ADVANCED FUEL DEVELOPMENT IN AECL

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ABSTRACT

This paper describes the strategy for advanced fuel development in AECL, summarizes current fuel development programs, and indicates future direction.

BACKGROUND

Importance of Advanced Fuel Development. Fuel is at the heart of a nuclear power plant. Its performance is central to operational efficiency and safety, and utility operators expect fuel performance to be problem-free. The fact that fuel is a "consumable" and is regularly replaced provides an opportunity to introduce improved fuel at any time. On-power refuelling in the CANDU® reactor allows the seamless transition from one fuel type to another without shutting down the reactor to replace the whole core. Advanced fuel can address not only issues directly related to the fuel, such as fuel cycle costs or spent fuel management, but can be a vehicle for addressing other station issues. A prime example of this is the use of CANFLEX® fuel to regain thermalhydraulic margins lost through pressure tube aging or steam generator fouling [1].

Given the central importance of fuel to the health of a nuclear power plant, it is very important that the industry maintains both depth and breadth in all aspects of fuel, including

- fuel design and performance
- fuel manufacturing and material supply
- fuel qualification
- fuel testing, both in- and out-of-reactor
- an in-depth understanding of the relationship between fuel design, manufacturing, operation and fuel performance
- spent fuel storage
- an ongoing program to measure and understand fundamental fuel properties as a function of irradiation and reactor conditions, including
    - fuel chemistry (of the fuel system, including the pellet, gap, CANLUB coating and sheath; and with steam or water in the case of defected fuel),
    - fuel thermodynamics (for normal operating conditions (NOC), off-normal incidents, postulated accidents, wet- and dry-storage, and disposal),

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  - o diffusion coefficients of fission products,
  - o thermal conductivity, and
  - o other mechanical and thermal properties.
- the facilities required to support existing fuels and to develop advanced fuels
- a response capability to failed fuel excursions.

AECL'S Role in Advanced Fuel Development. AECL is the defacto CANDU fuel design authority, and assists the Canadian utilities in executing this function. AECL has always played a central lead role in advanced fuel development. In Canada, the CANDU Owners Group (COG), the utilities, fuel manufacturers, and universities all have important, although more narrowly focused roles in fuel support and development. AECL has also trained many of the key resources in the Canadian fuel community.

AECL is uniquely positioned to support CANDU fuel through its people, facilities, and programs. AECL is able to maintain at least the minimum level of key core competency in people and facilities by leveraging the funding of its fuel specialists through a variety of programs: COG, commercial services to utilities, internally-funded fuel programs, and most recently, through the development and qualification of the Advanced CANDU Reactor (ACR)™ fuel [2]. Without this variety of funding and program sources, it would otherwise be impossible to maintain the minimum level of both staff and facilities required to support and advance CANDU fuel, as well as the breadth of the CANDU fuel technology base. AECL also leverages its fuel expertise through participation in national and international collaborative programs.

Advanced fuel development requires a wide variety of technologies, both within and outside of the fuel discipline, including fuel design, fuel safety, waste management, fuel channel thermalhydraulics, fuel handling, fuel channel behaviour, system chemistry and reactor physics. AECL possesses many facilities that support fuel development: fuel development labs (including the Recycle Fuel Fabrication Laboratory (RFFL) for fabrication of alpha-active fuels [3]), irradiation loops in the NRU reactor for fuel testing, post-irradiation examination (PIE) facilities with associated advanced characterization techniques [4], surface science facilities, thermalhydraulics labs, and the ZED-2 zero-power reactor for reactor physics measurements.

AECL's organizational structure also reflects the importance of fuel development, with branches that focus on fuel design, fuel development, and fuel safety. The Fuel and Fuel Cycle Working Group provides the direction for advanced fuel development, and integrates the various fuel programs, with participation from the technology disciplines, commercial, product development, and the ACR project.

