reactors dedicated primarily to a single research/test/isotope role. Secondly, it is apparent that in both Europe and the United States a few key facilities are intended to serve a multitude of users through a wide variety of contractual arrangements. It is suggested here that Canada should follow similar patterns. This paper proposes a fuels and materials test reactor that could, if required, fill a secondary role as a neutron beam facility and/or an isotope production facility.

3. Needs and requirements

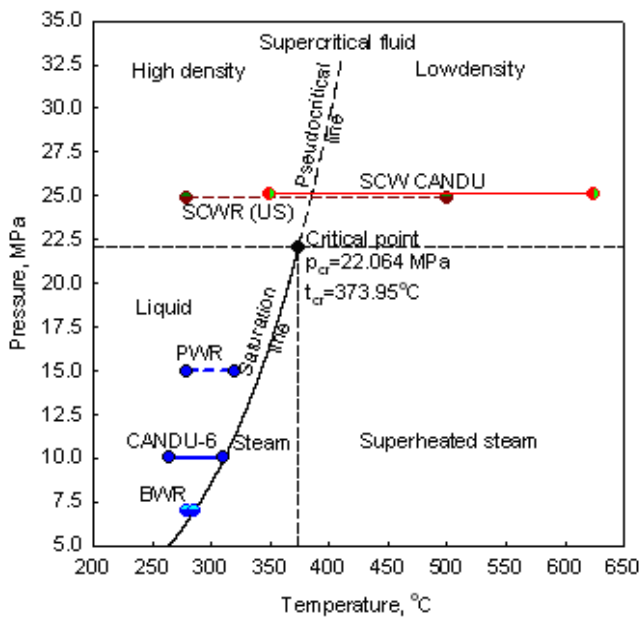

Figure 1: GIF Operating Conditions [21]

Canada's future reactor research and development direction is defined by the Generation IV International Forum (GIF) agreement, and by the associated Canadian national program designated as Gen-IV. The main objective of this R&D program is development of fuels and materials [16, 17, 18} capable of long-term service under high temperature and stress conditions, as illustrated in Figure 1. The final objective of this work is to design, build, and operate power plants able to operate at 25MPa with a thermal efficiency of close to 44 percent [19,20]

Table 1 shows the major characteristics of the six advanced design concepts being studied in the GIF program. Canada has agreed to participate in two of these concepts; namely the SCWR and the VHTR programs, with our main emphasis on the thermal reactor version of the SCWR. Naturally, the additional work being conducted within Canada's Gen IV project is also concentrated on the SCWR design concept.

System	Neutron spectrum	Coolant	Temp °C	Fuel cycle	Capacity (MWe)
VHTR	thermal	helium	900-1000	open	250-300
SFR	fast	sodium	550	closed	30-150, 300-1500, 1000-2000
SCWR	Thermal/ fast	water	510-625	Open/ closed	300-700, 1000-1500
GFR	fast	helium	850	closed	1200
LFR	fast	lead	480-800	closed	20-180, 300-1200, 600-1000
MSR	epithermal	fluoride salt	700 800	closed	1000

Table 1: Characteristics of concepts in the GIF agreement [22]

From Table 1 it is obvious that the maximum temperature of the SCW CANDU concept includes that of most of the leading candidates addressed in the GIF program.

Therefore, the fuels and materials work being conducted within the Canadian program is mostly relevant to all other GIF concepts, as well as being useful in defining the SCW CANDU concept.

Canada participates in the VHTR program mainly to assist the development of high temperature methods for producing hydrogen and oxygen from water [23,24]. The chemistry and engineering of this technology is particularly interesting to our national projects aiming to the development of nuclear-based hydrogen production, as one component of the task of manufacturing various synthetic transportation fuels. Such fuels are needed to replace the petroleum currently used for transportation. Petroleum supplies are expected to increase in cost and to become relatively scarce sometime within this century. [25]

While these long-term research programs proceed, it is essential to sustain and increase the production capacity of the two reactor types currently available; namely the CANDU “Classic” as well as the ACR 1000. Fuels and materials for these reactors are already well developed. However, it is also true that advanced fuels and improved materials could improve the performance and economics of these commercial machines, as well. An engineering test reactor such as the one proposed in this paper must be capable of supporting these reactors and their associated production facilities.

