BRUCE POWER NEW FUEL PROJECT

Design and Implementation of Bruce CANFLEX-LVRF

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ABSTRACT

Bruce Power[1] has initiated a plan to refuel the four reactors at its Bruce B facility with low void reactivity fuel (LVRF), beginning in 2006. The LVRF will provide the necessary safety margins to allow the Bruce B reactors to operate at their design capacity to beyond 2015. The project, called "New Fuel Project" (NFP), includes the design of the fuel, out-reactor testing and a demonstration irradiation, and addresses system and process changes pertaining to the receipt, use, storage and management of fresh and used LVRF.

NEW FUEL PROJECT OVERVIEW

Background

At the time Bruce Power entered a lease to operate and maintain the Bruce nuclear facility, the Bruce B units were limited to 90 per cent full reactor power (90%FP) owing to reactor physics issues pertaining to a postulated large loss of coolant accident (LLOCA). In addition, further deratings could be experienced in the future owing to reactor aging resulting in a reduction of margin to fuel dryout during a neutron overpower event. Bruce Power initiated the New Fuel Project to enhance existing safety margins, thereby providing a basis for restoring the reactor units to full output and sustaining that output to beyond 2015.

In addition, reactor operation is restricted to below full power owing to feedwater limitations and increasing reactor coolant inlet temperature owing to heat transport system aging. Additional projects are being implemented concurrent with the NFP to return the reactor units to full power. The suite of projects, including the NFP, is being managed under the Improve Output Program for the Bruce B units. This paper describes the NFP. The scope of the Project is depicted in Figure 1. The Project includes designing and implementing any changes required to support receiving and storing fresh LVRF, operating a reactor with LVRF, and wet storing used LVRF. The Project also includes assessing the impact of LVRF on the transfer of used fuel to dry storage.

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[1] Bruce Power, located approximately 250 kilometers north west of Toronto on the shores of Lake Huron, is a recently formed limited partnership made up of Cameco Corporation, TransCanada Pipelines, Ontario Municipal Employees Retirement System, Power Workers Union and Society of Energy Professionals. As Ontario's largest independent power producer, Bruce Power employs more than 3,000 employees and generates approximately 15 per cent of Ontario's electrical power needs.

Project Management

Bruce Power is managing the overall project while Atomic Energy of Canada Limited (AECL) is managing the design and qualification testing of the fuel. A consortium formed by Nuclear Safety Solutions (NSS) and AECL, under contract to Bruce Power, performs analysis of accidents, system performance, and the potential for out-reactor criticality of the fuel. Various other contracts will be in place for specialized services such as assessing impacts on the fuel handling system, developing an in-house criticality prevention program, designing and testing transportation containers, and enhancing the performance of a limited number of existing support systems where required.

The Bruce Power NFP is progressing concurrently with separate initiatives by Cameco and Zircatec Precision Industries (ZPI) to develop the necessary manufacturing industry infrastructure in Canada for CANFLEX and CANFLEX-LVRF designs. In anticipation of future markets for these fuel designs, Cameco is modifying their powder processing facility to accommodate fuel designs with enrichments somewhat higher than that required for the Bruce CANFLEX-LVRF design.

The Bruce Power NFP team consists of a project management team, project technical team, representatives from Cameco, ZPI, and AECL, and various support staff within Bruce Power. Functional roles, specific responsibilities, authorities and accountabilities for each team position are specified in detail in the Project Execution Plan. Representatives from Cameco, Zircatec, and AECL attend all Bruce Power project meetings to ensure there is effective communication at the scope and schedule interfaces. The project team consists of about 15 stakeholder representatives (i.e. representatives of those most affected by the project), most of whom coordinate various sub-teams having specific areas of expertise.