AECL is a commercial crown corporation, with the Federal Government of Canada its shareholder, and must lessen its reliance on government appropriations through increased commercial revenue. Revenue from the implementation of new fuel technology will be important for sustaining and advancing CANDU fuel technology, both within AECL, and within the Canadian CANDU indusry. In performing commercial services, AECL is striving to become more

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Characteristics of CANDU Fuel. To understand the direction of advanced fuel development, one must first appreciate the outstanding characteristics of the current fuel. CANDU fuel is elegantly simple in design: CANFLEX fuel has only 8 distinct components. Reactivity devices are located in the unpressurized, low temperature moderator, so neither reactivity devices nor their structural materials are associated with the fuel. CANDU coolant chemistry is benign, and no neutron absorbers are dissolved in the coolant (avoiding the possibility of their deposition onto the fuel). CANDU fuel is easy to manufacture (all countries having CANDU reactors manufacture their own fuel), and has the lowest fuel cycle costs of any commercial reactor (half that of LWR fuel). CANDU fuel performance is excellent, with many stations observing no failures in a given year. With on-power failed fuel detection and location systems, and the ability to remove failed fuel on power during refuelling, the economic impact of failed fuel is minimized.

The CANDU reactor was optimized to enable the use of natural uranium fuel, and as a consequence, the reactor and its fuel have high neutron economy. U-235 is burned to low levels (~0.2%), and the concentration of plutonium in the spent fuel per unit mass is low compared to spent LWR fuel, so there is little incentive to recycle the residual fissile material. Hence, the reference fuel cycle in Canada is once through. There have been no significant obstacles encountered in licensing and building dry-storage facilities for spent fuel in Canada. Permanent disposal in a geological repository in the Canadian Shield has been determined to be technically sound [5], and there has not been pressure for permanent disposal of fuel. While the quantity of spent natural uranium CANDU fuel is higher than the quantity of spent LWR fuel because of its lower burnup, the impact on storage and disposal is offset by its much smaller decay heat, both in the short and long term. Hence, "quantity" is generally an inappropriate metric for spent fuel [6], [7]. CANDU fuel cycle economics are optimized at very slight enrichments, typically between 0.9 and 1.2% U-235, corresponding to a burnup between 15 and 21 MWd/kg. Hence, there is no incentive to push CANDU fuel to the limits of its performance.

The evolution of the CANDU fuel bundle geometry has followed the same trend towards increased subdivision as with LWR fuel, with an increasing number of fuel pins in an LWR fuel assembly and CANDU fuel bundle. This has allowed either more power to be generated from the bundle, or increased operating and safety margins. In Canada, the original 7- and 19-element fuel bundles in the first reactors at NPD and Douglas Point have been followed by 28-element fuel at Pickering, and 37-element fuel bundles in the CANDU 6, Bruce and Darlington reactors. The CANFLEX bundle is now ready for commercial implementation, and features 43 elements and two element sizes, which further reduces peak ratings [1].

Low fuel cycle costs and excellent fuel performance have led Canadian utilities to focus on addressing short term station issues not pertaining to fuel. Nonetheless, advanced fuels offer several benefits to operating stations, including

- improved fuel cycle performance: for example, use of slightly enriched uranium (SEU), or recovered uranium from reprocessed spent LWR fuel, to reduce fuel cycle costs, and to reduce spent fuel volume [8];

- increased thermalhydraulic margins: for example, the use of CANFLEX with natural uranium, where CHF-enhancing appendages improve critical heat flux (CHF) and critical channel power (CCP, [9]); the use of enrichment results in an inlet-skewed axial power profile, which also increases CCP [10];
- increased operating and safety margins: greater subdivision in CANFLEX reduces maximum fuel temperatures and hence, fission gas release, and generally improves safety margins; this benefit can also be taken through increased bundle power [11];
- tailored reactivity coefficients; Low Void Reactivity Fuel (LVRF) allows tailoring void reactivity and fuel burnup [12].

