Generic PRPP issues for Gas cooled Fast Reactor (GFR)

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1. Introduction

GFR operates with a closed fuel cycle, thereby combining the advantages of fast spectrum systems (long term resources sustainability, in terms of use of uranium and waste minimization, through fuel multiple reprocessing and recycling of Plutonium and minor actinides) with those of the high temperature (high thermal cycle efficiency and the possibility of hydrogen production and other industrial applications).

Its development approach is to rely as far as possible, on technologies already used for the High-Temperature Reactor (HTR), but with significant modifications (if not breakthroughs), needed to meet the objectives stated above. Thus, it calls for specific R&D beyond current and planned future work on thermal HTRs.

2. System Elements and Potential Adversary Targets

The reference system of GFR is ALLEGRO which has a core outlet temperature of 850°C for 2,400MWth, the core consists of an assembly of hexagonal fuel elements, each consisting of ceramic-clad, mixed-carbide-fuelled pins contained within a ceramic hex-tube [3].

The ALLEGRO is seen as a single unit with its fresh and spent fuel management and storage unit. The fuel reprocessing and fabrication unit is located outside and radioactive materials are transported by trucks like below layout [4].

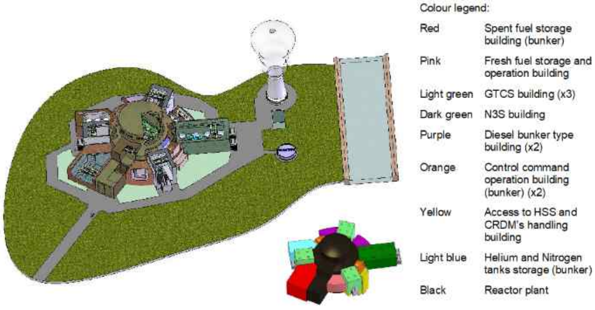

Fig. 1. General design of a GFR plant layout [2] (HSS = Helium Supply Service; GTCS = Gas Turbine Conversion System; N3S = Nuclear Steam Supply System; CRDM = Control Rod Drive Mechanism)

Fresh fuel assemblies are delivered by truck to the interim storage unit. They are stored in air. Spent fuel assemblies are discharged from the reactor building and keep cooling in the pool storage unit. This unit is designed as a protective bunker to prevent external hazards and theft of nuclear/radiological material.

Materials movements between the different system elements involve the transfer of intact fuel assemblies, in air or under water. Surveillance and accounting safeguards will be ensured diversion of declared material will be detected. At this stage, the low maturity level of the GFR design gives the opportunity to envisage many other safeguard systems and to specify their optimal locations inside the plant system elements.

With respect to the physical protection of the site, the GFR design appears to be fully compatible with the systems and procedures that are applied to existing reactors.

2.1 Proliferation Resistance Considerations Incorporated into Design

Inherent Proliferation Resistance mainly arises in connection with the fuel cycle. It is based on the idea of avoiding the separation of certain trans-uranic elements from uranium. Contributions to Inherent Proliferation Resistance can be claimed to come from the following elements [1]:

- fissile materials are diluted in the fuel matrix.
- there is no use of enriched U; reprocessed U or depleted U.
- low grade Pu coming from PWR irradiated fuel is used.
- fresh fuel elements or sub-assemblies will incorporate Minor Actinides increasing radiation levels conducted for other GIF systems.

Finally, fuel elements are not separated from their sub-assembly on reactor site, and the presence of the wire wrapped around each pin suppresses the risk of clandestine pin extraction. This means that the potential targets are entire fuel assemblies rather than individual pins, increasing the logistical difficulties involved in fuel handling and transport.

Concealed diversion or production of material is deterred primarily by the application of effective international safeguards. The GFR shares a similar fuel cycle with other fast reactors that use aqueous processing with group extraction of actinides, and thus would use similar safeguards methods. Because the GFR shares its reprocessing technology with other Gen IV reactor types,

Fuel fabrication processes have not been considered within the scope of the Gen IV GFR System Steering Committee, so information is not available. It is assumed that these fabrication processes will share safeguards approaches and PR&PP characteristics with other Gen IV ceramic fuel fabrication technologies. The major variants will depend upon whether the fuels involve recycling of plutonium in glove boxes, with separate fabrication of minor actinide targets, or full transuranic recycling with fabrication in hot cells [5].
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In terms of fuel transport, it is likely that safeguards protocols that will be at least as effective as for other reactors.

Undeclared production of valuable material would require one to irradiate a few pins containing pure uranium. However, a potential scenario for undeclared production would be to insert a few target pins while preparing the assemblies at the fuel fabrication facility and to divert them at the reprocessing facility. In this scenario, the proliferating action performed onsite would just be irradiation, and it reasonably could be possible and hard to detect. With a few fertile pins, the quantities of fissile material would be very small, so although the scenario would be difficult to detect, its impact would be limited. To be effective for ^{239}Pu breeding, it would be necessary to irradiate tonne quantities of ^{238}U and this implies a large number of pins, possibly an unfeasible amount. This helps ensure that undeclared production of a Significant Quantity of fissile material is unlikely to be practical.

It is expected that GFRs will operate in fuel cycle states that will also provide other fuel cycle services including enrichment. In the longer term, in the objective of a closed fuel cycle, GFRs may eliminate the need to perform enrichment. GFRs operate with plutonium isotopes ranging from reactor-grade to deep-burn grade. In a case where GFRs will use breeding blankets, as envisaged for other fast neutron systems, one possibility is to use fertile blankets loaded with Minor Actinides (MA) [6]. In such a case, MA and U are mixed in the fresh blanket and produce Pu and transmute MA under irradiation. The global isotopes of the blanket fuel never give access to pure Pu. Because breakout would focus on misuse of fuel cycle facilities, GFR breakout pathways are likely to be similar to pathways for other fast reactors using aqueous recycling technologies.

