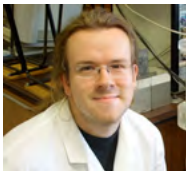

Open questions regarding proliferation resistance assessments of future nuclear fuel cycles

Stephen F. Ashley

The barriers that impede the acquisition of materials which could be used to manufacture a weapon of mass destruction or weapon of mass effect can generally be classified into two groups (e.g. as done by the Generation IV International Forum [1]). The first group are classed as intrinsic barriers, which are characteristics that impede the diversion or undeclared production of nuclear material or misuse of technology by the Host State to acquire nuclear weapons or other nuclear explosive devices. The second group are classed as extrinsic barriers, which are characteristics that impede the theft of materials suitable for nuclear explosives or radiation dispersal devices and the sabotage of facilities and transportation by sub-national entities and other non-Host State adversaries. Proliferation resistance assessments generally focus towards the intrinsic barriers, with physical protection assessment catering toward appraising the extrinsic barriers.

The intrinsic barriers can be subdivided into material barriers and technological barriers [2]. Material barriers cover the qualities of materials that reduce the inherent desirability or attractiveness of the material as an explosive. Technological barriers cover intrinsic technical elements of the fuel cycle, its facilities, processes, and equipment that serve to make it difficult to gain access to materials and/or to use or misuse facilities to obtain weapons-usable material.

Technical assessments can be used to appraise the proliferation resistance of technologies operating with different nuclear fuel cycles. For appraising material barriers, the existing Figure of Merit methodology by Bathke et al. [3] provides a single score derived from four parameters: the mass, decay heat, neutron emission rate, and radiotoxicity of the material. This methodology is particularly insightful in civil nuclear fuel cycles for appraising how the material evolves whilst it is being irradiated. For appraising technical barriers, different methodologies have been developed, which include multi-attribute utility analysis [4] and the use of fuzzy logic [5]. These methodologies factor for the infrastructure relating to civil nuclear fuel cycles, safeguards and timing and for weightings to be elicited from expert panels.

Although the factors contributing towards technically appraising the proliferation resistance of technologies and nuclear fuel cycles are well defined, there are a number of open questions which can impact the results of such assessments, especially in novel nuclear fuel cycles operating in technologies of the future.

One question surrounds the potential weaponisation of uranium-233. Traditionally, weapons-grade plutonium, containing more than 94% plutonium-239, and weapons-grade uranium, containing more than 93% uranium-235, have most frequently been used in nuclear weapons programmes. However, another fissile isotope that has been previously used in nuclear weapons tests is uranium-233 (namely "Shot MET" in Operation Teapot in the US [6] and JOE-19/RDS-37 in the Soviet Union [7], both tests taking place in 1955). Uranium is generally considered more straight-forward to weaponise than plutonium, due to the limited heat source and lack of spontaneously emitted neutrons that can cause pre-ignition. However, it is often noted that the formation of the isotope uranium-232, from high-energy neutron-induced reactions on thorium-232 and uranium-233, adds to the proliferation resistance of thorium-based nuclear fuel cycles. This is mainly due to the formation of the highly radiotoxic daughter product thallium-208 that can impede access to this material. Parts-per-million concentrations of uranium-232 within large nuclear fuel assemblies can provide near self-protecting dose rates. However, definitions of self-protecting dose rates vary considerably: 1 Sv/h from IAEA [8], 5 Sv/h from US DOE [3], and 100 Sv/h from an Oak Ridge report [9]. This in turn has significant implications on the quantities of uranium-232 that can make a material self-protecting. Therefore, a set of isotopic vectors that defines weaponisable uranium-233, with corresponding uranium-232 and uranium-234 fractions, needs to be defined and ratified [10].

Another question surrounds the technological barriers from the development of new civil technologies. Future nuclear energy technologies, such as those listed by the Generation IV International Forum [1], are typically geared towards operating in reprocessing based nuclear fuel cycles. Historically, reprocessing has involved the aqueous PUREX process to recover plutonium from spent nuclear fuel. Currently, the COEX process to co-extract uranium and plutonium is being developed by AREVA. Future reprocessing based schema include advanced aqueous reprocessing techniques (e.g. GANEX and DIAMEX) that would prospectively be operated at a national scale, or novel pyroprocessing techniques that can be employed

on an individual reactor scale. For pyroprocessing techniques, questions surround the ability for individual streams of special nuclear materials to be separated (e.g. protactinium-233, which decays into uranium-233) and the potential for military use of such technologies if wide-scale deployment is required.

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Disclaimer

The contents of the aforementioned piece are solely the views of S.F. Ashley.

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