It is anticipated that the introduction of any of these advanced fuels will "break the ice" and lead to the rapid introduction of new fuels in other CANDU utilities.

AECL's Strategy for Advanced Fuel Development. The conundrum in advanced fuel development is the long lead-time required to qualify new fuel. Qualification can involve in-reactor testing in a research reactor (NRU) and/or a power reactor; thermalhydraulics testing in freon and/or water; reactor physics measurements in the ZED-2 critical facility; and a host of out-reactor tests to ensure compatibility with interfacing systems. Advanced fuel development can hence take on the order of a decade or more.

With the long lead-time required for developing advanced fuels, it is possible that the final application of a specific advanced fuel may not be what was originally anticipated at its inception. As an example, CANFLEX was initially developed as a high power bundle that would provide power-uprating capability; however, improved thermalhydraulic capability is what is of most interest to operating stations now, as a means of addressing eroding margins due to pressure tube aging. Also, the ACR is using the lower ratings in CANFLEX to achieve higher burnups. LVRF was initially developed by AECL in the early 1990's as a backup for new CANDU plants in jurisdictions in which positive void reactivity could be an impediment to licensing; however, its first application may very well be in Canada in the Bruce Nuclear Generating Station [13].

Since customer needs must be anticipated a decade in the future, fuel development must be proactive, rather than reactionary. By the time the customer identifies the need for a new fuel, much of the development must have already taken place. Also, in response to the inevitable changes in customer requirements over the development timeframe, advanced fuel must incorporate the largest degree of flexibility.

AECL is responding to this reality in 3 ways.

1) AECL is developing a "basket" of advanced technologies that can be implemented into any fuel design when needed. This technology basket includes a proprietary, optimized internal element design for extended burnup fuel; advanced CANLUB coating for improved power ramp performance; graphite disc and annular fuel and for reducing fuel temperatures; and measures to further improve thermalhydraulic performance.
2) AECL performs "generic qualification" of advanced fuels, so that the qualification time required for a specific reactor and application can be greatly shortened. Examples of this

approach are CANFLEX fuel with natural uranium, extended burnup with SEU fuel, and LVRF. These technologies form the technology base for ACR fuel.

3) AECL follows an "evolutionary" approach in fuel development, consistent with AECL's strategy for advanced reactor development. This approach enables advanced technology to be applied to both existing and future reactors. It also allows features to be demonstrated in existing reactors.

CURRENT ADVANCED FUEL DEVELOPMENT

Support for Existing Stations. AECL provides direct fuel support to operating stations in several ways. It conducts fuel PIE as part of ongoing fuel surveillance programs at the stations, or as part of root-cause analysis of fuel defects. AECL helps the stations resolve manufacturing non-conformances. AECL maintains the suite of analysis codes required in fuel design and analysis, the principal ones being ELESTRES-IST [14] for normal operating conditions, and ELOCA-IST [15] for accident conditions. COG also funds a small program on fuel technology. Currently, one focus of the COG program is on determining the in-reactor condition of the fuel. Through fuel PIE, the in-reactor bundle geometry is determined, and from that, the impact on fuel performance and thermalhydraulic margins [16]. The COG fuel program also funds PIE of generic interest to the industry, such as for extended burnup fuel [17]. Very accurate measurements of the oxygen-to-uranium ratio axially and radially in pellets in both intact and defected fuel, are being undertaken in the COG program to determine the effect of oxidation on fuel performance [18]. COG has also funded the development of a fully qualified fuel PIE database, and summaries of important fuel performance measures such as fission gas release, hydriding and oxidation, and sheath strain.

