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Design Requirement on HYPER Blanket Assembly

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Submission Statement

To : The President of KAERI

This report is submitted as the report for the word of "Design Requirement on HYPER Blanket Assembly".

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요약문

본 문서는 HYPER용 블랭킷집합체의 설계에 필요한 길잡이로써 전반적인 설계요건을 기술하였다. HYPER 블랭킷집합체는 블랭킷 연료봉, 탑재선로, 간격체, 취급소켓이 부착된 상부노즐, 탑재선로가 부착된 하부 노즐, 노즐연결지지체로 구성된다. 블랭킷봉은 상부봉단마개, key way가 부착된 하단봉단마개, 블랭킷연료심 및 피복관으로 구성된다. 블랭킷집합체내의 블랭킷봉은 삼각배열로 다발을 이룬다. 본 보고서에는 블랭킷 연료집합체에 대한 기능적 요건, 성능 및 운전요건, 인접계통 요건, 노심 연계 요건, 설계한계 및 강도 요건, 계통배열 및 필수특징적 요건, 지진시 요건, 구조적 요건, 환경적 요건, 신뢰도안전 요건, 표준 요건, QA 요건 및 기타 요건 들을 기술하였다.

Summary

This document describes design requirements which are needed for designing the blanket assembly of the HYPER as design guidance. The blanket assembly of the HYPER consists of blanket fuel rods, mounting rail, spacer, upper nozzle with handling socket, bottom nozzle with mounting rail and skeleton structure. The blanket fuel rod consists of top end plug, bottom end plug with key way, blanket fuel slug, and cladding. In the assembly, the rods are in a triangular pitch array. This report contains functional requirements, performance and operational requirements, interfacing systems requirements, core restraint and interface requirements, design limits and strength requirements, system configuration and essential feature requirements, seismic requirements, structural requirements, environmental requirements, reliability and safety requirements, standard and codes, QA programs, and other requirements for the blanket fuel assembly of the HYPER.

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1. General

The basic criteria on a blanket design of HYbrid Power Extraction Reactor(HYPER) are; (1) it must be economical as a spent fuel treatment / waste cleanup system and a producer of heat, (2) it must provide a subcritical burner that produces and utilizes an intense source-driven neutron flux for fission of transuranics and transmutation of fission products. The details of design requirements for HYPER blanket rod and assembly design are described in this text.

The method universally adopted for assembling HYPER blanket fuel rods into manageable clusters is to collect them into a hexagonal bundle. The rods in assembly are in a triangular pitch array. The bottom end of each assembly duct is formed by a nozzle which provides the lower restraint function and the coolant inlet. In blanket assembly, each rod is mounted on the mounting rails, and each mounting rail is attached to the hexagonal tip of bottom nozzle. It is also the structural tie between the top and bottom end hardware of the assembly.

Either TRU-Zr metal alloy or (TRU-Zr)-Zr dispersion fuel shall be considered as a blanket fuel for HYPER (HYbrid Power Extraction Reactor). In case of dispersion fuel, the particles of TRU-Zr metal alloy are dispersed in Zr matrix. Blanket rod is made of sealed tubing containing fertile material in columns. In TRU-Zr ally fuel, the blanket fuel slug is immersed in sodium for thermal bonding with the cladding. The blanket-fuel cladding material is ferritic-martensitic steel. In HYPER blanket fuel alloy rod, a fission gas plenum is located in the rod as a reservoir for gaseous fission products produced during irradiation. A fission gas plenum is located above the blanket fuel slug and sodium bond.

The blanket-fuel system design shall be performed according to general design process as shown in Figure 1. This procedure is similar to the driver fuel system design for KALIMER. This document establishes technical design requirements for the design of safe, reliable, and economic HYPER blanket fuel system and their sub-components including the assemblys. The design requirements in this document are intended to be used for the design of the blanket fuel assembly of the HYPER. The word "shall" or "must" are used to denote a requirement; the word "should" is used to denote a recommendation; and the word "may" is used to denote a permission, neither a requirement nor a recommendation.

