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Conceptual design of the space disposal system for the highly radioactive component of the nuclear waste

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ABSTRACT

A system for space disposal of the most radioactive component of the spent fuel produced by the nuclear reactors is designed conceptually with an intent of ensuring safety. Unlike the earlier design by NASA, this system is to use a commercially available launch vehicle and be launched from the western Pacific Ocean. It will fly low until it acquires Earth-escape velocity, so that the nuclear package will not fall on land in case of system malfunctioning. The package will be parked in one of the lunar libration points L4 or L5, and kept vigilant by a watch-dog orbital transfer vehicle which will push the package away in case an asteroid approaches. The calculation shows that such a safe system will be feasible and relatively cheap. The details of how the nuclear package is made, how the launch vehicle is made and flown, and how the nuclear package is managed in the final parking orbit are described.

1. Introduction

Nuclear power plants produce spent fuel that needs to be disposed of for thousands of years, because they emit radiation dangerous to humans. It takes over 300,000 years for a spent fuel to decay radioactively to the level of the natural uranium. The chemical breakdown of a spent fuel out of a light water reactor is shown in Fig. 1[1]. The half-lives of the radioactive ingredients are listed in Table 1[2]. A spent fuel assembly consists of 95.3% actinides and 4.7% fission products in this case. In essence, approximately 4.6% fission products (0.5% hot nuclides and 4.1% short half-life nuclides) of the mass of the spent fuel assembly becomes a highly radioactive waste and must be disposed of semi-permanently. One batch of such waste weighs typically 23 kg. One nuclear power plant produces on the average about 18.4 tons of such spent fuels a year. The high level radioactive waste to be disposed of is, therefore, about 0.85 tons per power plant per year. As an example, Republic of Korea, with its 19 nuclear power plants using the light water reactors, will produce nearly 16.1 tons of such waste per year. As of 2014, there were 14,984 such spent fuel assemblies accumulated in the past operations that are waiting to be disposed or placed in interim storage [1]. This means that there are 345 tons of these highly radioactive waste materials that need to be disposed of.

Traditionally, the preferred method of disposal of spent fuel assemblies was thought to be to store underground. However, such storage is constantly under the threat of water seepage and tectonic movements [3]. Besides, for small and crowded countries such as Korea, it is difficult to find such a site for ground or underground disposal. Here in this work, it is proposed that the radioactive material, i.e. 4.6% fission products extracted from spent fuel assemblies, be launched into space, and taken to and kept in a stable dump site.

A similar proposal was made earlier by NASA [4–6]. The waste materials to be disposed were to be I (iodine) and Tc (technetium) extracted from the spent fuel. The system was to consist of the waste payload, a cargo launch vehicle, the Space Shuttle, and an orbital transfer vehicle. First, the cargo launch vehicle is to place the orbital transfer vehicle into the 270 km altitude low Earth orbit (LEO); then Space Shuttle is to transport the waste payload into LEO; a rendezvous is to be performed in LEO between the Space Shuttle and the orbital transfer vehicle to transfer the waste payload; and the orbital transfer vehicle is to transport the waste payload from LEO to the permanent parking station in a heliocentric orbit at 0.85 AU.

NASA's proposal was not adopted by the nuclear community at the time. First, the cost of space launch was very high: the cost of lifting 1 kg of payload to space was about $20,000 at that time. (For