AECL funds its CANDU Fuel Design Authority role through government appropriations in its internally-funded R&D program. This program provides an underlying fuel technology base that supports both existing reactors, and advanced fuels and fuel cycles. This includes development, qualification, and QA support for a dozen fuel design and performance computer codes. AECL has a collaborative program with SCN of Romania to demonstrate the load-following capability of CANDU fuel elements in the Triga reactor at Pitesti [19]. A new stress-corrosion cracking (SCC) power ramp criterion is being developed which will improve the predictive capability for multiple power ramps and extend our predictive capability to higher burnup [20]. AECL maintains and updates its fuel design drawings, technical specifications, and other fuel design documents. Sophisticated surface science techniques (such as Imaging X-ray Photoelectron Spectroscopy [XPS]) are being used to gain a better understanding of the micro-chemistry in the fuel-to-sheath interface, including the migration of gaseous and volatile corrosive fission products, and the role of CANLUB in protecting against SCC failures [21]. We have international collaboration to measure the intrinsic diffusion coefficients of important fission products [22].

AECL also plans on extending its "SMART Reactor" concept to include fuel, physics and thermalhydraulics. "SMART Reactor" is an integrated package of hardware and software tools, sensors and work processes that facilitate on-line monitoring, analysis, diagnostics and control of processes and equipment to optimize performance and maximize plant life. Areas in which this approach might be broadened to include fuel-related technologies are on-line margin calculation and optimization, and improved on-line monitoring and diagnostics for failed fuel detection and location.

CANFLEX with Natural Uranium. CANFLEX Mk 4 is now formally qualified and ready for commercial implementation [23]. The near-term application in operating stations is to offset the degradation of thermalhyraulic margins due to plant aging (pressure tube creep, steam generator fouling), thereby keeping the plants running at full power [24]. AECL is working with the CANDU 6 utilities in Canada to define roles and responsibilities in obtaining licensing approval from the Canadian regulator, the Canadian Nuclear Safety Commission (CNSC).

In Korea, a demonstration irradiation (DI) of 12 CANFLEX bundles in the Wolsong 1 reactor is underway [25]. This parallels the DI conducted in Canada in the Point Lepreau reactor. It is hoped that the DI will include a couple of CANFLEX Mk 5 bundles, having higher bearing pads than the Mk 4 design. The higher bearing pads raise the bundle and position it more centrally in the channel, reducing the flow bypass over the top of the bundle in a crept pressure tube, thereby further increasing CHF.

CANFLEX with SEU. The use of the CANFLEX fuel bundle as the carrier for SEU combines the benefits of increased thermalhydraulic margins and lower linear heat ratings with the benefits of SEU. SEU offers lower fuel cycle costs, a reduced quantity of spent fuel and lower backend costs, improved thermalhydraulic margins and a reduction in pressure tube creep due to the inlet-skewed axial power profile, and the potential for reduced fuelling machine usage [8]. Recovered uranium from reprocessed spent LWR fuel offers particular promise as an economical source of enrichment. Several programs provide support for the use of SEU in CANDU. Computer codes are being extended to higher burnup. Several irradiations continue in the fuel loops in the NRU reactor supporting the use of SEU: steady-state and power-ramp irradiations; a demountable bundle containing various advanced CANLUB coatings; a demountable bundle containing pellet geometries optimized for higher burnup. AECL is collaborating with NA-SA, the nuclear utility in Argentina, on a feasibility study and business case for the use of SEU in the Embalse reactor. AECL is also working with BNFL and KAERI (Korea Atomic Energy Research Institute) on the use in CANDU of recycled uranium from reprocessed spent LWR fuel. An important element of this program will be reactor physics tests in the ZED-2 reactor at the Chalk River Laboratories of ~35 CANFLEX bundles containing recycled uranium.