Nuclear fuel improvement is the central task for this facility. Provision must be made for today’s fuels, the “conventional” fuels typical of the Classic CANDU [26] and the ACR 1000 [27]. Recently, interest has increased for use of thorium in CANDU; its very well thermalized flux spectrum makes the CANDU Classic the best available option for utilizing this abundant resource, especially in countries where uranium resources are limited. It is expected that a regular progression of fuel improvements will be tested in the ETR, including slightly enriched bundles, and higher temperature designs. The clear objective of these tests will be to achieve steady improvement of the economics of the CANDU fleet, both in Canada and around the world. Testing capability of the ETR will range from small sample irradiations to multi-bundle bundle endurance tests.

The fuel testing capabilities are enhanced by provision of four large vertical channels passing through the ETR core. These special channels are intended for testing of future fuels for the SCWR program and for tests under extreme operating conditions, including severe accident simulations. These four channels are very large to accommodate both test assemblies and adequate safety protective shields to protect the test reactor against the very high temperature that may be reached in these tests.

Next in line to fuel testing is the need for improvement in fuel channel materials, initially for the pressure tubes of CANDU Classic and ACR 1000. Zirconium alloys now used in pressure tubes are reaching their metallurgical limit of stress, temperature, corrosion, and hydrogen ingress. A new approach is needed to pressure tube design, and/or to redesign of the fuel channel to improve the environment of the pressure tube while in service. One interesting possibility is introduction of carbon fiber reinforcement of the zirconium alloy to dramatically increase the high temperature performance of this component. Obvious objectives include longer service life and higher pressure coolant; both of which promise to improve operating economics. This dramatic change is expected to follow more of the less exciting but steady enhancements of pressure tube material that have already greatly enhanced the performance of today's CANDU power reactors.

The expected operating conditions of water reactors operating at super-critical pressure illustrate several important aspects of the need for the CANDU ETR. It is already known, from recent work on fossil-fuelled supercritical systems, that materials are available that can tolerate the high temperature and stress conditions that exist in those systems. However, in the SCWR these conditions exist at the same time and place as do the additional factor of extremely high neutron and gamma fields. It follows that it is absolutely necessary to test these same materials in a reactor with comparable high levels of neutron and gamma fluxes, in order to prove the suitability of fuels and structural components in commercial service.

The two central tasks for the ETR by no means exhaust the wide range of test possibilities that could be carried out in the future. An obvious notion is to use modified ETR fuel bundles as carriers for Molybdenum-99 production. The existence of an on-power refueling system removes one of the primary difficulties of such production in the NRU reactor. Another lower-priority possibility is to install beam tubes on the side of the ETR calandria, to provide capability for metallurgical research programs that may eventually provide better in-core materials for our power reactors.

Yet another aspect of the ETR operation is its capability of producing electricity. Depending on the intensity of the experimental program at a given time, the plant can produce up to about 60 megawatts of electricity for the Ontario grid. Located, as it will be, far from major load centres ETR can serve as a Small Modular Reactor (depending on load distribution and economics, the first ETR is admirably suited for replication either on site, at another relatively remote site, or at extremely remote facilities required in Canada's High Arctic). Its base technology is the same as that used in 29 commercial CANDU systems in service in Canada and around the world today, so that operations and maintenance of such a small unit acan be easily integrated into the existing nuclear infrastructure.

4. Concept design and major features of ETR

The CANDU ETR is conceived as a flexible engineering test reactor to serve present-day and future power plants growing from the classic CANDU concept.

The original reference design was designated as CANDU 80, a concept developed by Ralph Hart and others at AECL SP in the 1990s. This design was first scaled down to 200 MWt by reducing the number of fuel channels, and then was further modified by deletion of its inner steel containment. The outer containment structure was retained in anticipation of the needs of advanced programs that may involve deliberate fuel destructive tests and other relatively hazardous experiments. The high-integrity steel-lined containment structure ensures that the resulting plant will be licensable in Canada and around the world.

