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# ROBUST STORAGE OF SPENT NUCLEAR FUEL: A Neglected Issue of Homeland Security

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## EXECUTIVE SUMMARY

The 103 nuclear power plants operating in the USA contain massive amounts of radioactive material in their reactor cores. In addition, the reactors have discharged more than 43,000 tonnes of irradiated fuel, containing an amount of long-lived radioactive material that substantially exceeds the amount in the reactor cores. This irradiated fuel is commonly described as "spent fuel", because it is no longer suitable for generating fission power. Cumulative national production of spent fuel is likely to exceed 80,000 tonnes over the currently-licensed lifetimes of existing nuclear power plants.

Most of the nation's spent fuel is now stored in high-density spent-fuel pools adjacent to the reactors, and the plant owners intend to continue using these pools at high density. As the pools become full, plant owners are building independent spent fuel storage installations (ISFSIs) to accommodate the growing inventory of spent fuel. Present and proposed ISFSIs are generally at reactor sites, but away-from-reactor ISFSIs may be established at Skull Valley, Utah, and elsewhere. In the USA, ISFSIs store spent fuel under dry conditions inside storage modules that are arrayed on concrete pads in the open air.

This situation poses a very high risk to people and the environment, because the loss of water from a high-density pool will cause spent fuel in the pool to heat up, self-ignite, burn and release a huge amount of long-lived radioactive material -- including tens of millions of Curies of the isotope cesium-137 -- to the atmosphere. Water could be lost from a pool by evaporation, displacement, siphoning, pumping, a breach in the pool floor or wall, or overturning of the pool. These mechanisms could be exploited in various ways by knowledgeable and determined attackers, who could thereby create a pool fire that contaminates large areas of US territory with radioactive material. Nuclear reactors are also vulnerable to attack. A successful attack

on an operating reactor would release large amounts of short- and long-lived radioactive material to the atmosphere. Knowledgeable and determined attackers could achieve this result in a variety of ways. Table 1 shows some potential modes of attack.

The safe operation of a reactor or a spent-fuel pool depends upon the continuing availability of cooling water, electrical power and operator attention. By contrast, ISFSI modules are passively safe, because they are cooled by natural circulation of air. Nevertheless, these modules are not designed to resist a determined attack. Moreover, ISFSI modules are comparatively easy to attack, because they are stored in the open air in a closely-spaced array.

Thus, nuclear power plants and their spent fuel can be regarded as pre-deployed radiological weapons that await activation by an enemy. The US government acts as if it were unaware of this threat. Responsibility for overseeing the security of civilian nuclear facilities has been delegated to the US Nuclear Regulatory Commission (NRC). This agency has a longstanding policy of not requiring its licensees to protect their facilities against enemy attack, and has continued this policy with little change since the terrorist attacks of September 2001. As a result, US nuclear facilities are lightly defended and are not robust against attack. This situation is symptomatic of an unbalanced US strategy for national security, in which offensive capabilities are assigned a higher priority than homeland defense. The lack of balance is a potentially destabilizing factor in the current international environment, because it could promote an escalating spiral of violence. Moreover, a weak defense of the homeland exposes US citizens to a variety of threats. In the case of nuclear facilities, the lack of defense exposes US citizens to the risk that an enemy will create widespread radioactive contamination.

This report offers a way forward in an important area of national defense. Specifically, the report articulates a strategy for providing robust storage of US spent fuel, where the word "robust" means that a facility for storing spent fuel is designed so as to be resistant to attack. Implementation of robust storage will be needed whether or not a repository is opened at Yucca Mountain, Nevada. The proposed robust-storage strategy should be implemented as a major element of a four-component strategy for the security of each US civilian nuclear facility. The four components are: site security; facility robustness; damage control; and offsite emergency response. Together, these components could provide a defense in depth for each nuclear facility, within the context of a national-security strategy that provides solid protection of our homeland. Figure 1 shows how robust storage of spent fuel would contribute to the national security of the USA.