Design

The New Fuel Project will replace the current 37-element fuel bundle design (37NU), used in all four Bruce B CANDU® units, with a 43-element CANFLEX-LVRF® fuel bundle designed by Atomic Energy of Canada Limited (AECL). Each Bruce B unit is a Pressurized Heavy Water Reactor (PHWR) with a design electrical output of approximately 900 MWe at 100% FP. Each reactor vessel contains 480 horizontal fuel channels and each fuel channel contains thirteen 37-element fuel bundles stacked end-to-end and centred across the core. The 37-element fuel bundle design is a cylindrical array of 36 fuel elements in 3 rings surrounding a central element. All elements are of the same diameter and each element contains uranium oxide ceramic pellets formed from natural uranium. See also Figure 2 and Table 1.

The original design of the Bruce B units was for "fuelling against the flow" (FAF). The units are in the process of being converted (Core Conversion) to "fuelling with the flow" (FWF), which partially addresses the reactor physics issues associated with a postulated LLOCA. Currently, a mix of normal (495.3 mm) and long (508.0 mm) fuel bundles are used to reduce the power pulse associated with fuel string relocation during a postulated LLOCA using FAF. As a last step in the Core Conversion Project, the inlet fuel bundle will be removed such that each channel will have only 12 fuel bundles. The reduced fuel string length eliminates damage to the fuel channel at the inlet resulting from fuel bundle vibration. In addition, the reduced string length eliminates stresses on the fuel that could potentially arise during a LLOCA if the fuel string during thermal expansion became constrained by the fixed components at the end of the fuel channel.

Following Core Conversion, including the removal of the thirteenth bundle, the remaining 37-element fuel bundles will be replaced during normal FWF refuelling with the new 43-element Bruce CANFLEX-LVRF design. The length of the new bundles will be normal length only. The CANFLEX-LVRF design comprises 2 distinctly different design concepts: CANFLEX and LVRF.

Similar to the existing 37-element design, the 43-element CANFLEX fuel bundle is a cylindrical array of 42 fuel elements in 3 rings around a central element. The elements in the outer 2 rings, though, are smaller in diameter than the remaining elements. The element power ratings for a CANFLEX bundle are lower than those for a 37-element bundle for the same bundle power, making CANFLEX an ideal carrier for enriched fuel and for extended burnup. The CANFLEX fuel bundle was also designed to compensate for reductions in fuel dryout safety margins in aging reactors. The critical heat flux (CHF) enhancement "buttons" offset the reduction in thermal hydraulic safety margins caused by reactor aging, particularly fuel channel diametral creep. As a result of neutron absorption during normal reactor operation, the fuel channel diameter expands, allowing coolant to be redirected over the top of the bundle positioned eccentrically at the bottom of the fuel channel. This phenomenon is known as flow bypassing. The CHF enhancement buttons promote turbulent mixing of the coolant flow, thereby improving heat removal capability. Owing to its design features, the CANFLEX design has been selected as a carrier, or platform, for the LVRF concept.

The LVRF design includes a neutron absorber in the central element to reduce the positive void reactivity effect associated with a postulated LLOCA. During a LLOCA, the reduction in coolant pressure results in steaming and the formation of voids in the fuel channels. The presence of voids increases neutron reactivity until the shutdown systems terminate the rise in reactor power. During voiding, the neutron flux peaks at the centre of the bundle. Thus, the presence of an absorber in the centre of a bundle reduces the positive void reactivity effect. Since the neutron absorber is also present during normal reactor operation, all remaining fuel elements in the fuel bundle must contain slightly enriched uranium (SEU) to offset the reduction in bundle burnup that would result during normal operation if SEU were not used.

Dysprosium, the neutron absorber selected for use, is a non-radioactive rare-earth metal used in magnets, halogen lamps and in the electronics industry. A form of dysprosium oxide will be mixed with uranium oxide powder and formed into ceramic pellets for use in LVRF. The fuel composition (i.e. the amount of dysprosium and SEU used) is determined primarily by the magnitude of void reactivity reduction (VRR) and burnup required.

