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Implications for Advanced Safeguards Derived from PR&PP Case Study Results

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The proliferation resistance and physical protection (PR&PP) working group produced a case study on the Example Sodium Fast Reactor (ESFR). The ESFR is a hypothetical nuclear energy system consisting of four sodium-cooled fast reactors of medium size collocated with an on-site dry fuel storage facility and a spent fuel reprocessing facility using pyroprocessing technology. This study revealed how safeguards would be applied at such site consisting of integrated multiple fuel cycle facilities and the implications of what safeguards technology and safeguards concepts would need to be adapted and developed to safeguard successfully this Generation IV nuclear energy system concept.

The major safeguards concepts driving our safeguards analysis are timeliness goals and material quantity goals. Because the fresh transuranic (TRU) fuel to be produced in the ESFR fuel fabrication facility contains plutonium, the ESFR will be reprocessing, using in the reactor, and storing material on site that will have IAEA defined "direct-use material" in it with stringent timeliness goals and material quantity goals that drive the safeguards implementation. Specifically, the TRU fresh fuel, pyroprocessing in process material, LWR spent fuel sent to the ESFR, and TRU spent fuel will contain plutonium. This material will need to be verified at interim intervals four times per year because the irradiated direct-use material, as defined previously, has three-month timeliness goals and 8 kg material quantity goals for plutonium. The TRU in-process material is, of course, irradiated direct-use material as defined by the IAEA. Keeping the plutonium and uranium together with TRU products should provide a radiation barrier. This radiation barrier slows down the ability to reprocess the fuel. Furthermore, the reprocessing technique, if it has some intrinsic proliferation resistance, will need major modifications to be able to separate plutonium from the uranium and TRU mixture. The ESFR design should have such features in it if it is seen to have intrinsic proliferation resistance. The technical difficulty in diverting material from the ESFR is at least as strongly impacted by the adversaries overall technical capabilities as it is by the effort required to overcome those barriers intrinsic to the nuclear fuel cycle. The intrinsic proliferation resistance of the ESFR will affect how extrinsic measures in the safeguards approach for the ESFR will provide overall proliferation resistance.

I. INTRODUCTION

The proliferation resistance and physical protection (PR&PP) working group examined the proliferation resistance of the Example Sodium Fast Reactor (ESFR). The ESFR is a hypothetical nuclear energy system consisting of four sodium-cooled fast reactors of medium size collocated with an on-site dry fuel storage facility and a spent fuel reprocessing facility using pyroprocessing technology. The PR&PP working group defined how safeguards would be applied at such site consisting of integrated multiple fuel cycle facilities. From these safeguards approaches there are implications of what safeguards technology and safeguards concepts would need to be adapted and developed to safeguard successfully this specific Generation IV nuclear energy system concept as well as some of the other Generation IV revolutionary concepts.

The basis of safeguards at the ESFR will be International Atomic Energy Agency (IAEA) safeguards. The Comprehensive Safeguards Agreement (CSA), which a State adhering to the Nonproliferation Treaty (NPT) is obliged to have in force, is based on INFCIRC/153(Corr.). Safeguards based on INFCIRC/153 have the stated technical objective in INFCIRC/153 (Para. 28) that "the Agreement should provide that the objective of safeguards is the timely detection of diversion of significant quantities of nuclear material from peaceful nuclear activities to the manufacture of nuclear weapons or of other nuclear explosive devices or for plutoniumrposes unknown, and deterrence of such diversion by the risk of early detection." [1] It should be noted that the timeliness goals for detection in CSA safeguards assume that clandestine facilities

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could exist. Then in the 1990's after seeing the shortcomings of CSA safeguards in Iraq, the IAEA created the Additional Protocol[2] as part of the Strengthened Safeguards System to provide the IAEA access to not only the correctness of a State's declaration of nuclear activities but the completeness of that declaration. The concept of completeness of the declaration implies that the IAEA concludes after investigation that there are no undeclared activities in a State with the Additional Protocol in force. The IAEA calls this the "broader conclusion."

Hence, in the ESFR study the PR&PP working group assumed the following extrinsic policy measures described above are in place. The State has a Comprehensive Safeguards Agreement (CSA) under model INFCIRC/153 (corr.) Safeguards and the Additional Protocol is in force with a broader conclusion in place with Integrated Safeguards (IS). This is an implicit assumption to be taken with any GEN IV systems. We must note that the nature of Integrated Safeguards is evolving and involves the State Level Approach (SLA) linking all nuclear activity in a state and the explicit and implicit aims of a State's nuclear program as evaluated by the IAEA. It is easier to apply criteria and methods of known CSA safeguards, which are more conservative than IS and facility-based to evaluate the robustness of the extrinsic proliferation resistance of the ESFR complex on a facility-by-facility basis.