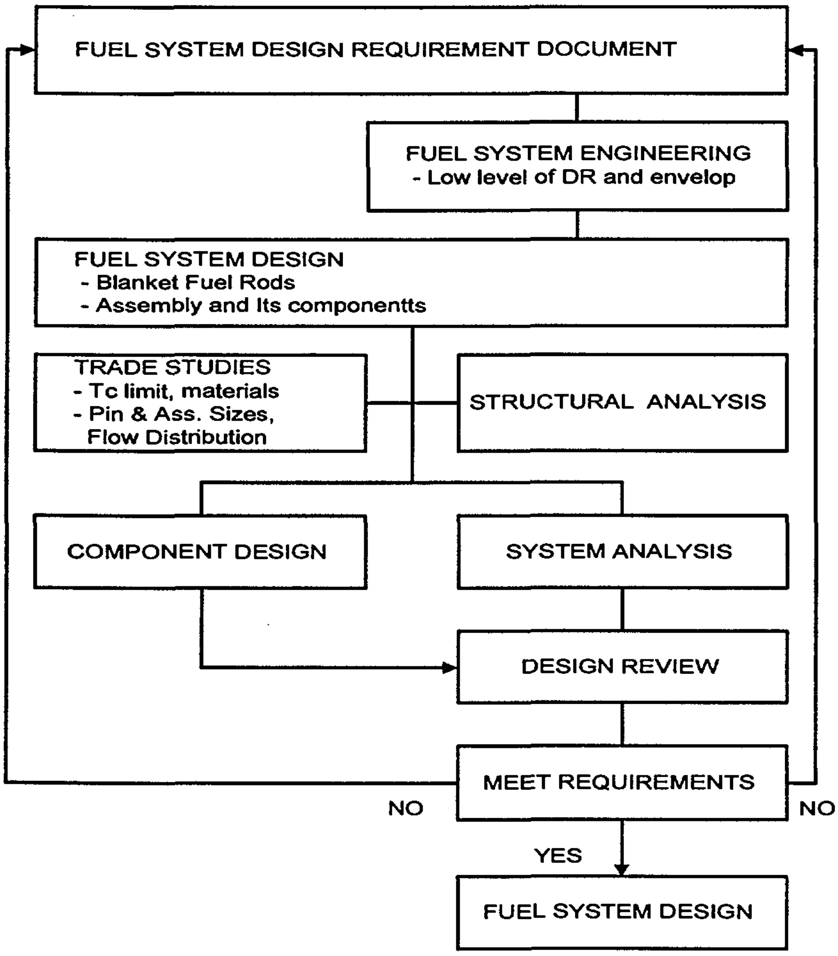


Figure 1. Fuel System Design Process.

2. Functional Requirements

2.1 Blanket rod

This sub-section describes the functional requirements for the HYPER blanket fuel rod under normal operating conditions (NOCs), including the effects of anticipated operational occurrences, and design basis events (DBEs). The blanket rod shall provide the following functions :

1) The blanket-fuel rod shall be designed to maintain their integrity under normal operation condition.

2) The blanket-fuel rod with a spacer shall be dimensionally compatible to accommodate blanket-fuel expansion due to irradiation.

3) The blanket-fuel rod shall be designed to accommodate expected dimensional changes, such as element swelling and its axial growth, during irradiation.

4) The blanket-fuel rod shall generate thermal power through controlled nuclear fission and transfer it to the coolant of the primary heat transport system.

5) The blanket-fuel rod shall contain and confine within the cladding the fissile material, and the solid and gaseous fission products that are generated as by-products of the fission process to prevent excessive contamination of the coolant.

6) The cladding shall provide structural integrity during irradiation and serve to separate the blanket-fuel from direct contact with the coolant, thereby preventing the fission products from entering the

primary coolant.

7) The sufficient plenum volume shall be provided to contain the fission gas produced at blanket-fuel slug, and to prevent overpressurization to cladding by fission gas accumulation during irradiation.

8) The bottom end cap with keyway shall be provided for fixing the rod to the mounting rail of the blanket-fuel assembly.