The concentration of Uranium-235 (U-235) used in Bruce B fuel will be increased slightly from the naturally occurring level 0.7 per cent U-235 to approximately 1.0 per cent. In comparison, reactors around the globe use fuel with a U-235 content anywhere from 3 to 5 per cent. The target burnup of the new fuel design is the same as that for existing 37-element fuel. Higher burnup fuel, which would require slightly higher enrichment to about 1.2 per cent U-235, may be considered in the future to reduce annual fuel costs.

Implementation

A Demonstration Irradiation (DI) of the Bruce CANFLEX-LVRF design is planned for the Fall of 2004 at the prevailing reactor power level. The DI is considered to be a confirmatory step in the design process given that:

- a DI for the CANFLEX natural uranium design has already been performed in a CANDU 6 reactor.
- some out-reactor testing and analysis has already been done for the CANFLEX-LVRF design
- only slight modifications and refinements (e.g. bearing pads, end caps, specific fuel composition) were made to the CANFLEX-LVRF design to develop the Bruce CANFLEX-LVRF design.
- all planned out-reactor testing and relevant analysis specific to the Bruce CANFLEX-LVRF, and a formal design review will have been completed by that time.

Twenty-four CANFLEX-LVRF bundles will be loaded into two relatively high power channels (twelve bundles in each channel) in one of the Bruce B reactor units. The bundles will be loaded in accordance with the normal refuelling schedule. At least one channel will be in the high power four-bundle shift refuelling region. Complete refuelling of the selected channel will take three refuellings of four bundles each over approximately a nine-month period. Discharge of the last bundles will occur after about twelve months. Some of the discharged bundles will undergo detailed post-irradiation examination. To minimize any differences or concerns between the DI bundles and production fuel, the DI bundles will be manufactured using equipment and conditions as near as practically achievable to the equipment and conditions that will be used for production fuel manufacturing.

Following receipt of a sufficient quantity of production fuel bundles, one of the Bruce B reactor units, the target unit, will begin normal refuelling with Bruce CANFLEX-LVRF bundles. Approximately four months later, the first channel will have to be refuelled. If after that refuelling there are no problems with the new fuel in the target unit, the remaining units will begin normal refuelling with Bruce CANFLEX-LVRF bundles. Approximately forty months are required to complete the replacement of all existing fuel bundles in each reactor unit. However, each unit is expected to be returned to full power after about twenty months and only 95 per cent of the existing bundles have been replaced. The last 5 per cent of bundles to be replaced have a negligible effect on restoring safety margins. The management of the transition core and obtaining regulatory approvals for subsequent raising of reactor power will be executed under a separate project.

CONSIDERATIONS FOR DESIGN AND IMPLEMENTATION

Normal Operation with CANFLEX-LVRF

The new fuel design is similar to the existing fuel design in terms of dimensions, flow resistance, burnup, and overall bundle power output. Thus, the impact on Heat Transport System (HTS) thermal hydraulic performance is expected to be small. There may be changes in the gamma and thermal neutron fluxes at the in-core detector locations, although the changes are expected to be small. Given the impacts on the HTS and flux detectors are expected to be small, the impact on Reactor Regulating System (RRS) operation is expected to be small. The localized increase in reactivity experienced during refuelling (i.e. refuelling ripple) is expected to be slightly higher with the LVRF, but no significant impact is expected for fuel management or safety analysis. The compatibility of dysprosium with materials in the HTS and other possible effects of dysprosium are being investigated under an out-reactor dysprosium behaviour program including testing and assessments.

Fuel Handling

Fuel handling within Bruce B includes receipt and storage of fresh LVRF bundles, reactor refuelling, wet storage of used LVRF bundles, and transfer of used bundles to Dry Storage Containers (DSCs). It is expected that the fuel handling process for LVRF bundles will be essentially identical to the existing process except for additional physical or procedural barriers implemented to prevent out-reactor criticality owing to the presence of SEU. International experience is being reviewed to determine the appropriate overall approach to managing the risk of criticality.