The original design incorporated counter-flow in adjacent channels, and a single fuelling machine servicing 10 bundles in each 5-metre channel. This layout has been changed to single-direction flow in all channels. Each fuel column consists of ten half-metre long bundles held together by a central rod; this subassembly can be grappled upstream out of the channel by the fuelling machine. Subassemblies can be transferred to one of a number of fuel transfer tubes, where each bundle in a given string can be shuffled or replaced, after which the central rod can be reinserted for fuel reloading.

All feeders at the outlet end of the reactor are connected to a single outlet header. Two flow lines connect this header to the hot leg of each of the two steam generators located above the inlet end of the reactor. Each steam generator outlet is connected to the inlet of one heat transport pump. Each pump delivers flow to half of the fuel channels in a fully interleaved configuration. The current reference core configuration (10 bundles) and flexible fuel handling system allows for high peak neutron flux in the core. A 50 cm axial reflector can be located at each end of the fuel subassembly, if desired.

Several revisions of the original reference design have been made to facilitate experiment access to the reactor core. Horizontal access is provided via the fuelling machine, and also is available via beam tubes placed perpendicular to the fuel channels. In addition, the special provision of large vertical penetrations through the reactor core makes possible the testing of SCWR fuels and materials under their projected extreme operating conditions.

The configuration of ETR is also capable of producing approximately 60 MWe (net), as well as having an alternate capability of supplying approximately 200 MWt of steam at 6 MPa and 300 C for demonstration of non-electric applications, if desired. Concept specifications for the current design are given in Table 2.

Reactor Specification	
Reactor Type	Demonstration CANDU Power Plant
Core Thermal Power	170 MWt
Core Electrical Power	58 MWe
Neutron Flux	~1×10^{14} n/cm^2/s
Vertical Channel Access	Four vertical, perforated, guide tubes (dia. 28.6 cm) in centre lane
Core Load U235	1.93 kg U^{235} uniform, added to natural uranium driver fuel
Enrichment	1.0 % ^{235}U
Shut Down Systems	Two independent systems
Duty Cycle	~90%
Cooling	Heavy water primary coolant, light water secondary
Core access during operation	Remotely operated fueling machine access to all fuel bundles.
Blowdown	Blowdown test capability in vertical loops
Aging Tests of fuel channels	Re-entrant tubes may contain enriched coupons to boost fast flux
Material Irradiation	
Irradiation Facilities	Fuelling machine capable of transporting samples and fuel bundles
Bulk irradiation facilities	Bundle-mounted samples and /or target assemblies for Mo99 production
Large volume facilities	Yes
Fuel Testing	
On line testing for fuel failure	Yes. Standard equipment on CANDU
Flux and Pressure Conditions	5 m length provided. Adequate for mandated testing of power reactor fuel channels
Test Loops	Yes
Test Loop size	28.6 cm diameter
Isotope Production	
Medical Isotope Production	Yes. Use driver channels for this purpose. This usage may reduce electrical output.
Target enrichment	As required.
Neutron Research	
Beam Tubes	Space for beam tubes if required. These are not normally provided in a test reactor.

Table 2: Basic Specifications of the CANDU Engineering Test Reactor

5. Layout sketches of the ETR

Figures 2 and 3 show preliminary sketches of the current ETR design, intended only to embody the main features of the system. Obviously, these sketches must be followed by extensive detailed design work, prior to commitment of any consideration of actual construction of the facility. The underlying principle is of a "small CANDU", utilizing the main parameters, components, and systems of the so-called CANDU "Classic" typified by the well-established CANDU 6 design. The thermal power of ETR is chosen near the upper range of power now classified by the CNSC as a "small reactor". The most substantive deviations from the CANDU 6 design are the use of a single fuelling machine and single-direction channel flow. This choice was made both for the sake of economy and to leave more space for experimental access. The active channel length is 5 metres and the fuel enrichment is 1 percent U235.

