**StarCore Nuclear Response and Comments, 23 September 2016,**
**On CNSC Discussion Paper DIS-16-04, March 2016**
**Small Modular Reactors: Regulatory Strategy, Approaches and Challenges**

## Introduction

The discussion paper has done a very thorough job of laying out the approaches and challenges facing SMR development, licensing and acceptance. StarCore Nuclear has reviewed the challenges and background in the discussion paper and provides its response to questions in this document.

StarCore Nuclear, Inc. is a Canadian company currently in Montreal, Quebec. Once funding is in place the office will be moved to Ontario and staffed there.

For reference, the key elements of a StarCore Nuclear (StarCore) reactor plant project are:

- A passively-safe high temperature gas cooled reactor (HTGR) design will be used that is based on operating experience and proven materials.
- The reactor will use TRISO fuel particles that are made into compacts and loaded into hexagonal graphite blocks of the Fort St. Vrain design.
- Each reactor will produce about 35 MWt and provide 10 MWe of electricity and thermal heat.
- A reactor plant will consist of two reactors. If a site requires more than two reactor's output, one or more identical reactor plants will be added, each containing two reactors.
- A common control room will be used to control both reactors.
- Reactor plant design lifetime will be 40 years.
- StarCore's initially plans to build two reactor plants, one at Chalk River and one at a southern Canada utility site. Later projects in Canada will include mines and other facilities. A micro grid will be established serving these facilities as well as local communities.
- StarCore intends to export the reactor plants to other countries after proving them out in Canada, very much like the CANDU reactors were exported.
- StarCore will engineer, design, licence, procure, construct, commission, operate and decommission the plants through various affiliates, with StarCore EPC designing and constructing the plants and other affiliates licensing and operating the plants.
- StarCore will build, own and operate the reactor plants, requiring only a Power Purchase Agreement from the customer.
- The design, construction and operation of the Canadian reactor plants will be licensed by the Canadian Nuclear Safety Commission (CNSC). IAEA standards and requirements will be included in the Canadian plants if they are acceptable to CNSC. Foreign plants will use the same design as the Canadian plants for the nuclear portions, and will be modified in the commercial portions to suit the foreign customers or sites.
- The design of the nuclear portions of each reactor plant will be maintained as initially licensed, with no changes in later plants except for required or fundamental changes.

- The power conversion system, including the electrical and thermal output of each plant, will be tailored to the customer's needs.
- The plant systems, structures and components will be supplied as shippable modules, skids or subassemblies to the extent practicable.
- StarCore will fuel and refuel the reactor on-site. (Note that StarCore's listing in Appendix A is not correct; we are not proposing a transportable reactor).
- The spent fuel will be replaced with new fuel at its end of life, which is expected to happen about every five years.
- Spent fuel will be stored initially at the reactor plant site until cool enough to ship and then stored at licensed sites in accordance with CNSC regulations.
- StarCore will conduct the decommissioning of plants in accordance with CNSC regulations and the agreed-upon decommissioning plan.

**StarCore Response to Questions**

For convenience, we have restated each question block and provided our response below. In preparing our response we considered both the discussion in Section 2 and that in Appendix B. We would be pleased to discuss our responses with CNSC in more detail.

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**From section 2.2:**

For the topic of "technical information, including research and development activities used to support a safety case", are requirements regarding the scope and adequacy of supporting information sufficiently clear?

Of particular interest are whether existing R&D requirements are clear in key regulatory documents such as REGDOC-2.5.2, *Design of Reactor Facilities: Nuclear Power Plants*, RD-367, *Design of Small Reactor Facilities*, REGDOC-2.4.1, *Deterministic Safety Analysis*, and other documents related to facility lifecycle (e.g., REGDOC-2.6.3, *Fitness for Service: Aging Management*).

StarCore believes that the requirements are clear and recognizes that there may be significant gaps in information from past experiments, as some of the work was done decades ago. However, StarCore believes that the critical elements related to fuel, graphite and high temperature materials have been thoroughly tested recently in the Next Generation Nuclear Plant program in the USA, some of which continues today. There are other elements that will need to be tested further. StarCore looks forward to entering into a Vendor Design Review with CNSC and submitting its R&D plans.

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**From section 2.3:**

• For the topic of "Licensing process for multiple module facilities on a single site", are clarifications needed to REGDOC-3.5.1, *Licensing Process for Class I Nuclear Facilities and Uranium Mines and Mills*?

• In order to be better prepared for the use of replaceable reactor core modules or relocatable facilities, the CNSC is seeking information on facility deployment strategies being considered by developers, including impacts of such an approach on areas such as worker and public safety, environmental assessment and decommissioning.

