CREDIT TO FUEL BURNUP IN CRITICALITY SAFETY ANALYSIS OF FUEL MANAGEMENT SYSTEM OF TAPS-1& 2(BWRs),INDIA

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ABSTRACT

- Criticality safety analysis is the key point for designing storage pool or transportation casks, so that in most reactive condition sufficient sub-criticality margin is there.

- Any shipment cask must be designed and constructed in such a way that even in case of water ingress to containment, it would be sub-critical.

- Burn up is the amount of energy released from a fuel assembly in a reactor in terms of Megawatt-days/tone-U (or total heavy material) of initial weight. Clearly, burn up results in reduction of fuel assembly reactivity.

- Reactivity reduces with burn up because of reduction in fissile content of the assembly and production of fission product neutron absorbers. Therefore, for the criticality safety analysis fresh fuels are considered.

- If burn up is credited, more assemblies can be shipped as compared to fresh fuel assumption for criticality safety analysis.

REACTORS IN INDIA

Following types of reactors are operating/under construction for power generation as well research work:

- Boiling water reactors (BWR) (Operating)
- Pressurized heavy water reactors (PHWR) (Operating)
- Pressurized water reactors (PWR) (under construction)
- Prototype fast breeder reactors (PFBR) (under construction)
- Research reactors

Principal γ-emitting radio nuclides inventory of spent fuels of Tararpur Atomic Power Station(TAPS-1&2)

[1] The main gamma-emitting nuclides in TAPS spent fuel bundles are:
Kr-85(10.76 y),Rh-106(30 sec.), Cd-113m(13.6 y), Sb-125(2.71 y), Te-125m(58 days), Cs-134(2.06 y),Cs-137(30.0 y),Eu-154(16 y).

[2] The main gamma-emitting nuclides in irradiated FSPs(fuel support plugs) are:
Co-60(5.3 y), Co-58(71.3 y), Fe-59(45.5 days), Cr-51(27.8 days) and Mn-54(303 days). But main contributors are- Co-60,Eu-154,Cs-134 and Cs-137.

[3] The main gamma-emitting nuclides in irradiated control blades is – Co-60, which is generated from stellite material in control blade rollers.

AN OVERVIEW ON FUEL STORAGE OF TAPS-1&2

Following are the general storage areas constructed with enough sub-criticality margin (i.e. criticality safety consideration)

- FRESH FUEL VAULTS (FFV) (for the storage of fresh fuel)
- WOODEN BOXES (containing metal boxes inside) (for the shipment of fresh fuel)
- SPENT FUEL STORAGE NEAR REACTOR (SF Pool) (intermediate storage of burnt fuel)
- SPENT FUEL STORAGE AWAY FROM THE REACTOR (AFR) (long time storage of burnt fuel)
- AAFR (Additional Away From Reactor) , under construction
- DRY STORAGE CASKS (DSC) (long time storage of burnt fuel)

AN OVERVIEW ON FUEL STORAGE OF TAPS-1&2 (continued)

- Spent fuel of PHWRs is stored in multi-tier structures.
- BWR fuel bundles are stored in vertical racks.

To ensure safe storage of fuel assemblies following are the main points considered at [1] Design level [2] Operation level-

[1] At design level (criticality safety analysis i.e. $K_{effective}$):

(a) Size and shape of the pool (geometrical buckling)

(b) enrichment (material buckling)

(c) Type and thickness of the rack material

(d) Burn up of the discharged fuel

[1] At Operation level:

(a) sufficient water level in the pool for cooling and shielding.

(b) conductivity of pool water

(c) PH of the pool water

AN OVERVIEW ON FUEL STORAGE OF TAPS-1&2 (continued)

[1] **Spent fuel pool** (SF Pool), rack material is SS-304 :

(a) $K_{effective}$ is less than 0.9 (with **no burn up credit** i.e. fresh Reload-I fuel(2.24% average enrichment) and optimum water moderation).

(b) Fuel storage pool water temperature is 10 ^{o}C higher than ambient temperature but limited to 60 ^{o}C for maintaining concrete wall integrity.

(c) Three meter water above top of the burnt fuel during fuel handling. It is for shielding.

(d) Conductivity of the fuel pool water is less than 1 µmho/cm and limited to 10 µmho/cm and PH lies between 5.6 to 8.6 , it is to prevent corrosion of the fuel-clad, rack and other structural material.

AN OVERVIEW ON FUEL STORAGE OF TAPS-1&2 (continued)

[1]Away From Reactor (AFR) Spent fuel pool), rack material is SS-304 :

(a) $K_{effective}$ is less than 0.9 (with **no burn up credit** i.e. fresh Reload-I fuel(2.24% average enrichment) and optimum water moderation).