Fresh LVRF bundles will travel from the manufacturer to site in transportation containers specially designed to meet transportation requirements of the Canadian Nuclear Safety Commission (CNSC) Packaging and Transportation of Nuclear Substances Regulations (which adopt and reference International Atomic Energy Agency (IAEA) regulations) for fuel assemblies containing enriched uranium. Each transportation container is expected to consist of inner packaging holding the bundles and robust outer packaging (overpacks) designed to withstand normal conditions of transport and accidents. The types of tests include resisting water ingress, fire, and being dropped. The number of bundles transported per shipment will decrease and the number of shipments increase as a result of increased volume of packaging required to transport the bundles.

While the fuel handling process has not yet been finalized, it is expected that the process will be essentially identical to current practice. The transportation containers will be removed from the truck, overpacks will be removed and returned to the fuel manufacturer, and the inner containers stored on existing storage racks in the New Fuel Storage Room. Preliminary assessment indicates adequate margin to criticality exists for all credible fuel handling scenarios in the New Fuel Storage Area. Criticality analyses for severe conditions such as fire are being done to determine the likelihood of criticality and what mitigating provisions may be required (e.g. improvements in fire detection, or barriers, or protection systems, or additional storage space to increase separation).

When required for reactor refuelling, pallets of LVRF bundles will be moved to the New Fuel Loading Transfer Room where the bundles will be loaded into the New Fuel Transfer Mechanisms, which load the Fuelling Machines. No change in the existing process is expected except for the possibility of limiting the number of bundles in the New Fuel Storage Room to prevent criticality. Analysis shows that there is no possibility of criticality occurring in either the New Fuel Transfer Mechanisms or Fuelling Machines.

As per existing practice, used LVRF bundles will be discharged and stored in light water in the Primary Irradiated Fuel Bay (PIFB) prior to being relocated to the Secondary IFB to await transfer to the DSCs. Preliminary assessments indicate there is adequate margin to criticality during normal fuel handling and storage of used LVRF bundles in the IFBs. The potential for criticality as a result of an unplanned fuel handling event is being investigated.

No change to the dry fuel storage process is expected for transferring discharged LVRF bundles to DSCs. Similar to current practice, used LVRF bundles will be transferred to dry storage after typically 10 years of wet storage. Changes to the design of the DSCs are not expected. Modifications to DSCs, if required, would be pursued under a separate project.

Radiation Protection

Radiation protection for handling existing fresh 37NU fuel includes regular work coveralls, cotton gloves, and personal dosimetry. No additional radiation protection equipment is required for handling fresh LVRF bundles. Although the dose rate increases with use of SEU, the total dose associated with handling LVRF bundles remains an insignificant contribution to overall station dose. Few changes in radiation protection procedures are expected.

Failed Fuel Detection and Location

The Bruce B reactor units employ a Gaseous Fission Product (GFP) monitoring system to detect the presence of a defective element and a Delayed Neutron (DN) monitoring system to locate the specific fuel channel containing the fuel defect. At this time, the design concepts for the existing systems appear to be adequate for detecting and locating a defective LVRF bundle, although further assessment is continuing.

Accident Analysis

The CANFLEX-LVRF design is being implemented to substantially improve safety margins. As mentioned above, the LVRF feature specifically addresses the reactor physics issues associated with a postulated LLOCA. The CANFLEX feature improves safety margins associated with fuel cooling as a result of improved critical heat flux. Hence, Neutron Overpower Trip setpoints for the shutdown systems and maximum reactor power allowable by

RRS will be increased. The Bruce CANFLEX-LVRF design is similar to the existing 37NU design in many respects. Hence, although all accident analyses are being reviewed for impacts, no significant adverse impact is expected.