Low Void Reactivity Fuel (LVRF). AECL's LVRF program began in the early 1990's to provide a backup for new CANDU plants in jurisdictions in which positive void reactivity could be an impediment to licensing [12]. The LVRF concept is simple: a small amount of a neutron absorber is located in the center of the bundle, and enriched fuel is located in the rest of the bundle. The level of neutron absorber and the level of enrichment can be independently varied to give the desired value of void reactivity and fuel burnup. Upon a hypothetical loss of coolant, the thermal flux distribution through the bundle flattens very slightly, and the increase in thermal flux in the center of the bundle results in more absorption there, resulting in a negative component to void reactivity. AECL undertook a generic qualification program, using both a 37-element bundle and a CANFLEX configuration, having negative void reactivity in a CANDU 6 reactor. This qualification included fabrication of dysprosium-doped fuel, bundle fabrication, irradiation in the NRU reactor followed by PIE, reactor physics tests to validate the physics codes for this fuel type, thermalhydraulics tests in AECL's freon loop at the Chalk River Laboratories, and preliminary safety assessments.

Currently, AECL is working with Bruce Power to qualify a specific LVRF configuration for their reactors [13]. The reduction in void reactivity provided by the LVRF fuel will allow an increase in reactor power. The specific qualification for Bruce Power has been greatly simplified as a result of the generic testing already done. Some of the qualification tests currently underway will be applicable to ACR fuel qualification, particularly those pertaining to Dy-doped fuel, including additional NRU irradiations, measurements of thermal conductivity and melting temperature, and dissolution tests of Dy-doped fuel pellets. ZED-2 measurements of reactor physics parameters for the Bruce Power LVRF application will provide additional validation of the reactor physics toolset for similar applications.

ACR Fuel. Currently the qualification of fuel for the ACR is a major fuel program in AECL. There will be important spin-off benefits for existing stations, including extended burnup fuel design and experience, and improved computer codes qualified for higher burnup. The reference ACR fuel design uses the CANFLEX bundle geometry, with 2.1% SEU in all but the central element, which contains 7.5% dysprosium mixed with natural uranium [26]. Burnup is 21 MWd/kg, about three times that with natural uranium fuel in the current reactor. ACR fuel is based on experience with 3 underlying technologies [27]: the CANFLEX geometry, extended burnup fuel and LVRF. The qualification program will entail in-reactor tests in the NRU reactor, out-reactor tests, and analysis. The fuel will be qualified to meet Canadian and U.S. licensing requirements.

Advanced Fuel Cycles. AECL has long maintained research on a wide range of advanced fuel cycles. The intent is to establish technical feasibility of these fuel cycles, to support their introduction when and where warranted by local or national conditions, in either current CANDU reactors [28] or the ACR [29]. R&D generally includes fabrication development, irradiation in AECL's NRU research reactor to establish irradiation behavior followed by PIE, core design and fuel management analysis, reactor physics measurements in the ZED-2 reactor, thermalhydraulics measurements and analysis, safety studies, and waste management assessments. Other than the use of SEU, these are generally longer-term options, with development paced accordingly.

Several programs support fuel cycles that are synergistic with LWRs. AECL continues to collaborate with the Korea Atomic Energy Research Institute (KAERI) and the U.S. Department of State (DOS) on the "Direct Use of spent PWR or BWR fuel In CANDU reactors", or DUPIC. This fuel cycle involves the reconfiguration of spent PWR fuel into a form that can be used in a CANDU reactor using only dry, thermal/mechanical processes [30]. Three full-length DUPIC elements were fabricated by AECL from spent LWR fuel, and irradiated in the NRU reactor [31]. The first element was discharged at a burnup of 10 MWd/kg, the second at 16 MWd/kg and the third at 22 MWd/kg. PIE of the first two elements has now taken place [32].

The use of mixed oxide (MOX) fuel in CANDU, with plutonium from reprocessed spent LWR fuel continues to be an important element in AECL's advanced fuel cycle program [3]. The MOX program also supports the use of plutonium-bearing fuels in the ACR [33]. AECL's CANDU MOX program involves fuel fabrication and characterization in the Recycle Fuel Fabrication

Laboratory (RFFL) at the Chalk River Laboratories, irradiation testing in the NRU research reactor, PIE, reactor physics and fuel management studies. One MOX fuel irradiation currently underway in NRU is BDL-446, which is designed to investigate the effect of various levels of plutonium homogeneity in the microstructure of MOX pellets on the irradiation performance of the fuel. AECL's expertise in MOX fuel fabrication is also supported through the fabrication of plutonium-bearing fuels simulating the effect of burnup, for reactor physics measurements in the ZED-2 reactor for validating the reactor physics toolset.