A strategy for nuclear-facility security will have as its objective the reduction of the risk of a release of radioactive material. In the case of a reactor, the risk can be almost completely eliminated by shutting down the reactor and removing its fuel. In the case of spent fuel, the risk can be reduced but can never be eliminated. A strategy for robust storage of spent fuel must be judged by the extent to which it reduces risk. The strategy should assign the highest priority to reducing the highest risk.

The highest priority of a robust-storage strategy would be to re-equip spent-fuel pools with low-density, open-frame racks, as was the case when the present generation of nuclear plants began operating. This step would prevent fuel from igniting and burning if water were lost from a pool. Fuel that can no longer be accommodated in the pools would be stored in ISFSIs. Each pool would continue to operate at low density while its associated reactor remained operational, to provide storage space for fuel discharged from the reactor. After storage in the pool for several years, to allow its level of radioactive-decay heat to decline, fuel would be transferred to an ISFSI.

As a further measure of risk reduction, ISFSIs should be designed to incorporate hardening and dispersal. "Hardening" means that each fuel-storage module would be shielded from attack by layers of concrete, steel, gravel or other materials. "Dispersal" means that fuel-storage modules would not be concentrated at one location, but would be spread more uniformly across a site.

Hardening and dispersal of ISFSIs should not be conducted in a manner that encourages society to extend the life of an ISFSI until it becomes, by default, a repository. Therefore, a hardened ISFSI should not, unless absolutely necessary, be built underground. Also, the cost of implementing hardening and dispersal should be minimized, consistent with meeting performance objectives, and the timeframe for implementation should be similarly minimized. These considerations argue for the use, if possible, of dry-storage modules that are already approved by the NRC and are in common use.

The design of a hardened, dispersed ISFSI would be governed by a design-basis threat (DBT). This report articulates a two-tiered DBT. The first tier requires high confidence that no more than a small release of radioactive material would occur in the event of a direct attack on the ISFSI by a TOW (anti-tank) missile, a manually-placed charge, a vehicle bomb, an explosive-laden general-aviation aircraft or a fuel-laden commercial aircraft. The second tier requires reasonable confidence that no more than a specified release of radioactive material would occur in the event of a ground burst of a 10-kilotonne nuclear weapon at the ISFSI.

An ISFSI design approach that offers a prospect of meeting this DBT involves an array of vertical-axis dry-storage modules at a center-to-center spacing of perhaps 25 meters. Each module would be on a concrete pad slightly above ground level, and would be surrounded by a concentric tube surmounted by a cap, both being made of steel and concrete. This tube would be backed up by a conical mound made of earth, gravel and rocks. Channels for air cooling would be inclined, to prevent pooling of jet fuel, and would be configured to preclude line-of-sight access to the dry-storage module. Figure 2 provides a schematic view of the proposed design.

An alternative design approach might be used at a few reactor sites where space is insufficient to allow wide dispersal. In this approach, a number of dry-storage modules would be co-located in an underground, reinforced-concrete bunker. Similar bunkers would be dispersed across the site to the extent allowed by the site's geography. At especially-constricted sites, it could be necessary to ship some spent fuel from the site to an ISFSI at another location.

Any ISFSI, whether at a reactor site or an away-from-reactor site, should employ hardened, dispersed, dry storage. The design of an away-from-reactor ISFSI could, because the facility is entirely new, provide a degree of dispersal and a level of site security that may be difficult to achieve at some reactor sites. However, there are factors that argue against developing an away-from-reactor ISFSI: (i) overall transport risk would be increased, because fuel would be shipped twice before arriving at a repository; (ii) the massive amount of radioactive material concentrated at this ISFSI could provide an attractive target for an enemy; (iii) this ISFSI would not eliminate the need for at-reactor ISFSIs; (iv) this ISFSI could become, by default, an unsafe repository; and (v) storage in this ISFSI could be more expensive than storage at reactor sites.