9) The top end cap shall be provided for confining the fission gas within the rod.

10) The gap between fuel core and cladding ;
 - In case of alloy fuel, the large sodium-filled gap shall be provided to permit a good heat transfer, and to allow sufficient volume for blanket-fuel swelling.
 - In case of dispersion fuel, the gap between fuel core and cladding should be minimized in order to increase the efficiency of heat transfer through the gap.

2.2 Assembly

This sub-section describes the functional requirements for the HYPER blanket fuel assembly under normal operating conditions (NOCs), including the effects of anticipated operational occurrences, and design basis events (DBEs). The blanket assembly shall provide the following functions :

1) The blanket assembly shall be able to withstand the axial load caused by the hydraulic drag load of the primary cooling system.

2) The blanket assembly must be dimensionally compatible to

accommodate blanket-fuel rods expansion due to irradiation and thermal creep during the life time.

3) The top end of the assembly shall be compatible with the fuel handling tools and the bottom end of other assembly, respectively.

4) The blanket assembly must be designed to withstand axial compressive forces caused during loading or unloading of the assembly.

5) The blanket assembly shall be designed to accommodate expected dimensional changes, such as creep, swelling and its axial growth, during irradiation.

6) The blanket rod assembly must be designed to maintain their integrity.

3. Performance and Operational Requirements

3.1 General

The performance of the blanket-fuel assembly during normal operation, anticipated operational occurrences, and postulated accidents shall be evaluated to determine if all design bases are met.

The interaction between blanket-fuel rods in a bundle causes a varying temperature distribution around a rod, rod bowing, the bundle compression due to cladding swelling, and cladding wear due to friction between rods. The blanket assembly system shall be designed with appropriate margin to ensure that specified acceptable blanket-fuel design limits are not exceeded during any condition of normal operation including the effects of anticipated operational occurrences, and design basis events.

1) The blanket-fuel assembly is designed to tolerate a set of design-basis accidents with allowable consequences ranging from no significant degradation of expected blanket-fuel lifetime to maintenance of a coolable geometry.

2) The blanket assembly shall be designed to minimize vibrations which might cause damage to the blanket assembly themselves or to their flow tubes.

3) Coolability shall be always maintained.

3.2 Blanket fuel rod

The important performance aspect to be considered in the design of blanket fuel rod for HYPER is to maintain the integrity of the element under NOCs. The most important irradiation performance characteristics of metallic blanket fuel element are its diameter increase and fuel-cladding interaction (FCI) between fuel slug and cladding ; resulting from fuel swelling, fission gas release and internal pressure buildup, cladding creep and the interdiffusion of fuel and cladding constituents. Since the density of ferritic-martensitic cladding does not change significantly as a result of irradiation, the blanket fuel slug volume change shall be considered as one of major performance parameters.

Blanket-fuel rod design is a complex process that involves an integration of a wide range of phenomena. The rod design procedure must integrate the thermal analysis of the rod with an assessment of the characteristics of the fuel and cladding as a function of temperature and irradiation history and with the stress analysis of the fuel-cladding system. In actual design practice, all of the governing process must be integrated in large time-dependent rod analysis computer codes. Design basis requirements shall be satisfied including 2-sigma uncertainty allowances.

The followings are the core blanket-fuel performance and operational requirements :

1) The thermal conductivity of blanket-fuel slug shall be sufficiently high so that in-reactor maximum operating temperatures will be easily restricted to less than the melting temperature of blanket-fuel slug.

2) Cladding wastage during blanket fuel life in reactor shall be minimal, so that wastage of the cladding in the primary coolant under NOCs must not affect rod integrity for the longest expected residence time.

3) The linear heat generation rate must be less than TBD (67 kW/m) to prevent the centre melting of blanket fuel slug under NOCs.

4) The maximum temperature at the point of peak thermal power generation must be less than the melting point of blanket fuel slug under normal operating conditions, including worst-case operating conditions and maximum possible overload.

5) Power fluctuations and increase rates ; there are no constraints for restricting the rates of increasing power under NOCs, except for exceeding maximum LHGR.