(b) Minimum cooling period for transferring burnt fuel bundles to AFR pool from SF-pool is 10 years . It is for minimizing radiation dose during shipment as well as reducing the heat load of AFR pool.

(c) Fuel storage pool water temperature is less than 60 ^{o} C to maintain resin integrity.

(d) Three meter water above top of the burnt fuel during fuel handling. It is for shielding.

(e) Conductivity of the fuel pool water is less than 1 µmho/cm and limited 10 µmho/cm and PH lies between 5.6 to 8.6 , it is to prevent corrosion of the fuel-clad, rack and other structural material.

Criticality Studies for Dry Storage Cask (code used LWRBOX)

It was estimated that the maximum temperature which may be present inside the rod of the central most fuel assembly already cooled for 10 years may reach up to 150 ^{o}C . If water enters the cask, the cask interior may be covered with water steam mixture.

The lattice calculations are first performed by using 27/28/69 group WIMS cross section library. Then one group condensed microscopic cross section of each element in all the fuel regions are calculated. Thereafter the burn up equations are solved one by one for every fuel region. These are solved by either trapezoidal rule or Runge-Kutta method.

There are two burn up schemes:

[1] 33 fission products are considered explicitly and one pseudo fission products is considered.

Criticality Studies for Dry Storage Cask (code used LWRBOX) (continued)

[2] Second scheme is Nephew scheme used to treat fission products. In this scheme, the fission of uranium and plutonium isotopes would yield five pseudo fission products and elements Rh-105 and Xe-135. Due to short half life Rh-105 and Xe-135 are assumed at saturated concentration always.

Thus in the worse scenario -

K_∞ was found 0.954 at water density 0.35 gm/cm^3.

This value of K_∞ is very conservative.

AN OVERVIEW ON TAPS-1&2 FUEL STORAGE IN DSC (continued)

[1] Dry Storage Cask (DSC), cask material is SS-304:

(a) $K_{effective}$ is less than 0.95 (with **no burn up credit**)

(b) Minimum cooling period for storing in dry storage casks is 10 years.

(c) Materials emitting radiation field which can lead to higher dose than the back ground at the outer surface of the DSC must not be stored in dry storage casks.

(d) 37 burnt fuels can be stored in one DSC.

AN OVERVIEW ON TAPS-1&2 FUEL SHIPMENT

[1] Dry Storage Cask (DSC), cask material is SS-304 :

(a) $K_{effective}$ is less than 0.95 (with **no burn up credit**)

(b) Minimum cooling period for storing in dry storage casks is 10 years.

(c) Materials emitting radiation field higher than the transportation limit 200 mGray /hr must not be shipped in dry storage casks.

Fuel sparger plugs (FSP) are made of SS-304. Due to irradiation in the core they have a radiation field of approximately 25 Gray/hr . Control blade rollers are made of stellite material which get converted into cobalt-60, a hard gamma emitter, emit very high radiation field. Therefore a special high shielded cask was needed for the shipment of control blades and FSPs.

AN OVERVIEW ON TAPS-1&2 FUEL SHIPMENT (continued)

Therefore, before shipment of control blades rollers are removed resulting in drastic fall in radiation level . For FSPs, they are placed in the central region of the cask so that surrounding fuel assemblies provide enough shielding. Following three shipment configurations were analyzed and found justified :

(a) All 37 location are filled with 37 fuel assemblies then max. radiation field on the cask surface is less than 0.20 mGray/ hr .

(b) 32 location are filled with fuel assemblies and 5 locations are occupied by FSPs then max. radiation field on the cask surface is less than 0.35 mGray/ hr .

(c) 28 location are filled with fuel assemblies and 9 locations are occupied by FSPs then max. radiation field on the cask surface is less than 0.55 mGray/ hr .

AN OVERVIEW ON TAPS-1&2 (BWR) FUEL SHIPMENT (continued)

These fields are well within transportation criteria 2.0 mGray/ hr. It is worth noting, however, that not more than 9 FSPs should be substituted as that may lead to high streaming radiation field on the cask surface.