Three major requirements must be met if a robust-storage strategy for spent fuel is to be implemented nationwide. First, full-scale experiments are needed to determine the ability of various dry-storage design approaches to accommodate various DBTs. Second, performance-based specifications for robust storage, addressing both short- and long-term risks, must be developed with stakeholder input. Third, robust storage of spent fuel must be seen as an important component of national security, to ensure that sufficient funding is available and robust storage is implemented quickly.

| MODE OF ATTACK | CHARACTERISTICS | PRESENT DEFENSE |
|---|---|---|
| Commando-style attack | • Could involve heavy weapons and sophisticated tactics<br>• Successful attack would require substantial planning and resources | Alarms, fences and lightly-armed guards, with offsite backup |
| Land-vehicle bomb | • Readily obtainable<br>• Highly destructive if detonated at target | Vehicle barriers at entry points to Protected Area |
| Anti-tank missile | • Readily obtainable<br>• Highly destructive at point of impact | None if missile launched from offsite |
| Commercial aircraft | • More difficult to obtain than pre-9/11<br>• Can destroy larger, softer targets | None |
| Explosive-laden smaller aircraft | • Readily obtainable<br>• Can destroy smaller, harder targets | None |
| 10-kilotonne nuclear weapon | • Difficult to obtain<br>• Assured destruction if detonated at target | None |