6) The maximum temperature at the interface between blanket fuel slug and cladding must be less than the eutectic melting point under steady state condition.

7) The maximum temperature at the interface between blanket fuel slug and cladding must be less than the criteria of eutectic melting points under transient condition.

8) The blanket-fuel slug materials shall be stable thermo-chemically and under irradiation, and shall corrode slowly in event of a cladding defect.

9) The blanket-fuel rod internal pressure shall be less than the critical pressure for plastic deformation of cladding. The maximum permissible diameteral increase of blanket rod shall be compatible with the thermal-hydaulic requirements, and in any event shall be less than TBD (2 %).

10) The blanket fuel rods shall not be damaged as a result of normal operation and anticipated operational occurrences.

11) Operation through Levels A and B duty cycle events, considering normal and anticipated duty-cycle events which include load following and beyond cladding breach operation, shall not cause

more than 0.01% of the rods in the equilibrium core to fail per cycle.

12) The number of blanket rod failures shall not be underestimated for postulated accidents.

13) The diameter increases of the blanket elements including the swelling are not exceeded the level to assure an appropriate cooling of the rod.

14) The integrity of blanket element shall be maintainable up to TBD (10 at.%) local burnup of the initial heavy material.

15) Blanket rod should be designed to maintain its structural integrity during its lifetime under NOC. CDF (cumulative damage fraction) shall not be greater than following criteria;

- Steady state operation : < TBD (0.001)
- Transient operation : < TBD (0.2)

16) The coolant flow past the blanket-fuel rods can cause blanket fuel vibration. The motions of the rods must be sufficiently small that the fuel assemblies are not damaged internally.

17) Blanket rod should be designed to meet requirements on stress levels at power and during refueling.

18) Cladding wastage including the internal attack shall be limited to less than 10% of the cladding wall thickness, so that cladding strength degradation and the amount of fuel liquefied are minimized.

19) The peak fast neutron fluence (E > 0.1 MeV) shall be limited to TBD (3.8 x 10^{23} n/cm^2). This limit is based on the use of ferritic/martensitic steel as the core structural material.

3.3 Blanket fuel assembly

The performance and operational requirements on the design of the blanket fuel assembly are an important aspect of the fuel assembly in the presence of dilation due to thermal and irradiation effects. The dilation affects on the operation of primary heat transfer system and/or fuel handling system. The followings are the performance and operational requirements :

1) The blanket-fuel assembly shall be designed to minimize vibrations which might cause damage to the fuel assembly itself.

2) The blanket-fuel assembly shall be designed to prevent the flow blockage through a tube channel.

3) The structure of blanket-fuel assembly shall be designed to minimize the dilation.

4) The maximum allowable assembly dilation at end of life (EOL) shall be equal to or less than the internal dimension of the flow tube.

5) Assembly distortion shall be limited such that load limits on the in-vessel fuel transfer machine are not exceeded during core assembly insertion or removal.

4. Interfacing Systems

4.1 Core restraint and interface requirements

4.1.1 Blanket fuel rod

1) Coolant flow during normal operation shall be such that the fuel cladding will remain in LBE (Pb-Bi eutectic) coolant.

2) LBE coolant chemistry shall be controlled in order to minimize the cladding wastages or corrosion as described in chapter 9.

3) Bulk coolant temperature shall be less than 510 ℃ to maintain the integrity of cladding. The hot spot temperature of blanket cladding shall be less than TBD (650℃).

4) The light nuclei in blanket-fuel must be minimized or largely excluded from the fuel.

4.1.2 Assembly

The interfacing systems should compose a flow tube containing the core support structure, primary coolant system (PCS), and fuel handling system (FHS).

The requirements to allow clearance between assembly and flow tube to accomodate the swelling, and to constrain the core to resist bowing (due to swelling and thermal gradients) have the following functions:

1) Provide a predictable structure response of the core within the limits imposed by reactivity perturbation considerations during both long-term irradiation and transient conditions.

