CONSTAR--A FAMILY OF CONCRETE SPENT FUEL DRY STORAGE CASKS

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ABSTRACT

Several utilities have opted for dry storage of spent fuel to solve their near term needs. Virginia Power has recently demonstrated the feasibility of using metal casks at the Surry Facility. Carolina Power and Light has constructed and is performing initial tests on a horizontal vault (NUHOMS) facility at the H.B. Robinson plant. Larger NUHOMS facilities are planned for the Oconee site and the Calvert Cliffs facility. Thus, to date the available licensed technology has consisted of metal casks and vault systems. The vault systems, even though they involve building a structure, have proven to be less expensive because concrete is substantially less expensive than metal. Taking this one step further, another logical choice for dry storage would be a concrete cask. However, there are technical challenges to overcome for concrete to be used in a spent fuel cask application. The B&W Fuel Company is currently dealing with these issues in designing the CONSTAR cask.

CONSTAR DESIGN FEATURES

Named CONSTAR for CONcrete Storage At Reactor, it actually is a family of casks that can be customized to match individual customer or site requirements. The CONSTAR-125 cask (Figures 1, 2, and 3) is typical and consists of an inner steel liner and a concrete outer shell with a loaded weight of up to 125 tons. The CONSTAR casks are designed to be primarily compatible with dry fuel loading via a transfer cask, but also can be modified for in-pool operations. A summary of typical design features is presented in the following table. Similar casks with weights up to 180 tons and capacities of up to 28 PWR/63 BWR assemblies have been designed.

TABLE I

Summary of CONSTAR-125 Design Features

General	125 tons gross weight (consolidated fuel) Concrete shielding/steel containment 40 year design lifetime
Payload Capacity	16 intact PWR assemblies (CONSTAR125P) 36 intact BWR assemblies (CONSTAR125B) Equal number of consolidated fuel canisters
Thermal rating	20 KW
Criticality	Keff 0.95 for all cases, no burnup credit
Shielding	Surface dose rate 2 mrem/hr
Structural	ASME Section III

Cask Body

The cask body inner liner and its closure lids are designed per the ASME Code, Section III, Division 1, as a pressure vessel and act as the containment boundary for the CONSTAR casks. The two closure lids, primary and secondary, are attached to the upper flange of the liner. The steel liner is surrounded by a 24 inch thick concrete radiation shield. The four removable shield plugs are supported by the liner flange and inner cruciform. Inside the cask cavity four compartmentalized mini-baskets laterally support the fuel assemblies. Lifting provisions are located on the top of the cask and anchor into the concrete rebar.

The reinforced concrete body is designed structurally to the guidelines of the ASME Code, Section III, Division 2. A cage-like arrangement of steel reinforcement bars (Figure 3) provides structural strength and is effective in resisting crack formation in the concrete. The proprietary steel fiber reinforced concrete used for CONSTAR has been shown to have superior flexure strength and crack resistance when compared to concretes that simply use adders to increase density and improve neutron attenuation.

The containment closure utilizes a double lid system (Figure 4) to ensure leak-tightness. A primary lid that bolts to the upper flange in conjunction with a double metallic O-ring seal arrangement is the basic containment boundary; it also features recessed drain and purge line connectors. The secondary lid is welded to the upper flange and provides additional protection against leakage. A pressure tap in the secondary lid provides a means of monitoring primary seal integrity.

Fuel Basket

Both intact fuel assemblies and consolidated fuel canisters can be accommodated by the CONSTAR basket design. The layout for the CONSTAR-125P basket (Figure 5) shows the internal cavity of the module partitioned into four sections by the steel inner cruciform. The cruciform is positioned by four tracks welded to the liner. Clearances are provided to accommodate the differential thermal expansion between the inner cruciform and the liner.

Borated shrouds are used for the fuel cells in the mini-baskets and provide excellent criticality control, physical protection and heat transfer characteristics. The cell design takes advantage of natural convection loops to help transfer the head load from the assemblies or canisters to the liner. Each cask quadrant contains a mini-basket of four cells attached to a cruciform structure; the mini-baskets are loaded in the spent fuel pool and then inserted directly into the CONSTAR via a transfer cask/interface device.