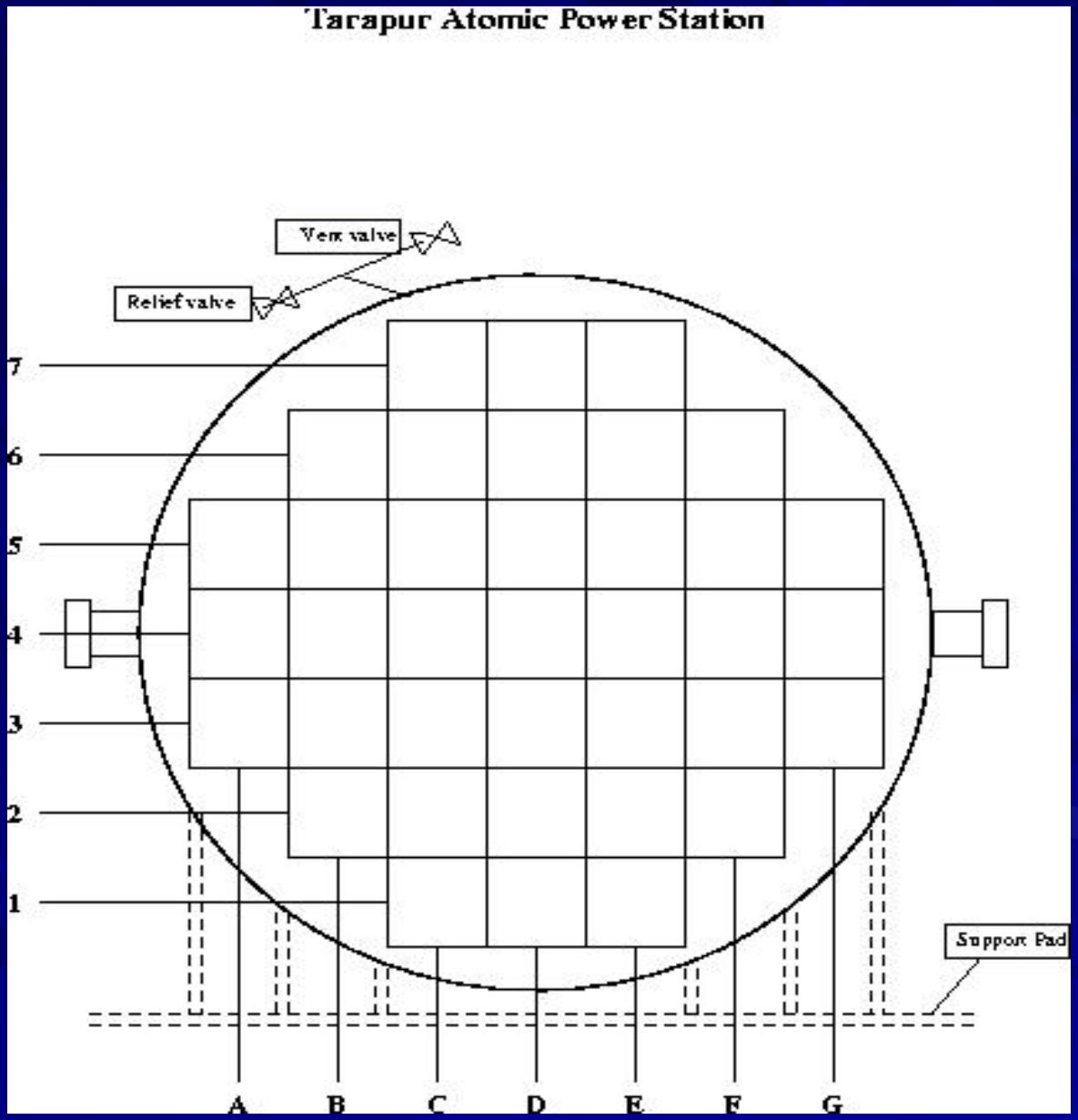
Actually major design objective of a dual purpose cask i.e. storage/shipment are as follows:

1. Radiological safety should be ensured.
2. Operational safety should be ensured.
3. Safeguards standards should ensured
4. Economical design

DIMENSIONAL DETAIL OF STORAGE/SHIPMENT CASK

- Fuel bundle pitch : 15.24 cm
- Total fuel bundles : 37
- SS square enclosure liner thickness : 3.25 mm
- SS Cylindrical storage cask thickness : 3.20 mm