• The CNSC will use this information for future more-detailed workshops to discuss regulatory implication of different deployment approaches.

StarCore notes the following:

- The Class I Nuclear Facilities Regulations define a Class 1A nuclear facility as *"(a) a nuclear fission or fusion reactor or subcritical nuclear assembly;"*.
- StarCore's plans as discussed above, state that a reactor plant will include two reactors, and there may be more than one reactor plant on a site.
- REGDOC-3.5.1 states in Section 6. That *"A single licence may be issued for multiple facilities, each at a different stage in their lifecycle",* but otherwise does not discuss multiple facilities or multiple reactors.

StarCore believes that clarifications need to be added to REGDOC-3.5.1 to include the model of multiple reactors, as StarCore expects to submit only one application each to prepare the site, construct the plant, and operate the plant for a two-reactor installation or for multiples of this arrangement at one site.

StarCore does not plan to use replaceable reactor core modules as discussed in the Introduction and in the deployment model discussed as part of the Section 2.6 answers.

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**From section 2.4:**

For the topic of "Licensing approach for a new demonstration reactor", is there a need for additional clarification or information beyond that found in RD/GD-369, *Licence Application Guide: Licence to Construct a Nuclear Power Plant*? If yes, what needs to be clarified or added?

With respect to addressing uncertainties introduced by the application of integrated multiple novel features in a demonstration facility, are requirements regarding the scope and adequacy of supporting information sufficiently clear?

What, if any, requirements need to be revisited to address activities involving demonstration reactors? For example, are additional requirements or guidance needed to address operational restrictions if the facility is being used to gather operating experience that would be normally be needed for commercial facility licences?

StarCore has no comments on this section.

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**From section 2.5:**

For the topic of "licensing process and environmental assessments for fleets of SMRs", how do you envision proposals for such fleets across large geographical territories proceeding through licensing and environmental assessments?

How would the principles discussed in REGDOC-3.5.1, *Licensing Process for Class I Nuclear Facilities and Uranium Mines and Mills* be applied and where might challenges exist?

StarCore does plan to build multiple projects in Canada, but they will be spaced out over several years and are likely to be in several different Provinces or jurisdictions. Therefore, it is difficult to envision how they could be combined in a single license, and StarCore does not currently plan to do so.

On the other hand, StarCore does intend to maintain the nuclear portions of the plant exactly as licensed in the first plant and expects that plant outputs of electrical or thermal power will vary due to customer requirements. As we participate in the Vendor Design Review process, we would like to explore with CNSC how our conceptual design fits into this concept and whether changes might be beneficial.

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**From section 2.6:**

> For the topic of "Management system considerations: Licensees of activities involving SMRs", to help the CNSC prepare for alternative ownership and operating models that would be used in SMR deployment, more details (such as case studies) are sought regarding areas including:
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> • how deployment of different SMR concepts (e.g., factory fueled transportable concepts) would proceed
> • how oversight for such deployments would be conducted
> • how issues such as licensee performs inspections of key components (e.g., a reactor module) when received from a vendor
> • how alternative ownership models will address requirements in CSA Group's standard N286-12, *Management system requirements for nuclear facilities* and in CNSC regulatory requirements
>
> The CNSC will use this information for future, more detailed workshops to discuss regulatory implication of different deployment approaches.
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> See section B.6 of appendix B for additional background information.

StarCore's plans are as follows:

- Deployment – we are planning on a conventional deployment model using these Organization assumptions: The Owner/Licensee is a single entity and is an affiliate of StarCore Nuclear, Inc. This entity will contract with other StarCore affiliates StarCore EPC, who will engineer, design, procure, and construct the plant, and StarCore Operations, who will commission, operate, and decommission the plant. We are prepared to elaborate more on this structure and discuss funding issues in a private session with CNSC.
- Our conventional deployment model provides for:
    - Equipment and materials to be provided by suppliers to the site or to fabrication shops to be assembled into modules or subassemblies. This includes the reactor pressure vessel and internals, other equipment with safety functions as well as commercial equipment.
    - Modules, skids, and subassemblies will be factory tested and shipped to the site.
    - Fuel will be produced by a supplier, loaded into hexagonal fuel blocks and shipped to the site.
    - A constructor will prepare the site, receive the equipment, materials, modules and other items and construct the plant.

- Commissioning will be performed, with all testing completed that can be done absent having fuel in the reactor.
- Fuel will be received at the site.
- Upon the Issuance of the Operating Licence, the fuel will be loaded in the reactor and final testing begun.
- Once the testing is complete and the Owner/Licensee and CNSC are satisfied with the results, the plant will begin commercial operation.