2) Maintain the tops of the blanket assemblies in a position such that handling heads can be remotely located and grappled by the grapple finger of IVTM (in-vessel transfer mechine).

3) Provide clearance for assembly insertion and removal, with minimal vertical friction, during shutdown refueling conditions.

4) Debris in the coolant shall be minimized.

5) The blanket assembly and related components must be dimensionally compatible with flow tube to accomodate any dimensional changes due to irradiation.

The flow tube structure provides the supporter of the blanket assemblies necessary to maintain them in their prescribed geometry during all modes of reactor operation.

In the vertical direction, tube channel shall provide a holddown function. The holddown system shall be attached on the top of the each flow tube.

4.2 Design requirements imposed on and by PCS

The growing demand for spent nuclear fuel transmutation provides renewed interest for the development of accelerator-based subcritical reactors. Lead is considered as the coolant for the transmutation reactors utilizing fast spectrum as the baseline. Although sodium has significant merit in thermalhydraulic and corrosion aspects its pyrophoric nature and positive void coefficient raised important safety concerns. On the other hand, liquid lead-bismuth eutectic(LBE) coolant with a melting temperature of about 170 ℃ has been explored from the early stage of fast reactor development, primarily at Brookhaven(BNL) National Laboratory. Relatively high corrosion rate of structural material and unfavorable pumping load made LBE less attractive than sodium coolant. Recently interest in LBE revived as both spallation target and coolant for accelerator based transmutation reactors. Its negative void coefficient and chemical stability became additional safety assets.

Design requirements imposed on and by PCS are as follows :

1) The calculated coolant flow in a tube during the normal operation shall not be exceeded to the critical power ratio. The coolant flow and temperature during normal operation shall be such that blanket fuel cladding will remain adequately cooled down below 650℃. The design mass flow rate will be provided by thermal hydraulic (T/H) analysis.

2) The primary coolant system shall provide a vibration-free environment which ensures that blanket assemblies are not internally damaged and that they do not damage the tube wall.

3) Coolant chemistry shall be controlled so as to minimize cladding corrosion.

4) Debris in the coolant shall be minimized.

5) The blanket assembly shall be able to withstand the axial load caused by the hydraulic drag of PCS.

4.3 Design requirements imposed on and by FHS

1) The blanket assembly shall be moved along an essentially vertical orientation during handling.

2) The blanket fuel assembly shall be handled from the top handling socket. The handling socket must be mechanically compatible with

the operation of the fuel handling tools of IVTM (in-vessel transfer machine).

3) The handling socket must be compatible with the grapple finger of IVTM during fuel handling operation.

4) The fueling operation shall be such that no torque is applied to the fuel assembly at any time during the refuelling operation.

5) Impact loads on cold irradiated assembly shall be minimized.

6) The blanket assembly shall be designed against inadvertent disassembly.

5. Design Limits and Strength Requirements

5.1 Blanket rod

Blanket rod design limits, such as temperature, burnup, and fluence, shall be established to ensure a failure rate of being no more than 0.01 % of the rods in the core. Fuel damage limits, such as cladding strain, amount of fuel melting, and fractional fuel failure beyond which accident consequences are unacceptable, shall be established from a set of design-basis accidents with allowable consequences ranging from no significant degradation of expected fuel lifetime to maintenance of coolable geometry. The followings are the requirements related to the design limits and the damage limits for the HYPER blanket rod design :

1) It has been shown by experiments and analyses that fuel centerline melting is not a direct cause of fuel failure in the case of metal fuel, since fuel expansion associated with melting is not large and causes little fuel cladding mechanical interaction (FCMI). None the less, considering that the consequence of an anticipated operational transient should not preclude restarting operation, blanket rod shall be designed so that no melting is occurred under normal operating conditions.

2) During the steady state operation, the fuel center and surface temperatures in the peak power blanket rod shall be lower than the solidus fuel temperature and eutectic temperature of fuel and cladding, respectively, with a TBD (15) % overpower margin. During the very short-term peak thermal conditions, the primary failure mode is rapid thermal stress rupture of the ferritic-martensitic steel cladding due to its low creep strength at elevated temperatures. For this situation, the peak cladding temperature under fast transient condition shall be less than TBD

(790 ℃).