**TABLE 1**

**SOME POTENTIAL MODES OF ATTACK ON CIVILIAN NUCLEAR FACILITIES**

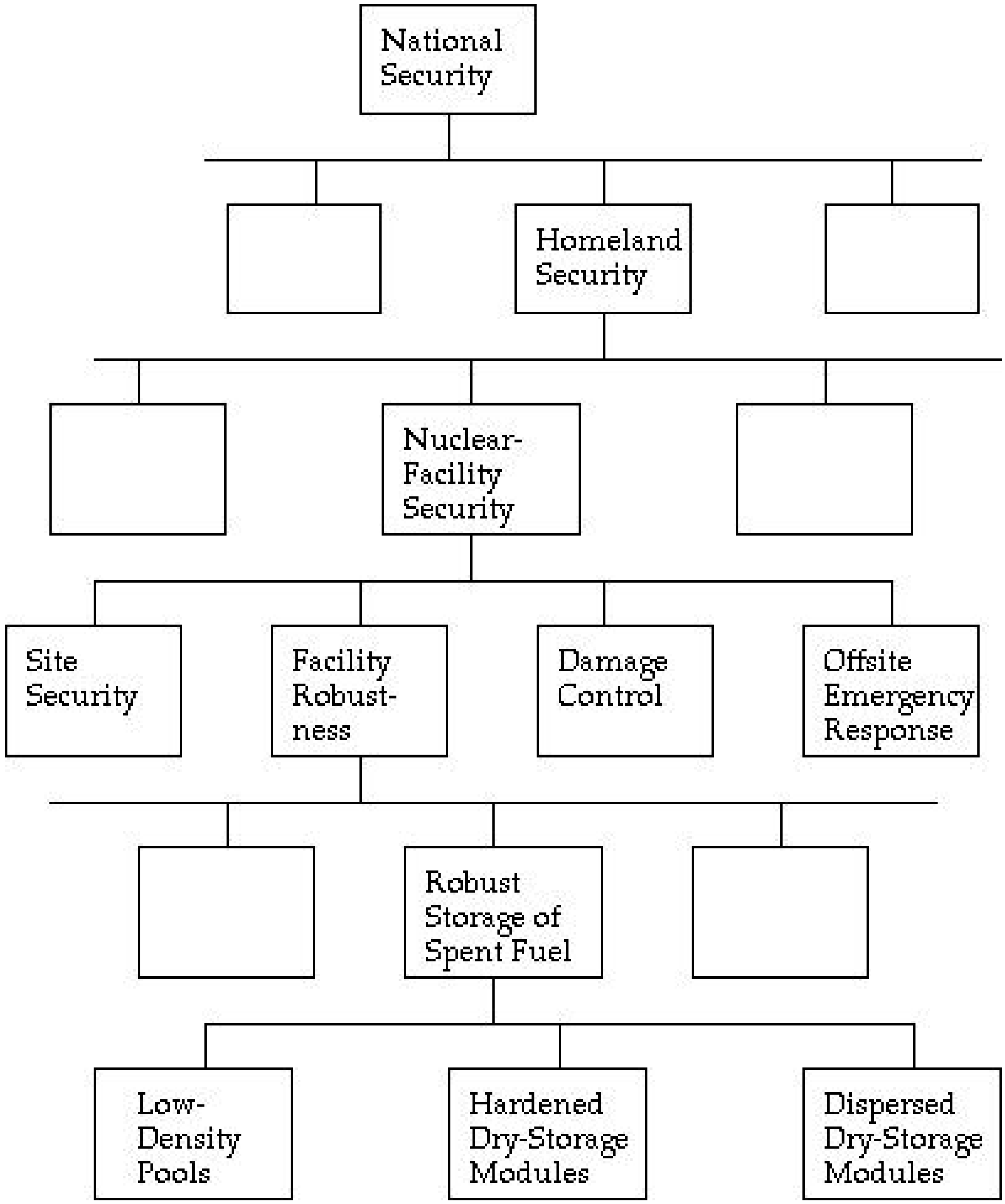


**FIGURE 1**

**ROBUST STORAGE OF SPENT FUEL**
**IN THE CONTEXT OF NATIONAL SECURITY**

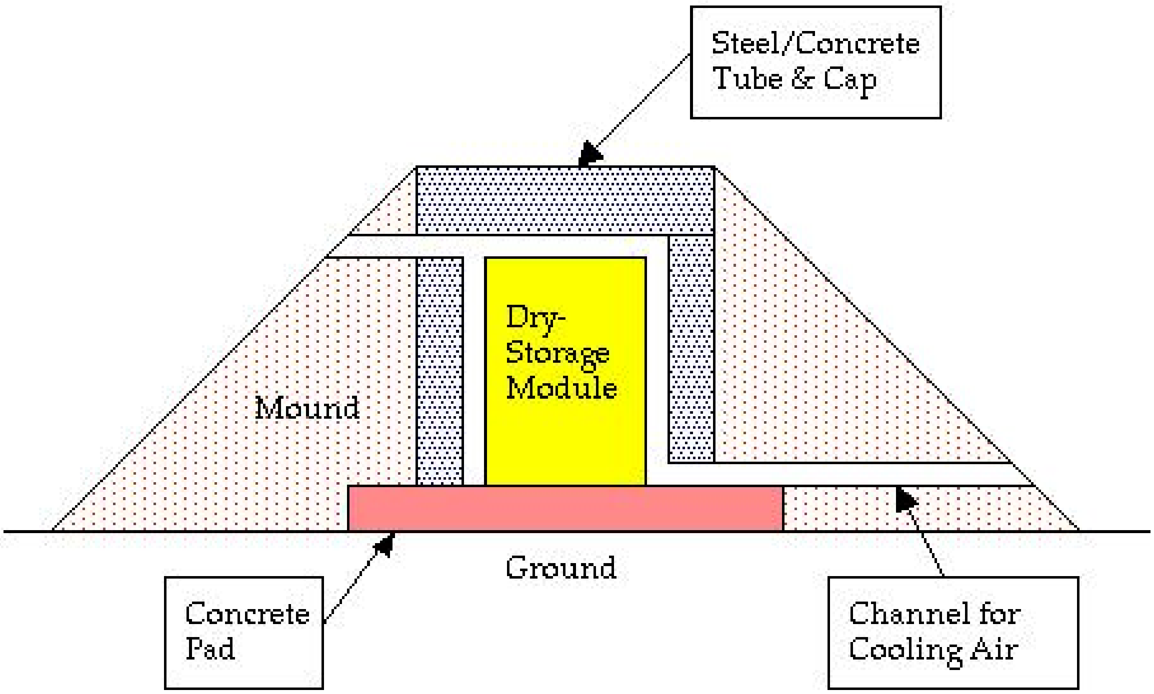


**FIGURE 2**

**SCHEMATIC VIEW OF PROPOSED DESIGN**
**FOR HARDENED, DRY STORAGE**

**Notes**

1. Cooling channels would be inclined, to prevent pooling of jet fuel, and would be configured to preclude line-of-sight access to the dry-storage module.
2. The tube, cap and pad surrounding the dry-storage module would be tied together with steel rods, and spacer blocks would prevent the module from moving inside the tube.
3. The steel/concrete tube could be buttressed by several triangular panels connecting the tube and the base pad.