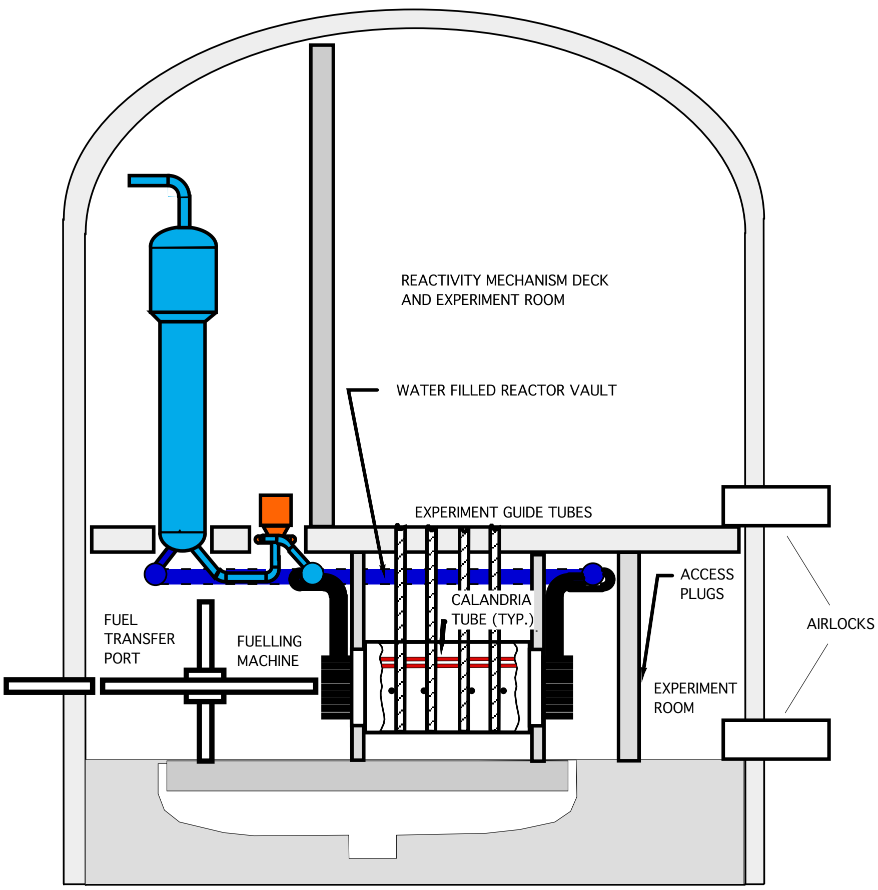

Figure 2: Vertical cross-section of ETR, parallel to fuel channels

Figure 2 notes a water-filled vault surrounding the reactor, along with two of the three experiment rooms adjacent to the reactor. Note also the configuration of the primary heat transport loops with associated pumps and heat exchangers. Channel outlet flow lines are placed both behind and in front of the water-filled vault. Also shown is the general arrangement of the fuelling machine. It is of the Gentilly I type, with capability for full rotation in the horizontal plane

Removable channel closure plugs are provided at both ends of each channel, even though coolant flows are uni-directional. The purpose of this arrangement is two-fold; it allows for access to the fuel from both ends in case of special needs, and also allows experimental access to the back ends of all fuel channels.

The large experiment room above the reactor is accessible only under shutdown conditions; equipment airlocks are provided to both experiment rooms. It is immediately apparent that adjustment of the steam generator height-to-diameter ratio might allow reduction of the containment building height as more detailed reviews of experimental and other factors proceed.

Four large vertical channels are shown in this view; these are also open to careful review in the future, as to the need for such large experimental features. These are now expected to provide adequate access to the high reactor fluxes for safety performance testing as well as for large-scale SCWR channel experiments. Finally, this sketch shows four horizontal penetrations for SDS2 injection nozzles. These obviously must be accompanied by additional penetrations for horizontal flux detector assemblies. It is expected that the large experiment rooms surrounding the reactor will be accessible only under reactor shutdown conditions. Shielding and access arrangements have been only worked out up to now in a very general way.