Quality Assurance and Quality Control

The New Fuel Project will be carried out following Bruce Power internal procedures and practices, which comply with the Canadian Standards Association N286 standards. AECL will conduct its own internal design review of the Bruce CANFLEX-LVRF design. Bruce Power will conduct a design review of all aspects pertaining to fuel design, qualification, and system and procedure modifications prior to performing the Demonstration Irradiation. In addition, the project will conduct self-assessments and be subjected to a Bruce Power internal audit by the Audit, Inspection, and Investigation Department.

As with existing fuel, the Bruce CANFLEX-LVRF bundles will be manufactured to CSA Z299.1 standards and fuel powders will be processed to CSA Z299.2 standards. Dysprosium and SEU pellets and elements will be distinguishable to prevent mix-up.

Environmental

A Project Description has been formally submitted to the CNSC in accordance with the requirements specified under the Canadian Environmental Assessment Act (CEAA). Implementation of the CANFLEX-LVRF design does not require any new construction of a structure on site, nor modification to any existing major structure (e.g. containment) nor modification to a major system (e.g. RRS, HTS, or moderator system). As such, only minor modifications to support systems or components (e.g. changes to fuel trays or stacks in irradiated fuel bays) may be required, none of which is expected to introduce a new pathway to the environment. There are no new or increased gaseous or liquid releases anticipated from the use of CANFLEX-LVRF. Dysprosium and its irradiation products will be minor additions, both radiologically and in terms of conventional toxicity. Consequently, environmental impacts are considered to be insignificant. Notwithstanding the expectation that environmental impacts will be negligible, the assessment of environmental impacts is an integral part of the Engineering Change Control process. Bruce Power is qualified to ISO 14001 international standards.

Regulatory

In accordance with the Reactor Operating License for Bruce B, Bruce Power will request the CNSC to approve the fuel design and, where required, to approve system or component modifications prior to the Demonstration Irradiation and production loading. Bruce Power has prepared and presented to the CNSC the outline of a formal Safety Case and is providing the CNSC on a regular basis updates on the development of the Safety Case.

The Safety Case is intended to include mutually agreed upon acceptance criteria, scope of reviews, and documents and analyses to be submitted. Although the action of raising reactor power and the approvals necessary to do so are not part of the New Fuel Project (they will be handled separately under another project for business reasons), such approvals and acceptance criteria are being discussed with the CNSC as an integral part of the Safety Case.

In Canada, the CNSC represents the International Atomic Energy Agency's (IAEA) interest in safeguarding new and used nuclear fuel. Information received by the IAEA to date confirms that IAEA operations and the use of surveillance monitoring equipment will remain the same as is currently used.

Table 1
Comparison Of Bruce CANFLEX-LVRF
And Existing 37-Element Fuel Bundles

	CANFLEX Bundle	**Current Fuel Bundle**
Number of elements per bundle	43 - Concentric rings of 21,14, & 7 elements around a central element	37 - Concentric rings of 18,12, & 6 elements around a central element
Diameter of fuel bundle	102.77 mm (maximum)	102.77 mm (maximum)
Length of fuel bundle	495.3 mm	495.3 mm and 508.0 mm
Weight of fuel bundle	23.1 kg	24.2 kg
Diameter of fuel elements	13.9 mm (maximum) for centre and inner elements. 11.9 mm (maximum) for intermediate and outer elements	13.10 mm (maximum)
Bearing pad height	>1.4 mm	1.2 mm
Location of bearing pads	inboard and outboard planes at both ends and at mid-length	inboard and outboard planes at both ends and at mid-length
CHF Enhancement buttons	Yes	No
Concentration of U-235	~ 1.0 %	0.71% (natural uranium)
Weight of uranium per bundle	18.5 kg U (21.03 kg UO_2)	19.2 kg U (21.8 kg UO_2)
Dysprosium in central element	Yes	No