Heat Pipes

CONSTAR casks utilize a heat pipe system that keeps the maximum concrete temperatures within acceptable licensing limits. Using this approach allows use of much hotter fuel or consolidated canisters without the concerns

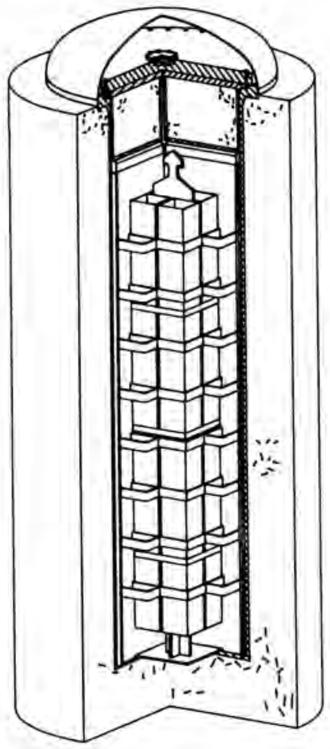


Fig. 1. CONSTAR - 125P -- 16 PWR Capacity (Shown Without Heat Pipes for Clarity).

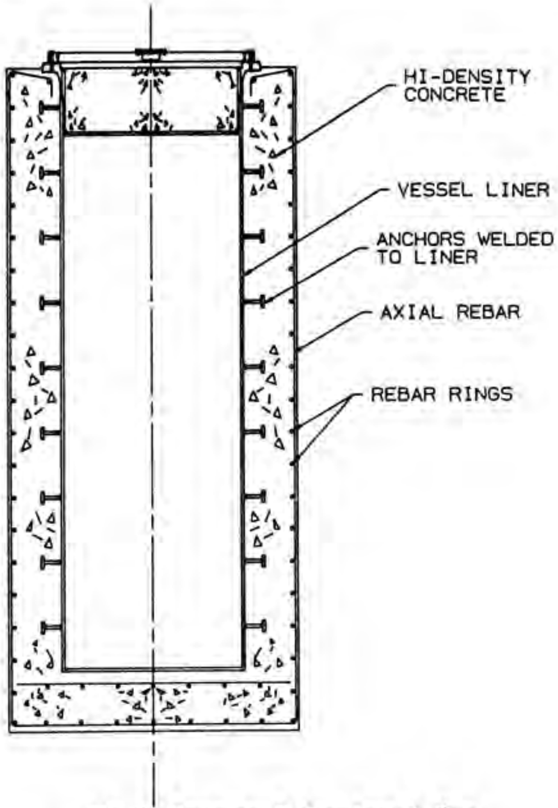


Fig. 3. Concrete Rebar Installation.

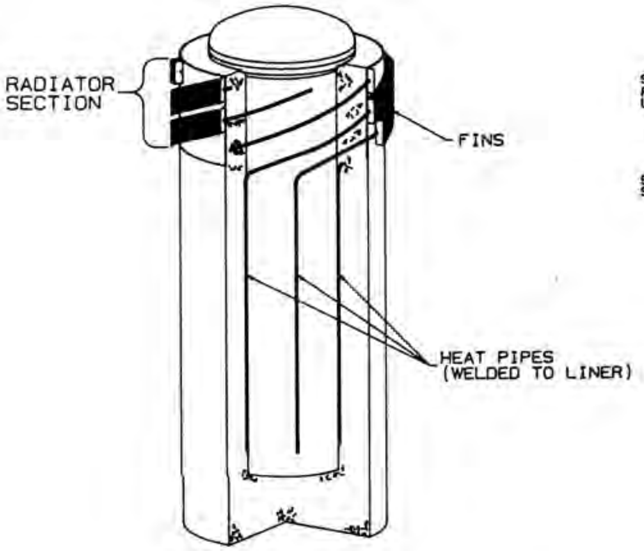


Fig. 2. CONSTAR - 125.