As new advanced recycle options are developed, such as the UREX process in the U.S. Advanced Fuel Cycle Initiative [34], or other advanced reprocessing technologies in the Advanced Reactor Generation IV initiative [35], AECL will continue to explore synergy between existing CANDU reactors or the ACR, and other reactor types.

The Parallex project also exploits AECL's expertise in MOX fuel fabrication and irradiation. Parallex is a parallel experiment demonstrating the use of U.S. and Russian weapons-derived plutonium (WPu) in CANDU MOX fuel elements [36]. A major component of the Parallex Project is the irradiation testing in AECL's NRU reactor of MOX fuel elements containing WPu manufactured in both the U.S. and Russia, as well as MOX fuel fabricated by AECL in the RFFL. A total of three fuel bundles were manufactured, and the first has successfully completed its planned irradiation and is undergoing PIE. The Parallex project establishes the technical feasibility of the fabrication and irradiation performance of CANDU MOX fuel from WPu as an option for Pu-dispositioning in either existing CANDU reactors, or the ACR.

A long-term advanced fuel option that has been supported by AECL is inert matrix fuel, for actinide and/or plutonium destruction [37]. Inert matrix fuel contains no fertile component, so no additional fissile material is produced during irradiation. AECL evaluated several candidate inert matrix fuel materials through irradiation testing using its tandem accelerator. SiC was selected for further evaluation, which included fabrication development in collaboration with Queen's University [38].

To support the longer-term use of thorium in the CANDU reactor, AECL has irradiations ongoing in the NRU reactor of thorium elements fabricated with optimized microstructure, to realize the benefits from the higher thermal conductivity of ThO_2 relative to UO_2. The focus on fuel cycles studies is the once-through thorium cycle, and on the direct-self-recycle option, which is a simple mechanical recycle option [39].

Generic Advanced Technology. AECL has an ongoing program on generic advanced fuel technologies that can be applied to both existing and new reactors. As mentioned earlier, a new formalism is being developed for the stress-corrosion power-ramp failure criteria, for multiple power ramps and extended-burnup fuel [20]. A particularly fruitful area of study is the use of Imaging X-ray Photoelectron Spectroscopy (XPS) to study the microchemistry at the fuel-sheath interface, which is yielding new insights into the migration of fission products, and their effect on stress-corrosion cracking [21]. Very accurate measurements are being made of the oxygen-to-uranium ratio axially and radially in pellets in both intact and defected fuel, to determine the effect of oxidation on fuel performance [18]. We have international collaborations to measure the intrinsic diffusion coefficients of important fission products [22]. AECL is also participating in the IAEA FUMEX II project on inter-code comparisons of fuel performance for high-burnup fuel.

As part of AECL's "basket" of advanced fuel technology, graphite or thermally conducting discs between pellets is an option for reducing fuel centerline temperature. It is now surmised that graphite discs also getter corrosive, gaseous fission products, thereby greatly improving power-ramp performance of the fuel. Annular fuel would also reduce fuel centerline temperatures [40]. These so-called "cool fuel" designs could be implemented in existing bundle geometries, or in the next-generation bundle described below. The technology basket includes other means of further improving the thermalhydraulic (CHF) performance of the fuel.

AECL will adjust the pace of development of the advanced fuel technologies described above to meet market requirements. With fixed development resources, emphasis is on near-term applications that are driven by short-term, specific market needs. However, ongoing effort is maintained on the longer-term technologies, so that they will be available when needed.