The preliminary system piping arrangement is shown; detailed design has not yet begun. Thermal-hydraulics of the primary system has so far been sized by similarity with known operating CANDU designs. This area requires expert designer effort to confirm the conceptual choices, or to modify the configuration as required in the final design. Secondary systems are shown enclosed separately inside the containment structure. Power system busses as well as instrumentation and control features remain to be added in future design work. Arrangement and sizing of the fuel handling system is complete only at the preliminary concept phase. The design intent is to be able to handle full-length fuel strings consisting of up to the 43-element size of CANFLEX [28], but with a central tie rod to clamp the bundles together, in the style of Gentilly I. Fuel bundle addition, reshuffling, and discharge are reference features of the system.

Figure 3 shows the design of the reactor assembly. It is a conventional CANDU layout with the central column of channels removed to accommodate the vertical guide tubes. These guide tubes may, of course, contain vertical experiment loops. The guide tube OD is equal to the lattice pitch.

6. Reactor physics

The lattice configuration is based on the standard CANDU 28.575 cm pitch. The U235 enrichment studied up to this time ranges from 0.712 to 1.0 percent. The normal active fuel channel length is 5 metres. The reference configuration (shown in Figure 3) has a fundamental-mode eigenvalue (k-effective) of approximately 1.032 for 1 percent fuel enrichment at mid-burnup, with full Xenon load and no zone controllers, guide tubes or reactivity mechanisms inserted. The vertical central gap was represented by pure heavy water. To accommodate vertical experimental channels, the central column of fuel channels can be left blank to allow installation of up to four re-entrant test channels of diameter equal to the reference lattice pitch.

Reactor physics at this stage of concept development is very simple, because the reference configuration does not include a number of the in-core components that will be required in the final design. Much more complexity may be introduced, of course, via insertion of various choices of test configurations. Perturbation of the flux distribution will be relatively small because of the large neutron migration area of this heavy water lattice, and the relatively high radial leakage. Spatial coupling is relatively good in this small core. If and when the larger vertical channels are installed, it will be necessary to incorporate a dual-core reactor regulating system to ensure stability in the horizontal plane. This difference will require limited modifications to the existing CANDU 6 reactor regulating system.

