ASSESSING THE SAFEGUARDABILITY OF TERRAPOWER'S NATRIUM® REACTOR

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INTRODUCTION: The global quest for low-carbon energy and the projected surge in the demand for electricity by hyperscalers, has heightened interest in advanced reactor technologies. These next generation nuclear reactors will be fast-spectrum reactors, which promise improved fuel utilization, waste reduction, and enhanced inherent safety features. In addition, most of these reactor designs claim to have enhanced proliferation resistance features, which would help facilitate the applications of International Atomic Energy Agency (IAEA) safeguards measures (herein referred to as 'safeguards'). This paper assesses the safeguardability of the industry-leading commercial fast reactor design: TerraPower's Natrium reactor. A review of how international safeguards are applied to a generic light water reactor (LWR) is used as a conceptual framework for how international safeguards may be applied to a Natrium reactor. This assessment also outlines potential challenges and gaps in safeguards coverage when compared to traditional LWRs. A roadmap for how these challenges and gaps may be addressed with the inclusion of safeguards-by-design (SBD) principles is also provided.

1. SAFEGUARDABILITY ASSESSMENT METHODOLGY.

Following a brief overview of the Natrium reactor design, a detailed review of how safeguards are applied to a generic LWR is provided. An assessment of the safeguardability of the Natrium reactor is performed using the generic LWR safeguards approach as a conceptual framework to identify challenges and potential gaps in safeguards coverage.

1.1. TerraPower's Natrium Reactor

Out of the multiple types of Generation IV reactor designs being developed, sodium-cooled fast reactors (SFRs) represent the most mature technology and have been the focus of demonstration facilities worldwide [1]. TerraPower's Natrium reactor is a pool-type SFR with integrated energy storage and is on track to be the first US-based next generation reactor constructed [2]. Approximate plant specifications are provided in Table 1, and a generic site layout can be seen in Fig. 1.

TABLE 1. NATRIUM REACTOR CHARACTERISTICS [3] [4],

FEATURE	DESCRIPTION
CONFIGURATION	Pool-type sodium fast reactor
THERMAL POWER	840 MWth
ELECTRICAL OUTPUT	345-500 MWe
FUEL	Metallic HALEU enriched between 5-19.75%
COOLANT	Liquid sodium
PRESSURE	Near atmospheric

ENERGY STORAGE SYSTEM	Molten salt-based thermal energy storage system integrated with reactor for flexible output

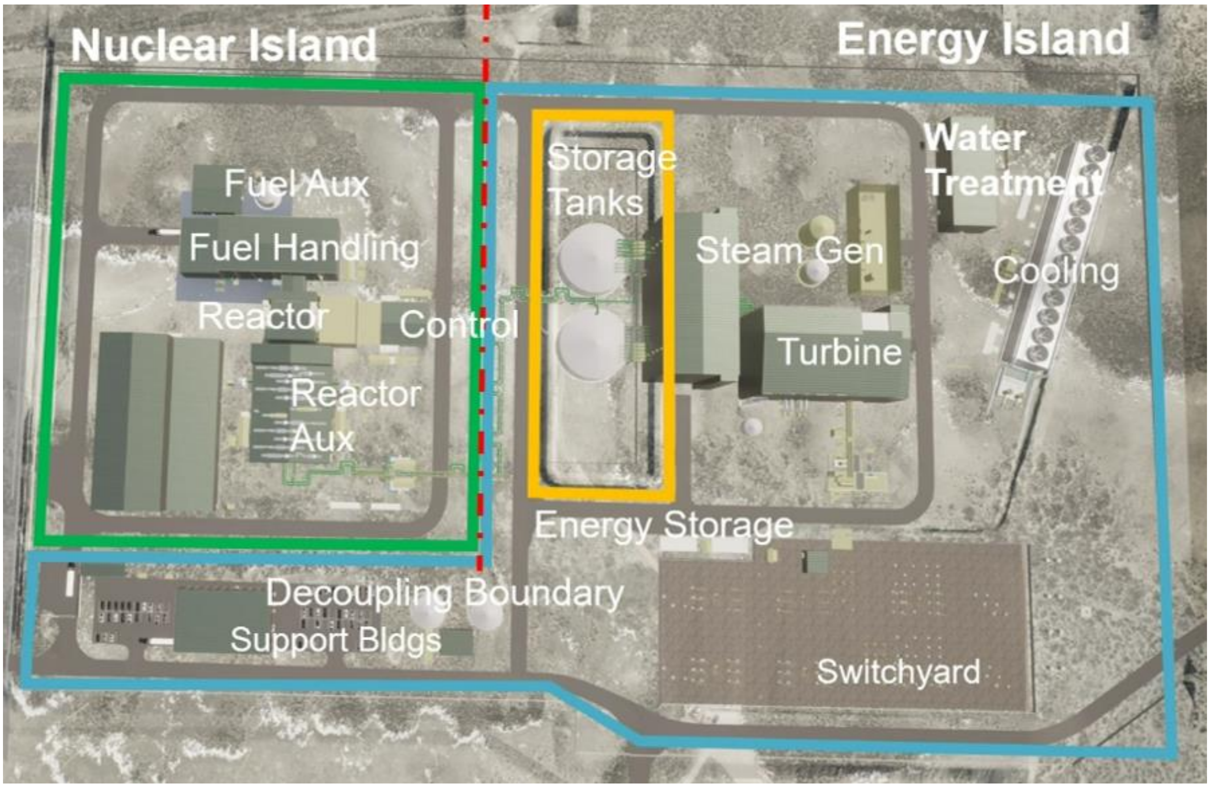

FIG. 1. Proposed Natrium reactor plant layout. The plant will be separated into two major 'islands': Nuclear Island (NI) and the Energy Island (EI). Connecting the two islands are the molten-salt based thermal energy storage system [3]

