2.3 Potential for Criticality

2.3.1 Evaluation of the Potential for Criticality

There are several scenarios in which the potential for criticality from spent fuel pool accidents exists:

1. A compression or buckling of the stored assemblies could result in a more optimum geometry (closer spacing) and thus create the potential for criticality. This situation could exist for BWR pools which contain no soluble boron. For PWR pools with soluble boron, this would not be a concern because of the additional reactivity holddown of the boron. For this scenario to occur, it must be assumed that the storage racks are somehow deformed due to a beyond design basis seismic event. Deformation due to cask drops or assembly drops are analyzed as part of the normal licensing basis review. Although it is probable that there would be no criticality concerns due to deformation since closer spacing of fuel assemblies in one dimension would result in increased spacing in the other dimension, for defense-in-depth, the working group recommends boration (approximately 2000 ppm) for all pools.

2. If the stored assemblies are separated by neutron absorber plates (e.g., Boral or Boraflex), loss of these plates could result in a potential for criticality for BWR pools. For PWR pools, the soluble boron would be sufficient to maintain subcriticality. The absorber plates are generally enclosed by cover plates (stainless steel or aluminum alloy). The tolerances within a cover plate will tend to prevent any appreciable fragmentation and movement of the enclosed absorber material. The total loss of the welded cover plate is not considered feasible. However, for defense-in-depth, the working group recommends boration (approximately 2000 ppm) for all pools

   non-mechanistic

   Boraflex has been found to degrade in spent fuel pools due to gamma radiation and exposure to the wet pool environment. Because of this, the NRC issued Generic Letter 96-04 to all holders of operating licenses, concerning Boraflex degradation in spent fuel storage racks. Each addressee that uses Boraflex was requested to assess the capability of the Boraflex to maintain a 5% subcriticality margin and to submit to the NRC proposed actions to monitor or confirm that this 5% margin can be maintained for the lifetime of the storage racks. Many licensees have subsequently replaced the Boraflex racks in their pools or have reanalyzed the criticality aspects of their pools assuming no reactivity credit for Boraflex. Licensees that rely on Boraflex for reactivity holddown will continue to monitor for possible Boraflex degradation.

3. If sufficient fuel rod cladding damage occurred such that many of the fuel pellets became loose in the pool, the pellets might be rearranged into a configuration that could lead to a potential for criticality. If the storage rack remained intact, that would tend to keep the pellets in separate regions and there would probably be no potential for criticality. However, if there is large-scale cladding damage as well as damage to structural parts of the pool, this could allow a large fraction of the pellets to reassemble into a minimum leakage configuration in one region causing a potential for criticality.

   pebble bed rx

   If a loss of cladding integrity occurred, for example, because the cladding is brittle and could easily fail upon the impact from a foreign object (another assembly or fuel handling tool), it is highly unlikely that the damage would be very extensive. Thus, the number of fuel pellets available to form some unfavorable configuration with a potential for criticality is considered quite remote, especially since spent fuel typically contains fission product absorbers and a relatively small percentage of fissile material. Therefore, the combination of both the limited extent of the expected damage and the need for a large amount of the optimally configured fuel suggests the potential for criticality is negligible for this case.

In the case of a zirconium fire (following a major loss of pool water), because of the assembly power peaking, a fire would initiate with cladding melt anticipated near the assembly midplane. The cladding temperature at the fuel bottom will be lower and the fuel rods are expected to remain intact in this region. Because of the closely packed fuel rods and the presence of grid spacers, there would be little room for fuel pellets to be expelled provided the wrapper (for BWR fuel) and/or rack canister remained intact. In this situation, rubble consisting of pellets and molten cladding would form on top of a spacer grid located below the assembly midplane. Since rubble would generate heat, it would eventually flow downwards slowed by the lower spacer grids. This rubble mass would be expected to grow, however, if not arrested by quenching from recovery actions. It is very likely that if not terminated at this stage, the rubble mass could melt the canister walls so that the fire could propagate towards the adjacent fuel assemblies. Thus, the amount of fuel debris material produced in a zirconium fire could be sufficient for criticality if early fire fighting recovery actions were not successful. Because of the low melting temperature and low density of Boraflex and Boral, it is likely that these would melt away early and collect below the rubble bed. Regardless of location, taking into account the potential for damaged fuel-moderator configurations to become more reactive than the original fuel lattice and given the uncertainty in reactivity absorber effectiveness, subcriticality in the presence of unborated water addition cannot be fully assured. If a criticality accident is deemed an issue in this zirconium fire scenario, it appears that a most prudent measure would be to use borated water (about 2000 ppm) when extinguishing a pool fire that causes substantial fuel damage.

2.3.2 Evaluation of the Potential for Criticality From Personnel Actions in Response to an Accident

Without moderation, fuel at current enrichment limits (no greater than 5 wt% U-235) cannot achieve criticality no matter what the configuration. If it is assumed that the pool water is lost, a reflooding of the storage racks with unborated water or fire-fighting foam may occur due to personnel actions. However, both PWR and BWR storage racks are designed such that they remain subcritical if moderated by unborated water in the normal configuration. The phenomenon of a peak in reactivity due to low-density (optimum) moderation (fire-fighting foam) is not of concern in spent fuel pools since the presence of relatively weak absorber material such as stainless steel plates or angle brackets is sufficient to preclude neutronic coupling between assemblies. Therefore, personnel actions involving refilling a drained spent fuel pool containing undeformed fuel assemblies would not create the potential for a criticality. However, personnel actions involved in fire-fighting operations should include consideration of using borated water.

2.3.3 Potential for Criticality Summary

Most scenarios that could result in inadvertent criticality of stored spent fuel assemblies are considered to be highly unlikely for the reasons given above. However, for defense-in-depth, the working group recommends the use of borated water (at least 2000 ppm) for all pools and for fire-fighting purposes.

It should be mentioned that most of the fuel stored in spent fuel storage racks has been removed from reactor cores because it has lost sufficient reactivity to be useful in producing a self-sustaining chain reaction and in producing power. In addition, the reactivity of stored assemblies has continuously decreased even further during long-term storage due primarily to Pu-241 decay and Am-241 growth. Therefore, it would appear difficult to achieve criticality with stored spent fuel assemblies.