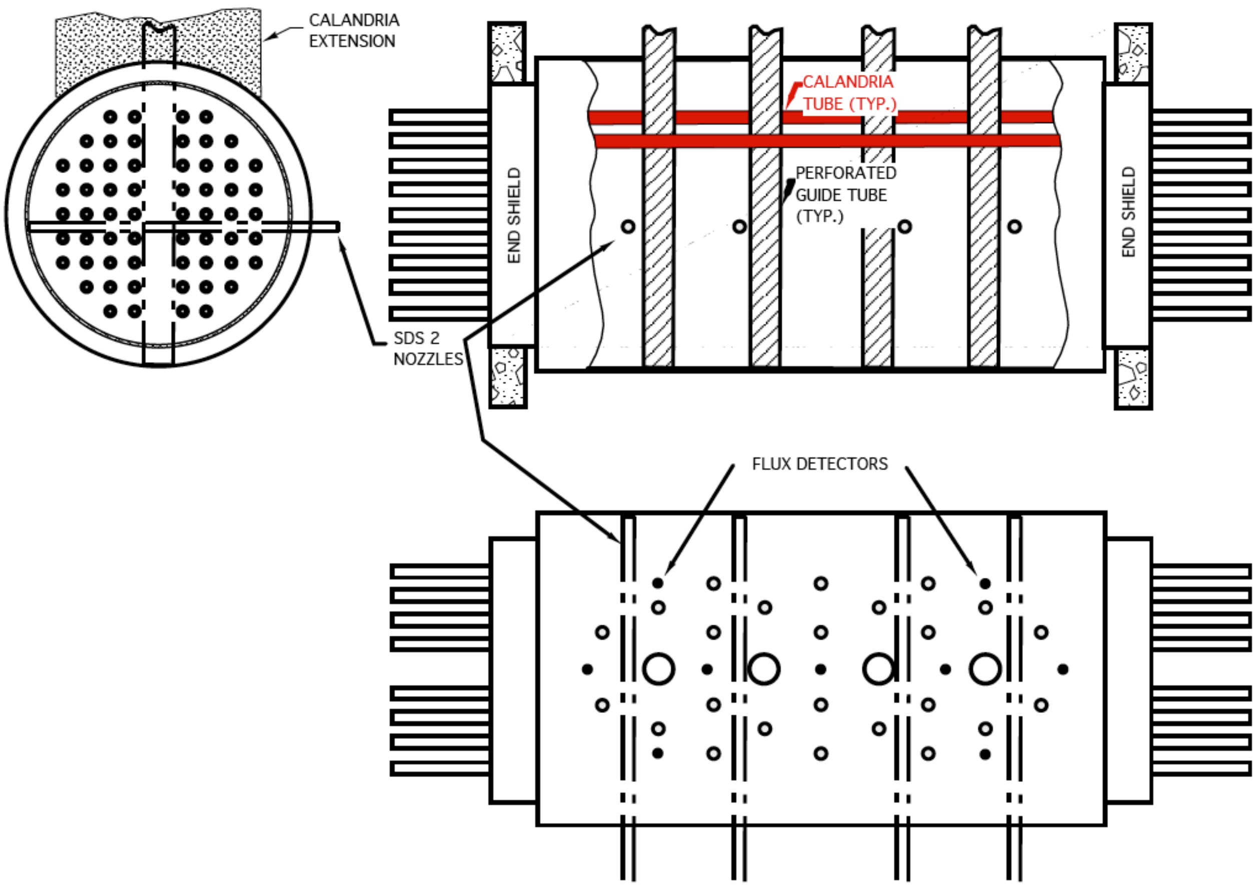

Figure 3: General Schematic of ETR Core Configuration

7. Advantages for Canada

The CANDU-ETR will provide a test bed for evolutionary improvement of all CANDU designs, up to and including future concepts. Technical support of the existing CANDU fleet will come from several different areas. Training of operating staff is one important aspect. Solutions for off-normal performance in components and systems are another aspect, especially in the field of radiation chemistry. Testing of “smart” instrumentation for systems health monitoring is a natural task in the ETR. Finally, a major contribution can be expected in improvement to pressure tubes and other in-core components. Support for the CANDU operating systems at home and abroad will be vital to the expansion of Canadian technology around the world. Now that Canada and India have reached an understanding at the governmental level, the opportunities for collaboration and large-scale buildup of the international CANDU fleet.

Canada is committed by treaty to support the Generation Four International Forum. This requires a range of experimental work to be carried out, along with theoretical development. The CANDU SCWR concept is included in the list of leading future reactor types; success in developing this reactor depends on availability of a test facility such as the ETR.

From the already established base of CANDU Classic, Canada has an opportunity to support the long-term sustainability of the nuclear energy. Estimates of the required total world generating capacity vary widely, but the most likely range is at least 10,000 gigawatts. On that large scale, nuclear energy will be similar in scope to today's world oil industry – which must be replaced within the next century by energy from uranium and thorium. Canada is positioned to be a major player in this exciting new world of sustainable energy resources.

8. Concluding remarks

Thanks to over fifty years of creative and productive development, Canada is in possession of a world-leading, fully developed technology for production of electricity from the atom. A splendid industrial opportunity is available to Canadians as they participate in building the world's first sustainable energy system.