II. ESFR

In the PR&P working group, extrinsic proliferation resistance, as a PR&PP high-level metric, can be defined as "measures, such as control and verification measures, will remain essential, whatever the level of effectiveness of intrinsic features." This was stated at Como II in IAEA STR-332, December 2002. These various measures can be categorized as policy measures or safeguards measures which will have ramifications on the needs for technology and labor to fulfill the safeguards technical objectives of Para. 28 of INFCIRC/153 for the types of facilities planned. The policy measures are a State's non-proliferation commitments, obligations and policies, its bilateral agreements between exporting and importing States, the bona fides of peaceful intent of its nuclear program, and the legal/institutional modes a State must answer to when the international community attempts to address a State's nonproliferation violations. The safeguards measures are the application of IAEA safeguards technical measures in a State and any regional bilateral and national measures a State has agreed to with other states or engages to fulfill national laws and to better address IAEA safeguards concerns and obligations, respectively.

To evaluate the safeguards at the ESFR complex and to define the needs for advanced safeguards at the ESFR, we define the ESFR site as consisting of multiple fuel cycle facilities. The ESFR has four Sodium Fast Reactors (SFRs) that the IAEA would categorize as "Other Types of Reactor." ESFR has a fuel cycle facility building that the IAEA would see as containing two specific types of fuel cycle facilities. The first facility is the reprocessing facility that the IAEA would categorize as "Reprocessing Plant." The second facility, which is collocated in the same building and associated with the reprocessing facility, is a fuel fabrication facility that the IAEA would categorize as "Fabrication Plants Handling Direct-Use Material." The IAEA defines "Direct-Use Material" as HEU or plutonium. Because the transuranic (TRU) fuel to be produced in the ESFR fuel fabrication facility contains plutonium, the fabrication facility will be under safeguards more stringent than at a LEU fuel fabrication facility because of the timeliness of plutonium defined by the IAEA as (1 month in unirradiated material and 3 months in irradiated material) versus the timeliness of LEU (1 year in all circumstances).[3] The ESFR will also be storing material on site that will have direct-use material in it. Specifically, the TRU fresh fuel and spent fuel will contain plutonium and the Light Water Reactor (LWR) spent fuel (SF) sent to the ESFR for feed stock for recycling into ESFR TRU fuel will have plutonium, too. The IAEA will categorize the ESFR storage IAEA would categorize as "Storage."

The IAEA would then safeguard the material in the ESFR under the following timeliness guidelines. There would be a Physical Inventory Verification (PIV) once per year looking at the spent LWR Fuel (stored at the LWR SF pool and received LWR SF shipping casks), fresh ESFR Fuel (stored at various locations on site), core ESFR Fuel (the four

SFRs), spent ESFR Fuel (stored at various locations on site), TRU fuel in process in the reprocessing and fuel fabrication facilities. The material above will need to be verified at interim intervals four times per year because the irradiated direct-use material, as defined previously, has three-month timeliness. Hence, the spent LWR fuel, fresh ESFR fuel, core ESFR fuel, and spent ESFR fuel all will be verified four times a year. The TRU in-process material is seen to be still irradiated direct-use material because of keeping the plutonium and uranium together with TRU products that should provide a radiation barrier that slows down the ability to reprocess the fuel and by the process if it intrinsically will take major modification to be able to separate plutonium from the uranium and TRU mix. This is an issue that the ESFR design must answer to state it has valuable proliferation resistance above and beyond the PUREX process in use in the UK, France and Japan under IAEA safeguards. If it does have an intrinsic proliferation resistance than the assumption that TRU material in the reprocessing facility is irradiated direct-use material holds. If it can be seen that the TRU material can be easily separated in the processes in the ESFR, then the more stringent monthly inspection regime and process monitoring that is at present at Rokkasho Reprocessing Plant (RRP) will be required as an extrinsic measure to balance less intrinsic proliferation resistance. Some of these technical safeguards measures will need to depend on advancements in safeguards methodologies and technologies.[4]

II. ESFR SAFEGUARDS ISSUES

Now we must specifically address the robustness of the extrinsic measures at the ESFR. If one has only INFCIRC/153 safeguards, the facility lacks the robust measures of AP. However, we have assumed the AP is in force but that IS cannot be assumed generically for a State or a facility under IS because of a lack of a universal application of IS. Hence, we have assumed that the safeguards measures are CSA safeguard measures for the facilities and materials defined above. As mentioned above, the material in the reprocessing facility may or may not be seen as irradiated direct-use material changing the safeguards extrinsic measures. If we assume the TRU Fresh Fuel is irradiated direct-use material, we can go with four times a year inspection. We may find that the TRU fresh fuel will be seen by the IAEA as unirradiated direct-use material because the radiation barrier in fresh fuel and fresh fuel pellets in the fuel fabrication facility is negligible. Hence, the fresh TRU fuel and the fuel fabrication facility will need to be subjected to a monthly, 12 times a year, inspection regime. The safeguards measures employed at the ESFR will rely on containment and surveillance (C/S) on the SFRs and the Fuel Cycle Facility and also on the storage facilities to observe and maintain Continuity of Knowledge (CofK) of the verified material and to verify in-situ material. Cameras, Radiation monitors (n,γ), ID tag readers will be a part of this C/S mix. Since there will be direct-use material on site with a maximum three-month timeliness and with material in "Difficult-to-Access" situations such as in buttoned up the core, under sodium in the reactor, and in storage casks, the C/S system to retain robustness must be a reliable system with redundancy and backup measures to avoid loss of CofK and possible alternative means to verify materials and freeze inventories to recover CofK.