FUTURE ADVANCED FUEL DEVELOPMENT

In the longer timeframe, thinking has begun now on the direction of the next generation of advanced CANDU fuel. Future fuel development will continue to be consistent with an evolutionary approach, so that new fuel products can be applied to existing and future reactors. The main drivers for new fuel development beyond that described above will be high burnup fuel for the ACR, and fuel for the CANDU Supercritical Water Reactor (CANDU SCWR).

<u>Next Generation Fuel Bundle</u>. A common denominator for long-term advanced fuel development will be the next generation bundle geometry. In this regard, one option is to continue the trend of increased subdivision. This would reduce linear element ratings, fuel centerline temperatures and gas release, improving operational and safety margins, and allowing further increases in fuel burnup. Current CANDU element sizes are still larger than for PWR fuel. AECL conceived a 61-element bundle design for high burnup application in advanced reactor studies with EPDC in Japan in the 1980's [41]. This is a possible contender for the next generation bundle, as peak element ratings would be reduced by about 40% compared to the 37-element bundle, and by about 25% compared to CANFLEX.

<u>High Burnup ACR Fuel</u>. In the ACR, fuel cycle costs and uranium utilization are optimized at a burnup around 40-50 MWd/kg [29]. Also, as ACR fuel burnup is increased, less neutron poison is needed in the central element to reduce void reactivity (which also improves uranium utilization). Designs with natural uranium in the central 8 elements of the CANFLEX bundle, and enriched uranium in the outer 2 elements can reduce uranium requirements by 30% compared to the reference ACR design. It is anticipated that as experience is gained with ACR fuel, there will be a drive to increase fuel burnup.

<u>CANDU Supercritical Water Reactor (SCWR) Fuel</u>. The CANDU SCWR is aimed at further reducing the generation costs for nuclear power, by significantly increasing the thermodynamic efficiency by using supercritical water, with much higher coolant temperatures and pressures [42].

The CANDU SCWR design continues the evolutionary path of advanced CANDU reactor development beyond the ACR. AECL is leading the SCWR group in the Generation IV initiative.

In order for early deployment of a prototype SCWR, the first fuel design will be based on existing technology to the extent possible. Hence, the fuel will use enriched UO_2, and probably the existing CANFLEX bundle geometry. The main fuel challenge will be developing a sheath material for supercritical water conditions. Development approaches will include Zirconium-based alloys with a thermal and/or corrosion-resistant barrier, and new alloys. First applications will be for fuel temperatures <625°C, while subsequent applications will aim for temperatures up to 1000°C.

In parallel with development of the reference CANDU SCWR fuel, an advanced bundle design will be developed, that will improve many of the Generation IV metrics, including safety, economics, reliability and sustainability.

SUMMARY

It is very important that the nuclear industry maintains strong fuel development expertise, in both people and facilities, and in Canada, AECL plays the lead role in fuel development. This expertise supports operating utilities, as well as AECL's advanced reactor development.

Advanced fuel development is a long lead-time activity that requires a proactive rather than reactive approach in order to anticipate customer needs a decade in advance. AECL's approach in advanced fuel development follows three principles: AECL is developing a "basket" of advanced technologies that can be implemented into any fuel design when needed; AECL performs "generic qualification" of advanced fuels, so that the qualification time required for a specific reactor and application can be greatly shortened; and AECL follows an "evolutionary" approach in fuel development that is consistent with its strategy for advanced reactor development.

It is believed that the introduction of LVRF in the Bruce reactors will open the door to the introduction of other advanced fuels and fuel cycles in CANDU, driven by local or national considerations. The use of CANFLEX with SEU offers many benefits.

Qualification of ACR fuel is currently a major focus of fuel activity in AECL. There will be important spin-off benefits for existing stations, including extended burnup fuel design and experience, and improved computer codes qualified for higher burnup application.

Longer-term advanced fuel development will require development of the next generation bundle design, post-CANFLEX. The key drivers will be advanced fuel for the ACR, and the CANDU SCWR.

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