9. Acknowledgements

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10. References

1. http://nrureactor.ca/
2. CNS, "Planning a New Multi-Purpose Research Reactor for Canada", Toronto (2010)
3. Institut Laue-Langevin HFR < http://www.ill.eu/reactor-environment-safety/high-flux-reactor/technical-characteristics/>
4. http://myrrha.sckcen.be/
5. http://www.gen-4.org/PDFs/Energy%20Focus%20Gen%20IV%20Article%20Spring%202009.pdf
6. D. Brady, T. Anderson, D. Guzonas, H. Khartobil, L. Leung, S. Quinn, and W. Zheng, "Canada's NSERC/NRCan/AECL Generation IV Energy Technologies Program", 30th CNS Annual Conference, Calgary, Alberta, Canada, June 2009.
7. D. Brady, D. Guznoa, L. Leung, W. Zheng, J. Poupore, and T. Anderson, "Enhancing University R&D Capabilities in Support of Generation-IV Nuclear Reactor Development", CNS Conference on Nuclear Education and Outreach, NEO-2010, Calgary, Alberta, Canada, June 20-22, 2010.
8. IAEA list of world research reactors: http://www.iaea.org/worldatom/rrdb/
9. PIK reactor description: http://www.iaea.org/worldatom/rrdb/
10. Jules Horowitz facility: http://www.rertr.anl.gov/Web2002/2003Web/Bergamaschi.html
11. http://www-naweb.iaea.org/napc/physics/research_reactors/database/rr%20data%20base/datasets/report/China,%20People's%20Republic%20of%20%20Research%20Reactor%20Details%20-%20CFER.htm
12. PALLAS reactor description http://www.pallasreactor.eu/
13. NRG consortium press release http://www.nrg.eu/general/nieuws/2010/20100920en.html
14. Advanced Test Reactor description http://www.ne.doe.gov/pdfFiles/factSheets/IdahoNuclearInfrastructure.pdf
15. High flux isotope reactor description http://www.ne.doe.gov/pdfFiles/factSheets/IdahoNuclearInfrastructure.pdf

16. W. Zheng, D. Guznoas, D. Brady, W. Cook, and J. Luo, "Materials Research in Support of SCWR Development: Current Areas, gaps, and needs" Proceedings of ICONE-18, International Conference on Nuclear Engineering, ICONE18-29899, May17-21, Xi'an, China, 2010.
17. E.F. Ibrahim and B.A. Cheadle, "Development of Zirconium Alloy for Pressure Tiubes in CANDU Reactors", Can. Met. Quarterly, Vol. 24: 273, 1985.
18. Z.L. Pan, "Delayed Hydride Cracking and Elastic Properties of Excel, a candidate CANDU-SCWR Pressure Tube Material" The 2nd Canada-China Joint Workshop on Supercritical Water-Cooled Reactors (CCSC-2010), Toronto, Ontario, Canada, April 25-28, 2010.
19. R.B. Duffey, I. Pioro, T. Zhou et al, "SCWRS: Current and Future Concepts – Steam Cycel Options" Proceedings of ICONE 16, ICONE16-48869, Orlando, Florida, USA, May 11-15, 2008.
20. I. Pioro, S. Mokry, W. Pieman, E. Saltanov, H. Thind, L. Grande, J. Samuel, and G. Harvel, "Supercritical Water-Cooled Nuclear Reactors" Thermodynamic-cycles Plant Layous and Thermal Aspects of Pressure-Channel Design", ENC 2010, Barcelona Spain, May 30, 2010.
21. Pioro,I.L. and Duffey, R.B., Heat Transfer & Hydraulic Resistance at Supercritical Pressures in Power Engineering Applications, ASME Press, New York, NY, USA, 2007, 328 pages.
22. http://www.gen-4.org/PDFs/GIF_Overview.pdf
23. M. Naidin, S. Mokry, F. Baig, and I. Pioro, "Thermal Design Options for Pressure-Channel SCWRs with Cogeneration of Hydrogen", Journal of Engineering for Gas Turbines and Power, Vol. 131 (1), 2009.
24. G. Naterer, S. Suppiah, M. Lewis et al., "Recent Canadian Advances in Nuclear-Based Hydrogen Production and the Thermochemical Cu-Cl Cycle", Int. Journal of Hydrogen Energy, Vol. 34:2901-2917, 2009.
25. IEA 2010 Annual Report http://www.worldenergyoutlook.org/
26. CANDU Classic reactor description http://www.aecl.ca/Reactors/EC6.htm
27. ACR 1000 reactor description http://www.aecl.ca/Reactors/ACR-1000.htm
28. CANFLEX fuel description http://canteach.candu.org/library/20031202.pdf
29.