- The Owner/Licensee will meet the requirements in CSA N286-12 as well as have the personnel and procedures to control and perform oversight of all of these activities.
- The Owner/Licensee will have access to the R&D results, design information, IP and any other data needed to support the safety case through the agreements with StarCore Nuclear, Inc. and StarCore EPC.

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**From section 2.6.1:**

For the topic of “management system: minimum complement in SMR facilities”, are the regulatory requirements and guidance related to minimum complement sufficient and clear as applied to activities involving SMRs? What, if any, proposed changes should be considered for the existing regulatory requirements? For example, in conjunction with the question in section 2.12, is additional guidance needed to address human coverage for failure of automated systems?

Yes, StarCore believes that the regulatory requirements and guidance are clear. Additional guidance would be useful to address human coverage for the failure of automated systems.

StarCore currently plans to have a small maintenance staff on site. These personnel will be qualified to perform their functions, which will include routine maintenance, reaction to deviations in operation and shutting down the reactors. We will also be doing offsite monitoring in our Central Control operation, and will be able to initiate actions from there if issues arise.

Of course, during certain operations onsite, such as the initial commissioning, the fueling of the reactors and the refueling operations, we will have additional qualified and certified personnel onsite.

We have not done enough design work yet to identify the deviations from normal operation, AOO, DBAs and BDBAs. It is our intent to put in place a management system, design our facility and develop an automatic control system to handle all of these events. Also, we will put in place a human factors engineering program. We recognize that we will have to make the safety case that we won’t need more than the people we plan to have at the site to react to events there.

As discussed in Section 2.9, we will have certified operators onsite for the first reactor plant.

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**From section 2.7:**

For the topic of “safeguards implementation and verification”, the CNSC would like to hear if its current framework provides enough clarity to effectively ensure safeguards verification of novel fuels and new designs.

The answer is yes for StarCore's design. We will build in the necessary design features generally along a "safeguards by design" approach to accommodate IAEA requirements and look forward to discussing these in the Vendor Design Review.

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**From section 2.8:**

> For the topic of "deterministic/probabilistic safety analyses", are the regulatory requirements and guidance clear for the kinds of alternatives that might be proposed for Deterministic/probabilistic safety analyses for SMR facilities? Do the existing requirements permit the establishment of a suitable level of probabilistic safety analysis for different novel designs?
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> Does enough information currently exist to apply probabilistic safety analysis to novel designs?

StarCore believes that the regulatory requirements are clear. Some work may be needed for the probabilistic safety analysis work, however. We will discuss these topics during the Vendor Design Review.

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**From section 2.9:**

> For the topic of "defence in depth and mitigation of accidents", given some of the novel safety approaches that vendors are proposing, are the existing requirements and guidance around defence in depth adequately clear for prevention and mitigation of accidents? Consider this question with particular attention to the following topics and combinations thereof:
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> • application of inherent and/or passive safety features
> • application of alternative instrumentation and control strategies (e.g., remote monitoring and intervention of a fully-automated facility)
> • non-water cooled technologies
> • transportable sealed and factory fueled SMRs (see section 2.11)
> • facilities proposed to be located in highly remote regions

Yes, the requirements and guidance are clear. The primary difference between them and our plans is in the area of operators, as our plant will be fully automatic, and will not need any on-site. However, we are planning to have operators on the first plant, and they will be trained and certified in accordance with CNSC requirements. We will keep them at the plant until we are convinced that our automatic controls meet all of the requirements, and we can make the safety case to CNSC to take the on-site operators off. The operators will move from the plant to StarCore's Central Operations facility when this happens.

Another difference is in the robustness of the containment design. An HTGR core utilizes no water, so hydrogen will not be an issue, and we will make the safety case that the core cannot melt down, thus removing some of the other containment requirements.

Also, we will make the safety case that we can operate with a zero exclusion zone and have no potential to release radioactivity from the plant above permitted levels.

Finally, we will make the safety case that we do not need active systems nor AC power to prevent damage to the core and radioactivity release to the public in any accident scenario, including BDBAs.