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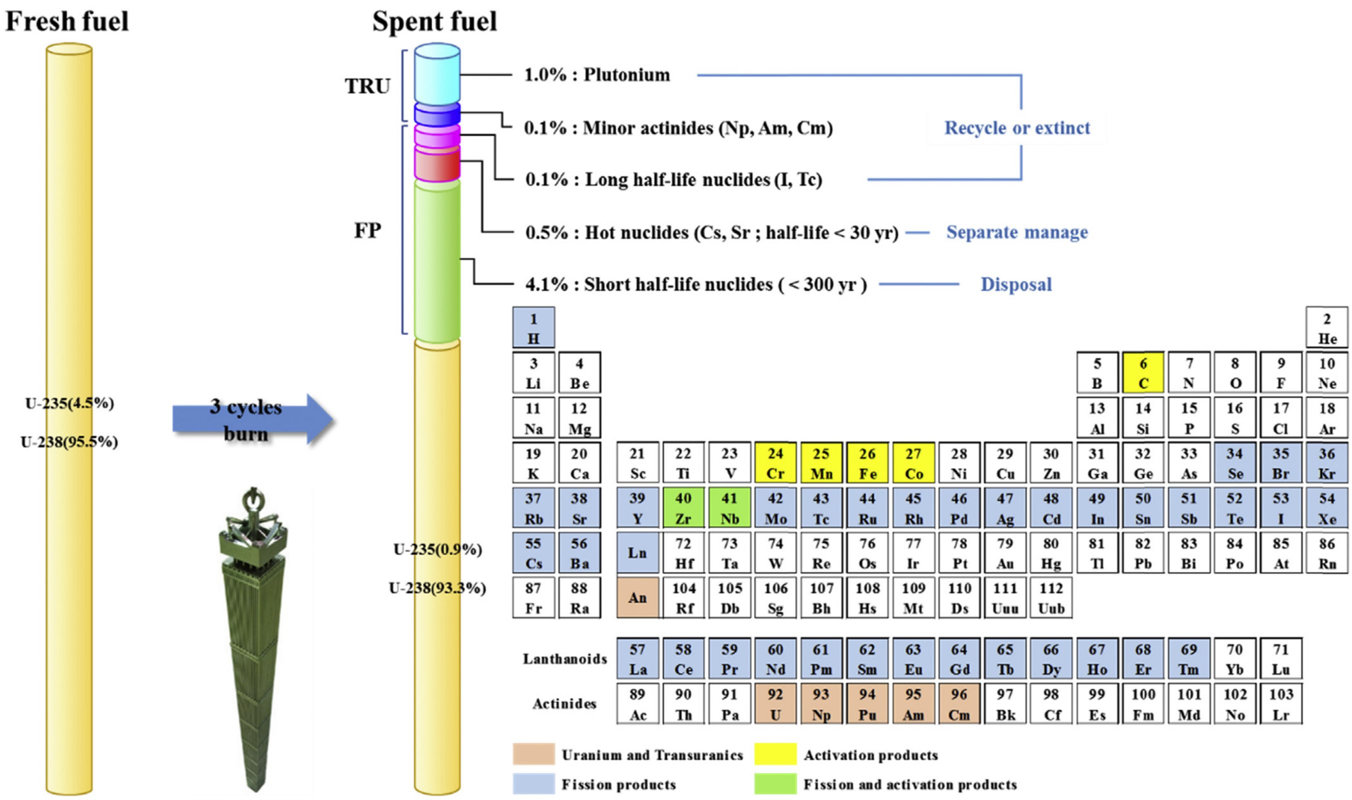

Fig. 1. Breakdown of radioactive materials in spent fuel produced by light water reactor.

Table 1
Half-lives of high level radioactive fission products [2].

Nuclide	Half-life
I131	8 d
Kr85	10.8 y
Sr90	28.8 y
Cs137	30.1 y
Tc99	211,100 y
I129	15,700,000 y

the Space Shuttle, one flight carrying 25 ton payload to LEO cost 500 million USD, resulting in $20,000 per kg.) Second, the cost of extracting the wanted material from the spent fuel was also high. Thirdly, the urgency of disposing was not great because above-ground storages had enough unused capacity.

Apart from those reasons, there was a possibility of exposure to radioactivity. There was a chance that the rocket engines on the launch vehicles may fail during the powered ascent, in which case the radioactive package may fall on land. And, even after the waste package was placed in the 0.85 AU orbit, an asteroid may collide with the package, in which case radioactive material may come back to Earth.

The reasons for rejecting NASA's proposal are not exactly valid today: the cost of reprocessing of the spent fuel is lowered, and the cost of launching into space became cheaper: launching 1 kg into space costs about $2000. And the difficulty of underground storage is becoming acute. For these reasons, it is felt appropriate to rethink space disposal of nuclear waste at this time. Besides, Space Shuttle is no longer available. In rethinking the problem, commercially available launch vehicle will be considered.

In resurrecting the earlier concept of space disposal of nuclear waste, one must now address the issue of safety more seriously. Not only the populace became much more aware of the environmental safety issue, there was an unfortunate event in which a Russian-made satellite carrying a nuclear package, Kosmos 954, fell on Canada and spread the radioactive material [7]. Therefore, the present design is focused on devising a radioactively fail-safe system. The system proposed in this work consists of the waste package, a launch vehicle, and an orbit transfer vehicle to function as a watch-dog. There will be no rendezvous in LEO. The system will be designed to eliminate the possibilities of exposure to radiation. Toward this end, the present work proceeds as:

- disposal materials selection and calculation of waste mass,
- calculation of the thickness of the radiation shield appropriate to the calculated waste mass,
- design of the waste package,
- determination of the dump site,
- determination of the launch system and rocket parameters,
- design of the flight trajectory that guarantees not to fall to the ground in the case of system malfunction, and
- design of a system to prevent a collision with an asteroid.

The system is designed following established procedures [8–10] to meet these goals. Calculation is made to show that, through these steps, the designed system can prevent an exposure to radiation in the case of system malfunctioning.

2. Conceptual design of the space disposal systems for spent fuel

2.1. Waste mass and package thickness

Calculation had to be made first for the mass of the nuclear