1.2. IAEA Safeguards Approach for a generic LWR

In order to assess the safeguardability of a new reactor design, it is first practical to review a typical safeguards approach for a generic LWR. Attention will be paid to three key components needed in the development of a safeguards approach for a generic LWR: a State supplied Design Information Questionnaire (DIQ), a facility level Material Balance Area (MBA), and a facility specific inspection and verification regime. This paper will provide greater detail on what each of these three key components are, and specifically how they are applied to a generic LWR.

1.3. Assessing a Natrium Reactor's Safeguardability

After an in-depth review of how a safeguards approach is applied to a generic LWR, the safeguardability of the Natrium reactor design will be assessed based on a review of how the three components referenced in the above section can be applied, specifically:

(a) How would a Natrium reactor DIQ, and an associated Design Inspection Verification (DIV) regime, compare to a DIQ/DIV for a generic LWR?

(b) How does a hypothetical Natrium reactor MBA compare to an MBA on a generic LWR? Included in this assessment will be a comparison of material balance and accountancy information, proposed key measurement points, and associated verification technologies.

(c) What will the inspection regime look like for the Natrium reactor compared to a LWR? How can operator burden be reduced by implementing SBD principles?

The strengths and weaknesses in the comparison of these three key areas will be analysed to help evaluate the safeguardability of the Natrium design before SBD measures are implemented. Subsequent sections will offer proposed solutions to any challenges presented here.

2. PRELIMINARY RESULTS

A preliminary analysis of the safeguardability of the Natrium reactor has been performed, and a number of key areas that may pose safeguards challenges have been identified. These challenges, along with some proposed solutions, are present in subsequent subsections. These preliminary findings will be greatly expanded upon after a complete review of the safeguardability of the Natrium reactor is performed.

2.1. HALEU Treatment

The first major uncertainty in how safeguards will be applied to a Natrium reactor concerns the treatment of its fresh fuel, specifically HALEU. At present, there is no consensus for how safeguards will be applied to fresh HALEU fuel. From a proliferation standpoint, the material attractiveness for HALEU is greater than traditional LWR fuels enriched from 3-5%, but it is not as attractive as fresh fuels containing plutonium such as MOX. Since the timeliness and inspection criteria for fresh HALEU fuel is yet to be determined, there is uncertainty in how SBD principles can be developed and implemented. Safeguards for fresh HALEU fuel is an area that requires greater collaboration with the IAEA.

2.2. Fresh fuel verification measures

After fresh fuel assemblies (FFAs) arrive to the facility and are inspected, they are placed into storage in the Ex-Vessel Storage Tank (EVST). During core loading, the FFAs are transported from the EVST to the core by the Ex-Vessel Handling Machine (EVHM), with no possibility for inspector access to a FFA. The current design for the fuel handling equipment includes an observation window at various stages of the transfer process which, in theory, would allow for item counting and identification of FFAs before core loading; however, unlike a traditional LWR, the fuel would be inaccessible for material verification measurements before being loaded into the core. The lack of access for measurement, combined with the higher material attractiveness of HALEU, can cause a significant challenge for implementing safeguards at a Natrium reactor.

2.3. Enhanced DIV measures relating to fuel handling

In addition to the challenges with fresh fuel access mentioned in the previous section, novel features of the Natrium plant design will require enhanced assurance when performing DIV activities at the initial and periodic stages. A preliminary review of the plant configuration determined a need for enhanced DIV measures in the following systems:

(a) Pin Removal Cell (PRC): the pin removal cell resides in the fuel handling building and will be used to remove pins from test assemblies for post-irradiation-examination, as well as identify failed fuel pins in damaged assemblies.

(b) Pool Immersion Cell (PIC): the PIC removes residual primary sodium from spent core assemblies prior to immersion in the SFP.

(c) EVST: the EVST provides a passive, controlled environment for temporary storage of fuel assemblies – both fresh and spent.

(d) EVHM: the EVHM transports fuel assemblies to and from the EVST and reactor core.

3. CONCLUSIONS

A surge in energy demand in the near future, and a subsequent desire to improve fuel utilization, will heighten the need for advanced nuclear reactor designs. At present, full scope safeguards have not been applied to an advanced fast reactor design. It will be crucial for designers of these advanced reactors to include SBD concepts to facilitate a more robust safeguards approach. In this work, the safeguardability of TerraPower's Natrium reactor was assessed. Areas that pose safeguards implementation challenges include the treatment of HALEU fresh fuel, verification measures for fresh fuel assemblies, and the need for enhanced DIV measures for fuel handling equipment and infrastructures. This work may be used as a starting point for improving the overall safeguardability of a Natrium reactor, as well as work towards facilitating improved SBD measures.

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