These differences are based on the normal operation and safety features that StarCore will design or build into the plant, including:

- TRISO fuel particles that will contain the fission products
- A helium purification system that will remove contaminants and any fission products that escape the graphite fuel compacts, therefore, making the radioactive source term extremely small.
- The negative temperature coefficient of a graphite core that will prevent extreme temperatures and make core meltdown impossible
- An embedded reactor and other systems and components with safety functions
- Reactor heat transfer into the soil matrix using passive means when active systems are not available
- A non-safety shutdown cooling system that will cool the reactor during Anticipated Operational Occurrences (AOO), but will not be required to respond to DBAs or BDBAs
- An automated control system that will be programmed to handle deviations from normal operation, AOO, DBAs, and BDBAs
- The control system will also have failure prediction capability for systems and components
- Maintenance personnel on site to handle deviations and issues with the plant
- Remote monitoring, with shutdown and other capabilities.

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**From section 2.10:**

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| For the topic of "emergency planning zones", are the requirements and guidance related to EPZs sufficiently clear to enable an organization to submit a licence application for a facility-specific EPZ while still meeting the CNSC's expectations regarding the environment and worker health and safety?<br><br>Are there specific considerations that need to be incorporated into requirements and guidance for specific siting cases like remote regions? |

Yes, StarCore believes that the requirements and guidance are clear and will enable us to submit full applications. Also, the process to work through the issues and interact with local and governmental agencies is well laid out. StarCore will make use of all of this material as we proceed forward into both the further development of our design and in the licensing process.

Remote regions, especially in Northern Canada, will need additional considerations. Emergency response actions from anyone not close to the plant may be impossible due to weather conditions. StarCore believes that the reactor types considered for such regions must be inherently safe – that is requiring no AC power nor human intervention to protect the public and the environment in the event of an accident. The HTGR is such a reactor. The IAEA has defined the HTGR as "*an inherently safe nuclear reactor concept with an easily understood safety basis that permits substantially reduced emergency planning requirements and improved siting flexibility compared to other nuclear technologies*", (IAEA, "Advances in high temperature gas cooled reactor fuel", IAEA TECDOC 1674, 2013).

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**From section 2.11:**

For the topic of “Transportable reactor concepts”, the CNSC is seeking information about deployment scenarios for further discussion. Examples of questions to inform future discussions include:

• How might deployment of such concepts proceed? (The CNSC seeks examples such as case studies.)
• What nature of activities will occur at the factory or service facility versus the site and how will those activities interface with one another from a management-system perspective?
• What would environmental impact statements look like?
• What would the relationship between the manufacturing facility, the facility fueling the reactor modules, the carrier transporting the modules and the site operator entail?
• How would post-shipment inspections be conducted and addressed by the licensee of the deployment site facility?
• How would these scenarios be impacted if major components or modules were imported or exported?
• How would transport be conducted such that transport requirements would be met throughout the deployment journey?
• What is the strategy for performing safety analysis for all deployment activities?
• How would these scenarios be impacted if major components or modules were imported or exported?
• How would transport be conducted such that transport requirements would be met throughout the deployment journey?
• What is the strategy for performing safety analysis for all deployment activities?

StarCore does not plan to use a transportable reactor.

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**From section 2.12:**

For the topic of “increased use of automation for plant operation and maintenance”, is additional clarity needed in existing requirements and guidance related to the implementation of automation strategies for SMRs?

Specific to autonomous operation with remote monitoring and intervention, what safety and control measures could be taken to help prevent/mitigate communication loss between the SMR and the monitoring facility?

The existing requirements and guidance appear to be adequate and will be built into the design of the control system. The key features of StarCore’s automatic control, remote monitoring and intervention plans are:

- A fully automated plant requiring no operators (except in the initial testing and operation of the first plant)
- A control system design based on systems used in many safety-critical aerospace applications
- A Central Control facility monitoring multiple reactor plants
- Automatic failure prediction for systems and components
- Alarms that uniquely identify any specific failures that have occurred or are predicted
- Controls that prevent wrong commands or actions being taken
- Automatic responses to arbitrarily complex failures
- Cyber security built in
- Human factors principals and practice implemented

- Redundancy in hardware design, with multiple processors and communication buses
- Use of “keep alive” signals ensuring good communications with the plant and the ability to shut it down if communications are lost
- Transmissions between Central Control and the reactor plants on multiple satellites
- Qualified equipment
    - Instrumentation – StarCore expects that qualified reactor instrumentation is available now as well as other instrumentation in the plant. If instrumentation is needed that is not qualified, we will test and qualify it.
    - Computers and other hardware – these items will be developed using aerospace experience, where key design criteria are reliability, vibration (seismic), harsh environments and high radiation levels. The specific hardware to be used on reactor plants may well need testing to qualify it, and StarCore will see that that is done.

StarCore recognizes that a significant body of evidence will be required to demonstrate that safety features can permit this mode of operation. We plan to build up this body of evidence based on design criteria, design review, software development and testing, use of a simulator, extensive commissioning tests and the operation of the first plant, with certified operators on site.