2.2 Physical Protection Considerations In the Design

As stated in the previous section, the high radiation level of either fresh or spent fuel elements or sub-assemblies prevent them from being easily stolen on reactor site, and standard safeguards should provide effective protection of the remote fuel handling systems from misuse.

The GFR has a similar fuel cycle with other fast reactor technologies that use centralized, aqueous reprocessing. The fresh fuel used in the GFR provides the most attractive target for theft, since it has the lowest level of contamination with fission products. In the case where the fuel is produced using group extraction of actinides, the radiation levels in fresh fuel requires significant biological shielding, which can also be designed to provide a passive barrier to theft. The GFR uses an advanced ceramic fuel design which requires a reprocessing technology not very different from the one used for conventional oxide fast reactor fuel (access to the fissile matter is made first through cutting the ceramic cladding and then nitric acid dissolves the fuel part).

The GFR has both a containment building and a guard vessel that provide physical isolation and protection to the primary system. In case of a breach of the primary containment caused by a direct attack, the inert behavior of Helium minimizes the consequences of an environmental hazard.

Even if they are bunkerised, the water storage pools where the spent fuel assemblies are cooling can also be the target of a direct attack. The ability of the SiCf/SiC cladding to withstand temperatures up to 2000°C provides time for hazard mitigation.

The normal shutdown cooling system relies on the power conversion system, for hot shutdown states and for short-term cooling following transition to cold shutdown states. It is located outside the containment building. For longer term hot shutdown and for cold shutdown states, the first level of emergency decay heat removal loops are used, as far as a sufficient pressure level is maintained in the primary circuit. If this system fails, the second level of emergency cooling system carries on the safety function. The second level can operate at low pressure. Those emergency systems are located inside the containment building but their ultimate heat sink is outside the reactor building. The first level system is operated through diverse AC power sources as it needs a limited electric power supply. This is not the case for the second level system that needs higher power supply. Each system is redundant with two or three loops.

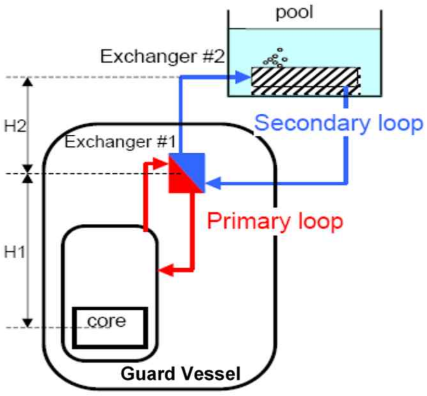

Fig. 2. Schematic of the emergency cooling systems, from the core to the ultimate heat sink.

3. Conclusions

GFRs share similar safeguards and non-proliferation characteristics with other fast neutron reactor systems. For proliferation resistance, the GFR's fuel cycle is the same as the one for SFR with aqueous recycling, using depleted U and high Pu content MOX fuel. Only slight distinguishing features can be cited due to the cladding and the fissile materials (respectively ceramic matrix composite and mixed carbide) or due to a specific design of honeycomb plate fuel element. At first, those differences do not affect the level of resistance to proliferation as we can evaluate it today. It is difficult to discuss proliferation resistance issues in a context of an agreement where only the reactor and its fuel are studied.

For physical protection, the present design of GFRs relies on many of the same protective measures used in PWRs, mainly with a reactor containment building, given the fact that inert gas is used as a primary coolant. A guard vessel that envelopes the primary system should give an additional level of protection. Specific attention should be paid to the protection of the emergency cooling systems on which the global safety of GFRs relies.

Beyond these factors, there are the uncertainties associated with a system that is not precisely defined today. Much of the development of proliferation resistance and physical protection characteristics for reactors is a result of careful examination of systems and interactions by designers, the nonproliferation community, the weapons community, and the physical protection community. Only such interactions over a period of time can provide high confidence about the actual characteristics of an advanced reactor.

REFERENCES

[1] C. Mitchell et al., GCFR: The European Union's Gas-Cooled Fast Reactor Project, pp. 540, Proceedings of ICAPP'06, Reno, NV, June 4-8, 2006.

[2] L. Bělovský, J. Gadó, B. Hatala, A. Vasile, G. Wrochna, The ALLEGRO Experimental Gas Cooled Fast Reactor Project", IAEA-CN-245-96, 2017.

[3] JC. Garnier et al., Status of GFR pre-conceptual design study, Proceedings of ICAPP'07, Nice, France, May 13-18, 2007.

[4] The Proliferation Resistance and Physical Protection Working Group and the System Steering Committees of the Generation IV International Forum, Proliferation Resistance and Physical Protection of the Six Generation IV Nuclear Energy Systems, GIF, 2011.

[5] B. Hatala, B. Kvizda, A. Vasile, J. Gado, L. Belovsky, J. Malesa, Progress in GFR Technology, Proc. of the Int. Conf. ICAPP'19, Juan les pins, France, May 12-15, 2019.

[6] P. Vácha, G. Mayer, A. Vasile, B. Kvizda, J. Malesa, P. Ponya, P. Dařílek, M. Gren, B. Hatala, V. Matocha, Progress in the ALLEGRO Project - Neutronics and Thermal-Hydraulics, Proc. of the Int. Conf. ICAPP'19, Juan les pins, France, May 12-15, 2019.