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SCIENCE DIRECT
Progress in Nuclear Energy 48 (2006) 487–494
PROGRESS IN NUCLEAR ENERGY
An International Review Journal
www.elsevier.com/locate/pnucene

Design study of a modular dry storage facility for typical PWR spent fuel

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Abstract

A design study has been carried out for a modular, passively cooled dry storage facility for the spent fuel of a typical PWR. Each facility module has design capacity of a full reload-fuel batch for a 1000 MWth plant. It is shielded by a re-enforced concrete structure. The 102.48 W generated decay heat per module, is removed by natural convection of air flowing at 0.43 m/s and having exit temperature 229 °C which is favorably lower than the international norm of 380 °C. In the worst case scenario of completely flooded module, WIMS-D/4 and CITATION based two-dimensional diffusion theory analysis yields $k_{eff} = 0.8$ which is 11.11% lower than standard safe upper-limit. The proposed modular dry storage facility, with a passively cooled safe design and easy extensibility, offers economically viable solution to the problem of plants running out of on-site as well as interim wet storage capacity.

Keywords: Spent fuel; Dry storage; PWR; Decay heat; Radioactivity

1. Introduction

Currently, there are 441 nuclear reactors operating in 31 countries worldwide. A total of 2780 TW-h energy is generated by these plants amounting to around 16% of the global electricity supply. The net installed capacity of these plants is 359 GW(e) and another 27 GW(e) will be added by the plants under construction mostly in parts of Asia and Eastern Europe (IAEA, 2003). The current spent fuel generation rate is around 10,500 t HM/y which is expected to rise to 11,500 t HM/y by 2010. The cumulative spent fuel generated by the start of 2003 was estimated at around 225,000 t HM which is projected to rise to 340,000 t HM by 2010. Most of the presently operated plants will near their normal licensed operation lifetime by 2020 and by that time the spent fuel accumulated will rise to 445,000 t HM. The global world storage capacity, estimated in 2003, is around 244,000 t HM which is currently exceeded by 73,000 t HM. A total of 24,000 t HM spent fuel storage facilities are currently under construction. It is estimated that all available and currently under construction facilities will be completely filled by 2017 (Fukuda et al., 2003). However, these projections do not take into account the current shifting of the trend of simply storing, without

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0149-1970/$ - see front matter
doi:10.1016/j.pnucene.2005.11.002

reprocessing, spent fuel which will lead to the running out of storage space state much before the anticipated date of 2017. A rise in the operation cost of wet storage facilities along with recent trend of non-renewal of out-of-country storage contracts has aggravated the problem. As a result, a sizable fraction of operational nuclear power plants today face the problem of early shutdown in the absence of suitable spent fuel storage facility.

The pools that were designed initially for short term storage have become quasi-permanent storages because of the recent prohibition on the reprocessing of spent fuel. Wet storage needs special care to maintain good water chemistry pH-values, chloride and sulphate impurity concentrations and conductivity. Furthermore it has been found that specified pool water temperature control is essential for long term spent fuel integrity and to avoid structural damage to the facility. Several sites have documented degradation/corrosion of the spent fuel assemblies in wet storage resulting mainly from poor water chemistry control. This degradation of the spent nuclear fuel, in turn, produces several problems that ultimately result in an increased cost for continued storage and management. Also, wet storing of spent nuclear fuel was never intended to be permanent.

Clearly, new facilities are needed for the necessary interim storage of spent fuel until some suitable measures are taken for long term and permanent storage. Although the type of interim storage is mostly dictated by the type and burnup of the fuel along with the economic and radiation protection factors, there seems to be a growing consensus for dry storage facilities. This is indicated by the available data (IAEA, 2003) on facilities currently under construction, mostly in Europe, with 6000 t HM wet storage capacity and 9900 t HM dry capacity. In the USA, all such facilities currently under construction are of the dry storage type with 6800 t HM capacity. Currently, most of the effort on interim storage facilities is directed towards the dry storage concept. This is due largely to the lower capital and operational costs along with higher safety factors.

In this work, a design study has been carried out for a modular dry storage facility to meet interim storage requirements for a typical 1000 MWth plant. The dry storage offers many advantages over the wet storage technology and includes the following:

- The dry storage uses the natural air circulation for cooling. No mechanical or electrical equipment is required for cooling and therefore the loss of cooling is unlikely. The safety level is very high.
- Dry storage facilities are usually passive systems and require little care during their entire lifetime. Only routine surveillance is adequate to ensure safe storage.
- The passively cooled systems do not use any electromechanical equipment for circulation of coolant gas, therefore loss of coolant is highly unlikely. Moreover, there is no requirement of electrical supply for cooling purposes and there are no associated operational cost components.
- The spent fuel can be retrieved as and when needed.
- Since the fuel is sealed in self-contained units, it is self-protecting against war sabotage, or natural catastrophes. The containers provide a good barrier against the release of radioactive materials to the environment.

There is no production of low-level waste in contrast with the one from ion-exchangers and filters, as in the case of wet storage facilities. In the last several years, an increasing number of utilities have begun to consider the use of onsite dry storage facilities to supplement space available in their spent fuel pools for storing spent fuel. Dry storage reduces the corrosion concerns associated with extended storage of fuel under water while providing all the safety characteristics of wet storage. Also, it is less expensive to operate (IAEA, 1984). There are no large, up-front capital expenditure requirements in contrast with the wet storage facilities, where constructing a new storage pool is a capital intensive activity. Moreover, for the dry storage facility, the operation and maintenance costs are low and the final fuel disposal and station decommissioning activities are simplified. A detailed technical and economical comparison between dry and wet storage options has been carried out for Pt. Lepreau station in Canada. The results indicate that the cumulative costs of the dry storage option is typically 30–40% lower than the wet storage option. The assessment included engineering, construction, operating and decommissioning expenses (Pattantyus, 1990).

2. Calculational methodology

For the calculations the basic idea was that the system should be compact, should be sub-critical, should possess all the safety characteristics of wet storage, should be less expensive to operate, and it should be passively cooled. The