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**From section 2.13:**

> For the topic of “human/machine interfaces in facility operation”, the CNSC is seeking comments from technology developers who are proposing new HMI technologies approaches/architectures for use in SMRs.
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> Is additional clarity needed in existing requirements and guidance for HMIs used for facility operation and maintenance? If so, what areas could benefit from additional clarity?

StarCore has no comments on this section at this time.

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**From section 2.14**

> The CNSC is currently working on a separate discussion paper on human performance and will request feedback on this specific topic in the near future.
>
> For the topic of “The impact of new technologies on human performance” is additional clarity needed in existing requirements and guidance for human performance in an SMR environment?

StarCore does not believe that additional clarity is needed, but there will be some unique issues, such as maintaining performance at remote sites. We will provide our Human Factors Engineering Program Plan in a Vendor Design Review Submittal.

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**From section 2.15:**

For the topic of "financial guarantees for operational continuity", is additional clarity needed in existing requirements and guidance related to the implementation of financial guarantees for operational continuity to ensure safe termination of licensed activities?

Are there other financial instruments not listed in G-206 that would be useful in helping put financial guarantees in place?

Additional clarity is not needed. StarCore would be pleased to discuss our plan for financial guarantees and various financial instruments that may be used in a private session with CNSC.

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**From section 2.16:**

For the topic of "site security provisions", what regulatory issues may present challenges to deployment scenarios for SMR facilities? For example:

• How could subsurface or civil structures be implemented as part of the security by design approach?
• How might security provisions differ for SMRs with a very limited onsite staff and located in a remote region? How would possibly lengthy offsite response times be addressed?
• How would security provisions be addressed for offsite monitoring/control of facilities if used?

StarCore will have Category II nuclear material onsite (more than 10% and less than 20% U235, with more than 10 kg of material). Our security by design approach includes embedding the reactors below grade, with limited means of access to them. When unirradiated fuel is in transit or being loaded into the core onsite we will take additional security measures in accordance with the regulations. We will also follow the regulations when unirradiated fuel is stored onsite and will take them into consideration as we further develop our design.

We anticipate having no security personnel onsite except as noted above. We have not determined how we will handle emergency responses for remote sites, but will in the course of our project development. Please note the discussion in Section 2.10 also.

Our first two sites are expected to be at Chalk River and a southern Canada utility site. We plan on contracting for security personnel from the host site on these sites, as required.

We will be doing offsite monitoring in our Central Control operation, and will be able to initiate actions from there if issues arise.

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**From section 2.17:**

For the topic of "waste management and decommissioning", what are some of the key strategies for waste management, spent fuel management and decommissioning that the CNSC and licensees need to consider for various SMR deployment scenarios? For example, for companies considering a fleet of SMRs across a wide geographical area, how would waste and decommissioning be addressed?

In implementing these strategies, where are the challenges that exist in interpretation of current requirements and guidance?

StarCore has not proceeded far enough along in our design work to accurately predict waste streams, although we expect that they will be of conventional types, with perhaps some unique isotopes to be dealt with. We will contract with existing facilities to handle these waste streams. Spent fuel will be stored at site until cool enough to ship to a NWMO repository or to a site licensed to store it until the repository is available.

Our decommissioning plan will be presented to CNSC as part of the Vendor Design Review.

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**From section 2.18:**

For the topic of "subsurface civil structures important to safety", to complement the CNSC's investigation into ageing management of civil structures, where is SMR industry work is being performed in this area to address aging management issues in codes and standards? Of particular interest is ongoing work being done on technologies necessary to reliably demonstrate that such structures remain fit for service over the life of the facility including provisions for safe storage and decommissioning plans?

StarCore is not working on the aging management issue at present. We are aware of and following work being done in the USA on this issue [1, 2, 3]. As we proceed with our design we will require that aging be considered in the design, including material types, configuration and in service inspection provisions. We will also interact with CSA to determine what standards are being worked on to address the issue and participate in their development.

References:


1. D. J. Naus, ORNL and B. R. Ellingwood, JHU, *Report on Aging of Nuclear Power Plant Reinforced Concrete Structures,* NUREG/CR-6424, March 1996
2. D. J. Naus, ORNL, *Report 19: Considerations for Use in Managing the Aging of Nuclear Power Plants,* RILEM Publications, 1999
3. Y. Mori, JHU and B. R. Ellingwood, JHU, *Maintaining Reliability of Concrete Structures. II: Optimum Inspection/Repair,* March 1994