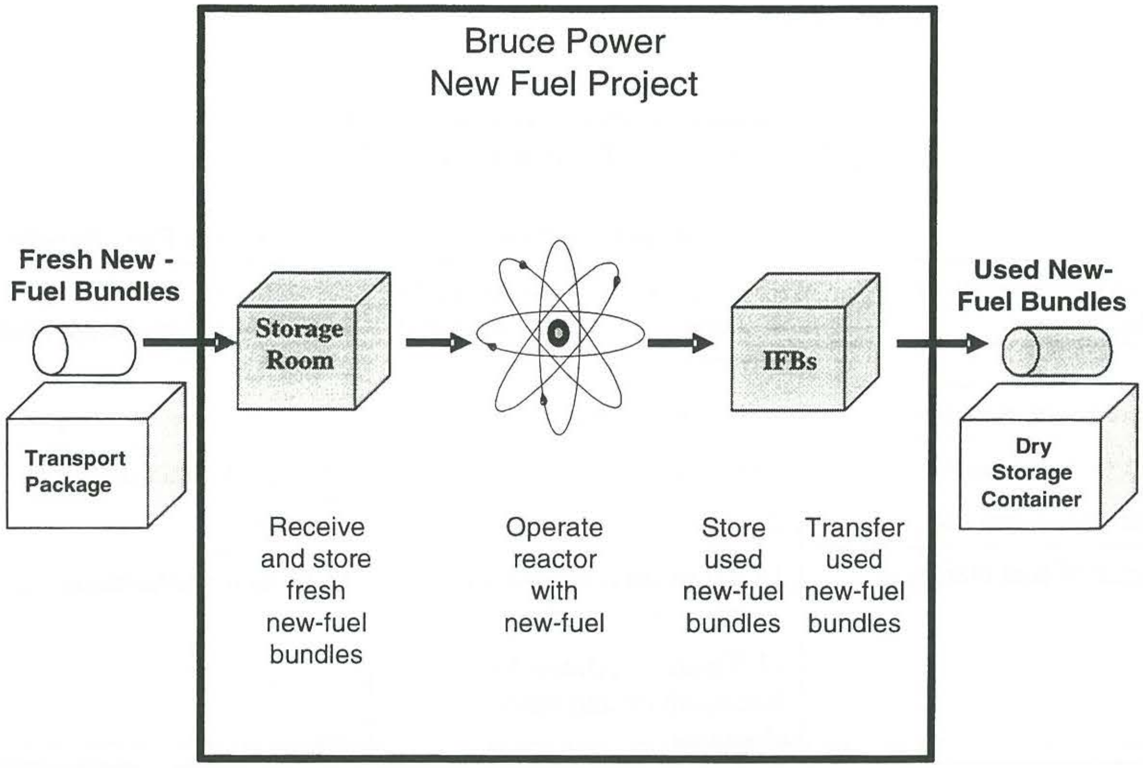
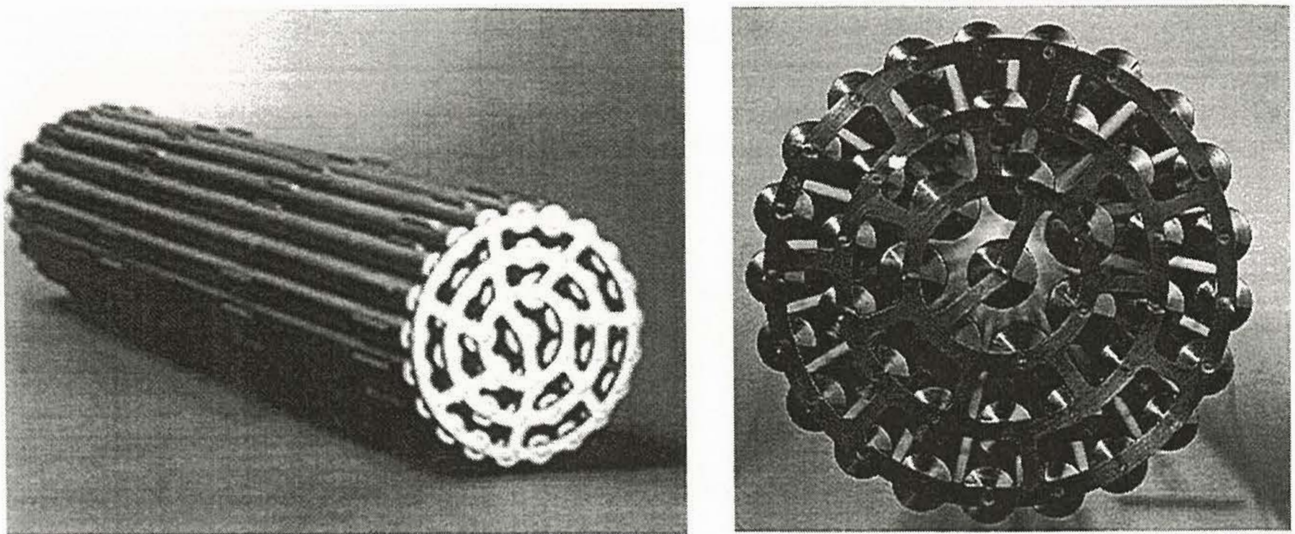
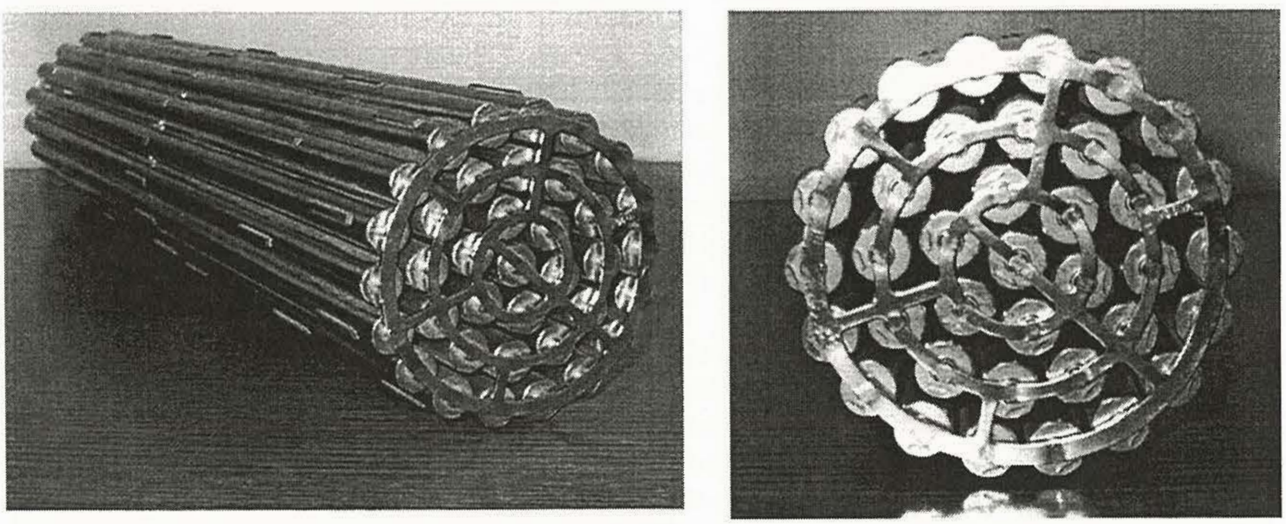


Figure 1
Overview Of Bruce Power New Fuel Project

Note: new-fuel = Bruce CANFLEX-LVRF



CANFLEX Fuel Bundle[1]



Bruce B Current-Fuel Bundle

Figure 2

Canflex And Current Fuel Bundles[2]

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[1] Not actual bearing pad configuration for Bruce B.

[2] See Table 1 for dimensions of fuel bundles.