The lessons learned from the above analysis are that various measures will affect the robustness of the extrinsic proliferation resistance of the ESFR complex. The application of safeguards policy will affect safeguards. Assuming that we have CSA with an AP in force with IS, the exact application of IS for a State and its fuel cycle facilities can be show us how proliferation resistant the safeguards approach can be if the policy has flaws that weaken the measures in the CSA by diluting them to save resources. A prime quality of safeguards is that it sets the boundary conditions on diversions and hence the extrinsic robustness of the system. We can also see that the GEN IV facilities and materials and how the IAEA defines them will determine the extrinsic resistance of the safeguards approach. If the TRU fuel is seen as irradiated direct-use material by the IAEA and safeguards are loosened from that practiced with unirradiated direct-use material, there may be a problem. The problem is that the material could in reality be unirradiated direct-use material and reducing the timeliness goals could open windows for diversions that will not be detected in a timely manner. The safeguards accountancy verification on fuels is a key issue where the ability of the safeguard measures to verify the spent fuel from LWR, fresh TRU, and spent TRU will determine how robust the safeguards are. At present, the IAEA lacks a means of verifying pin diversion in LWR spent fuel which, of course, would carry over to verifying spent TRU fuel. Furthermore, means to directly verify plutonium in TRU fuels need development to deal with the interference that the various TRU elements will create in unfolding the radiation signals from the TRU fuel to find plutonium. Hence, new combinations of uranium and plutonium in GEN IV reactor and NFC facilities such as the ESFR may challenge the robustness of the safeguards system. A further measure of the robustness of the safeguards is how well we handle "Difficult-to-Access" material. If a State can easily substitute and divert material since it being "Difficult-to-Access" it is difficult to verify and/or reverify and maintain CofK under C/S, the robustness of the measures falters. Another major lesson learned is that we need to quantify C/S measures to see the robustness of our safeguards approaches. We also need to make clear and quantify the "Nonproliferation Cost" of loss of CofK.

III. DEFINING NEEDED ESFR SAFEGUARDS ADVANCES

After defining the safeguards issues with the ESFR above, the advances in safeguards need to be categorized and discussed. The following paragraphs describe the technical challenges of safeguards approach for the ESFR.

The use of TRU fuel will create the largest need for advanced safeguards. Depending on the type of TRU fuel and the actinide content, the technical means of detection of plutonium in the fresh TRU fuel will be difficult since the presence of the actinides in TRU fuel will act to complicate the measurements possible in conventional MOX fuels containing only uranium and plutonium. Hence, new techniques such as those by Tobin, et al.,[5] will be crucial in allowing safeguarding of the TRU material.

The second crucial aspect of the ESFR safeguards is the measurement of spent fuel uranium and plutonium contents specifically the plutonium content. With the possibility of the maturation and deployment of pyroprocessing in an integrated system such as the ESFR, an inspectorate has the challenge of verifying the fissile material content of the spent fuel feed material to the reprocessing plant without the benefit of an accountancy tank such as seen in aqueous processes such as PUREX. If an inspector has only the operator's spent fuel declarations obtained by reactor performance burnup codes, he holds a declaration with at best a 3-10% uncertainty versus 0.3-1.0% uncertainty in an accountancy tank.[6] Hence, the need to develop better reactor burnup codes to allow for an operator to quantify his spent fuel declaration to higher accuracy and the development of spent fuel detectors with the ability to assay spent fuel fissile material content which both and operator and inspector would have use for in quantifying the spent fuel content declaration by the operator and verifying the spent fuel content by the inspector.[7] At present the IAEA has no ability to measure spent fuel content beyond a gross defect[8], where the IAEA defines defect tests in the following fashion:

1. *Gross defect* refers to an item or a batch that has been falsified to the maximum extent possible so that all or most of the declared material is missing.

2. *Partial defect* refers to an item or a batch that has been falsified to such an extent that some fraction of the declared amount of material is actually present.

3. *Bias defect* refers to an item or a batch that has been slightly falsified so that only a small fraction of the declared amount of material is missing.[9]

Hence, fuel pins from a spent fuel assembly could be diverted without any knowledge of an inspector and any means to detect it at the reactor or at a pyroprocessing facility.

The third crucial aspect of the ESFR is tracking the fuel in the difficult to access areas as noted above. Depending on the design, the TRU fuel will be under sodium from the time it is placed in the storage pool and removed to be cleaned for shipment with no visual access. Hence, a system of radiation detectors and under-sodium viewing devices will be needed to track the fuel.[10] This will stretch the technological envelope. If the fuel management system is such that the fuel is only under sodium in the reactor vessel as in the ABR1000 design then the ability to track and verify the material is not so difficult.

IV. CONCLUSIONS

We have examined the key advanced safeguards challenges for the ESFR. It can be seen that the spent fuel tracking and assaying of the spent fuel as well as the TRU fuel will be a key challenge. The ability to monitor direct use material will be tested in such GEN IV systems.

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