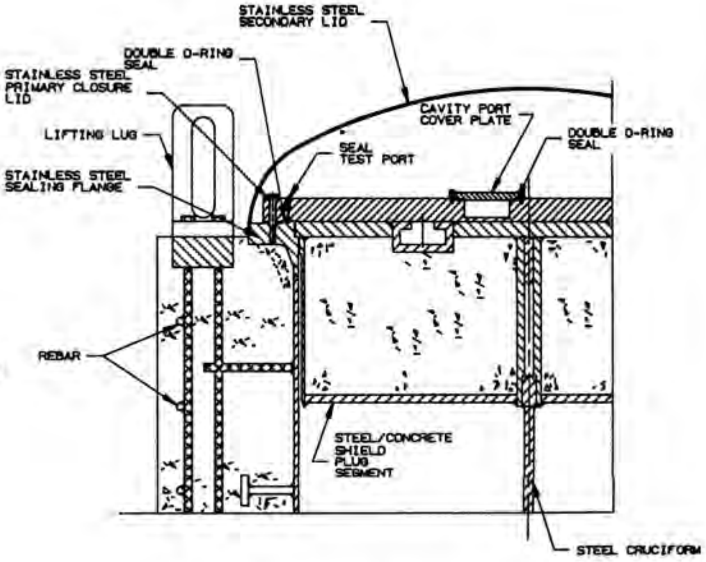
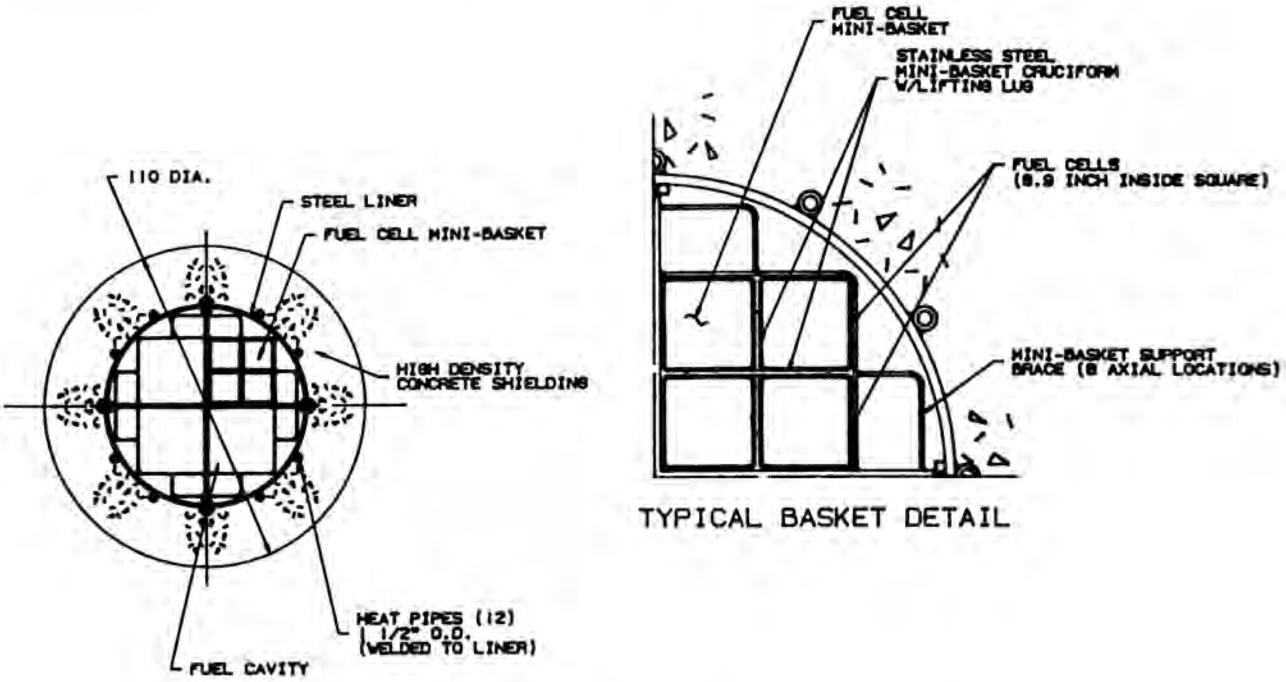


Fig. 4. Shield Plug/Closure Lid.



TYPICAL BASKET DETAIL

Fig. 5. Layout for the CONSTAR - 125P Basket.

inherent in systems that depend on air circulation. Each heat pipe has the capacity to transfer 5 KW to atmosphere; 12 pipes are used on the CONSTAR-125 to provide high levels of redundancy and to maintain low concrete temperature gradients.

The heat pipes are carbon steel tubes that contain a water based fluid. The pipes are welded to the outer wall of the cask liner and angle through the concrete and out the cask side to a finned section wrapping around the cask circumference (Figure 2). The heat pipes do not extend in height beyond the concrete shoulder of the cask.

PRELIMINARY ANALYTICAL FINDINGS

Shielding Analysis

Analyses indicate that outstanding shielding performance is achieved with the CONSTAR-125P design. These analyses utilized the ANISN transport theory code and the QAD-CGGP point kernel code. The ANISN code with the CASK-23E cross section set was used to evaluate a typical PWR and determine the neutron and gamma contribution to the surface dose rate. The predicted surface dose rate was found to be less than 30 mr/hr. Even lower dose rates can be obtained by increasing the concrete thickness, a unique option available on CONSTAR casks.