DRY STORAGE CASK TAPS-1&2

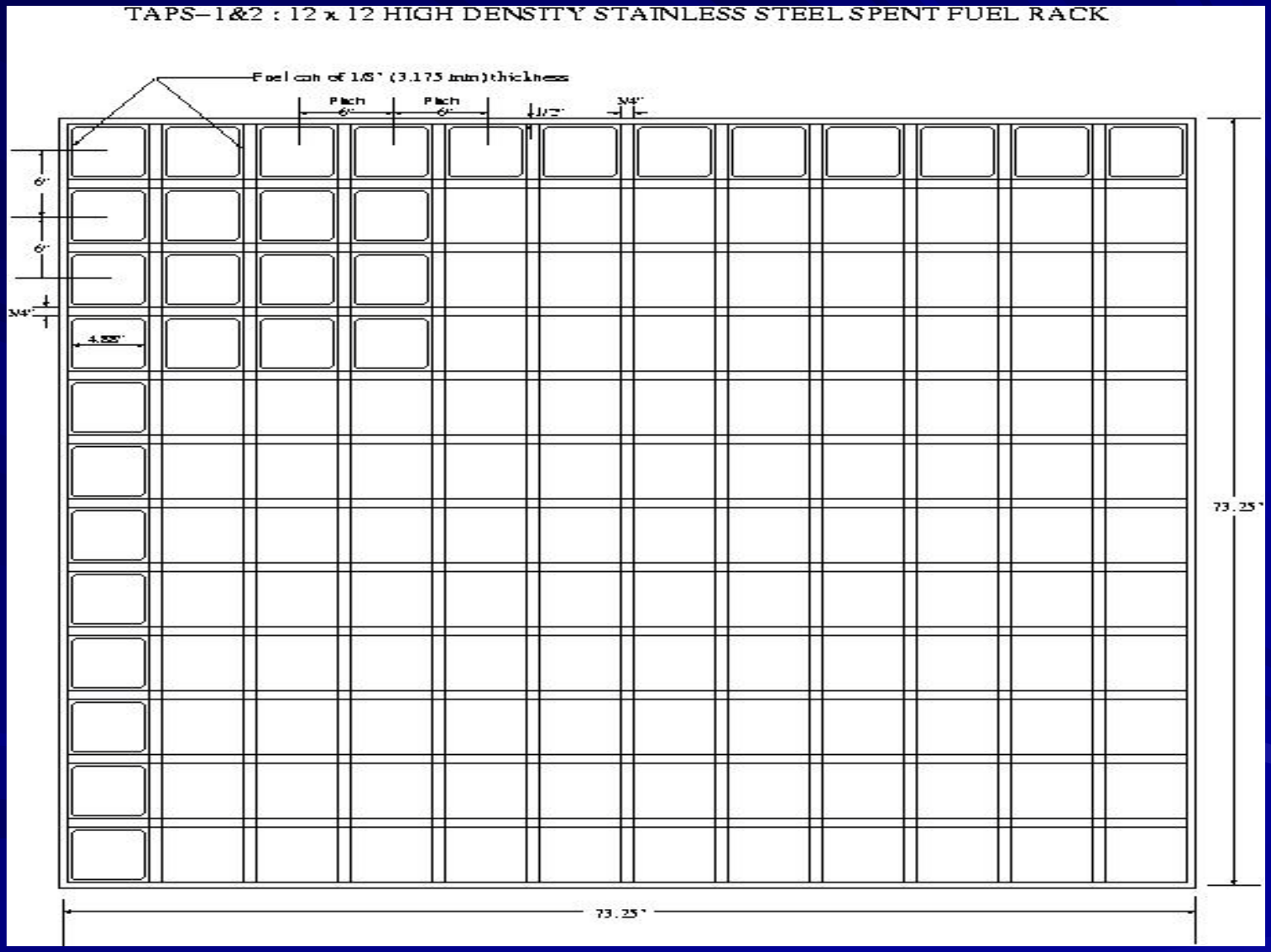


DIMENSIONAL DETAIL OF FUEL POOL RACK OF TAPS-1&2

- Rack matrix array : 12×12
- No. of bundles per rack : 144
- Fuel bundle pitch : 15.24 cm
- SS enclosure liner thickness : 3.25 mm

Note: One additional AFR (AAFR) is under construction will be having matrix array of racks as : 4×6 (i.e. 24 racks) and fuel rack pitch is 199.58 cm

FUEL POOL RACK OF TAPS-1&2



SPENT FUEL REPROCESSING AND DISPOSAL

- Spent fuel management is the integral part of nuclear fuel cycle.
- Fuel management is not a standard approach but varies for country to country.

Basically spent fuel management involves three policies:

1. Closed fuel cycle means reprocessing spent fuel i.e. recycling uranium and using extracted plutonium for fuel preparation for fast breeder reactors.
2. Once through fuel cycle means direct disposal of spent fuel into a deep geological repository.
3. wait and see means delaying for other technology development which economical and low man- Rem consumption.

SPENT FUEL REPROCESSING AND DISPOSAL (Continued)

- Spent fuel of TAPS-1&2 is stored in wet storage pools and dry storage casks. The wet pool storage capacity is being enhanced by constructing Away from Reactor spent fuel storage pools.

THANK YOU