CRITICALITY ANALYSIS

Criticality calculations for the CONSTAR-125P storage cask were made with the KENO IV Monte Carlo Code. For this phase of the design the Hansen-Roach 16 group cross section set was used. All calculations used intact fuel assemblies with 4.5 w/o U-235. Cases were analyzed for a full mini-basket (four assemblies) inside the transfer cask with pure water (maximum Keff .93) and for a fully loaded (16 assembly) cask in air (maximum Keff .5). Burnup credit was not taken into account per recent NRC direction on topical reports. Specific sites may be able to use burnup credit or boron content in their fuel pool to reduce the Keff (and absorber requirements/price) even more.

THERMAL ANALYSIS

The use of heat pipes on the outside of the steel liner makes the liner act like a cooling fin to the hot cask cavity. The fuel cell design leaves the top and bottom of the fuel assemblies exposed, thus creating natural convection loops that further enhance heat rejection. This system prevents large temperature gradients in the concrete and assures consistent mechanical and chemical performance over the life of the cask.

Operational and accident (fire) conditions were analyzed to identify crucial design areas. Conservative one-dimensional and two-dimensional finite element analyses were performed to predict the warmest rod cladding temperature and the temperature distribution throughout the CONSTAR-125P structure. These analyses indicated that substantial margins exist between the predicted and allowable warmest rod cladding temperatures. The concrete/liner profiles for 10 KW and 20 KW loads are shown in Figure 6. Loss of several heat pipes due to hypothetical accidents can be accommodated with little temperature change due to the redundancy designed into the system.

Results from these analyses indicated that there is no significant temperature increase for the fuel rods within the module for accident conditions. The largest cladding temperature change as a result of the postulated fire was an approximately 15oF increase over the steady-state prefire conditions. After thermal equilibrium returns, the post-fire steady-state temperatures of the CONSTAR casks will be slightly higher than for pre-fire conditions.

STRUCTURAL ANALYSIS

Designed as a concrete pressure vessel per Section III, Division 2 of the ASME Code, the concrete and reinforcing bars provide the structural strength for the vessel. The liner and closure lid are designed as a pressure boundary per the guidelines of the ASME Code, Section III.

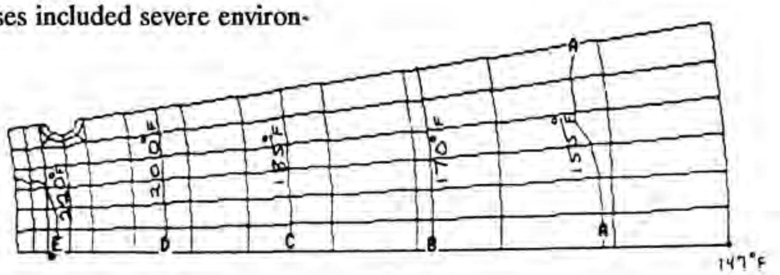
Operational loadings used in the evaluation of the cask included internal pressurization, thermal stresses due to insolation and fuel decay heat, normal operation and handling loads.

Abnormal or accident cases included severe environmental and weather conditions (tornadoes, floods, seismic events, missile impacts and other 10CFR72 design cases), and postulated accidents (cask drop or tip-over, fire accident, ruptured fuel pins).

All analyses have shown that the CONSTAR casks have adequate margin in every case. The materials of construction are well-documented in terms of strength, durability and relevance of application.

CONCLUSIONS

Concrete promises to be an economical material for spent fuel storage casks if the engineering requirements can be met. The CONSTAR design resolves two of the most difficult issues, structural strength and heat transfer capacity with two special design features a steel matrix concrete and the use of imbedded heat pipes. Early analyses have borne out the validity of these design choices and encourage the B&W Fuel Company to proceed forward to license the CONSTAR family of casks.

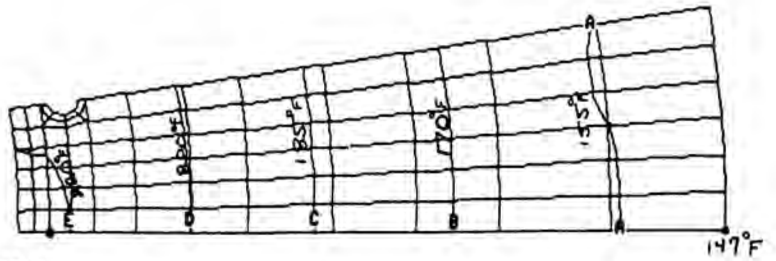


10 KW

T_{max} Concrete = 225°F

T_{max} Liner = 226°F

T_{max} Surface = 147°F



20 KW

T_{max} Concrete = 230°F

T_{max} Liner = 232°F

T_{max} Surface = 147°F

Fig. 6. Constar-125 Cask Body Temperature Isotherms - Heat Pipe Temp = 210°F.