3) For the long term soak at elevated temperatures, the cladding failure mechanism is creep rupture in weakened cladding where the effective cladding thickness has been reduced by the formation of low melting point eutectic of fuel and cladding. The temperature of the fuel/cladding boundary is limited to TBD(630℃) during the soak to preclude extensive eutectic formation.

4) The calculated thermal creep diametral strain under steady state condition shall be less than TBD (1.0%), total maximum diametral strain including design transients shall be less than TBD (2.0%).

5) The calculated CDF (cumulative damage fraction) value under steady state condition shall be less than TBD (0.001), and CDF under transient conditions shall be less than TBD (0.2).

6) To prevent the strength degradation by eutectic reaction between fuel and cladding during NOCs, the internal attack shall be restricted to be less than 10% of cladding thickness.

5.2 Assembly

The design limit and strength requirement are expected to be more severe than any intrinsic capability of the fuel assembly. The assembly and related components must be dimensionally compatible to accommodate the design limits of the assembly dilation.

6. System Configuration and Essential Feature Requirement

Figure 2 shows a typical horizontal cross section of a blanket assembly with 169 blanket rods. The HYPER blanket assembly along key section is shown in Figure 3. The rods contain columns of TRU-Zr alloy or a dispersion fuel of (TRU-Zr)-Zr. In all assemblies, the rods are in a triangular pitch array. The bottom end of each assembly is formed by a bottom nozzle which provides the lower restraint function, triangle array, and the coolant inlet. In blanket assemblies, the rod bundle attaches to the bottom nozzle with mounting rails.

6.1 System configuration

1) The core shall provide radial shield to reduce the neutron flux on permanent reactor components radially outward of the core.

2) The core shall provide near-core radial and axial shielding to limit neutron activation of in-vessel reactor components, and neutron damage to permanent structures.

3) The reactor core and its supporting elements shall be designed such that it contains negative feedback mechanisms that will provide negative reactivity to the core in response to an increase in the temperature of the core structures and/or to the supporting structures.

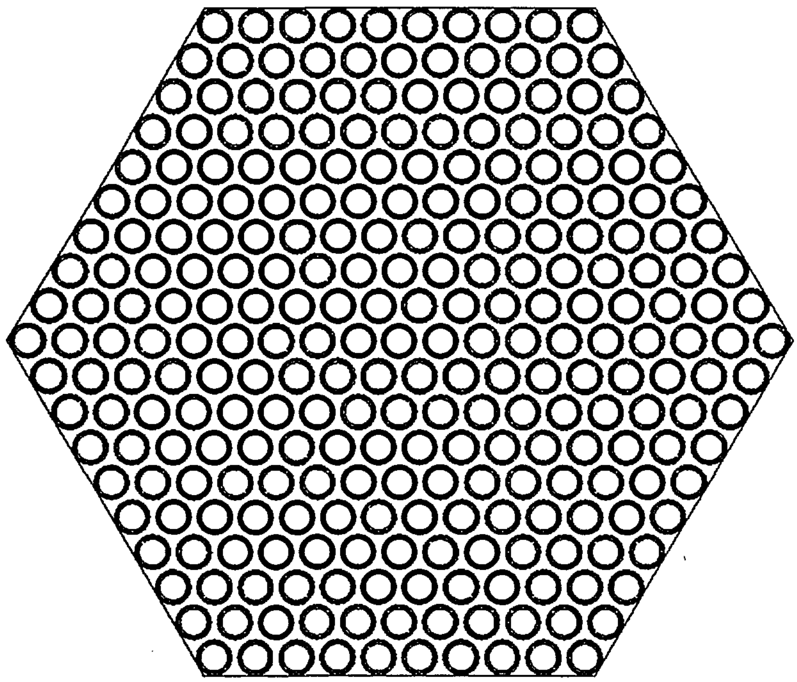


Figure 2. Array Configuration of the HYPER Blanket Assembly (169 rod array).

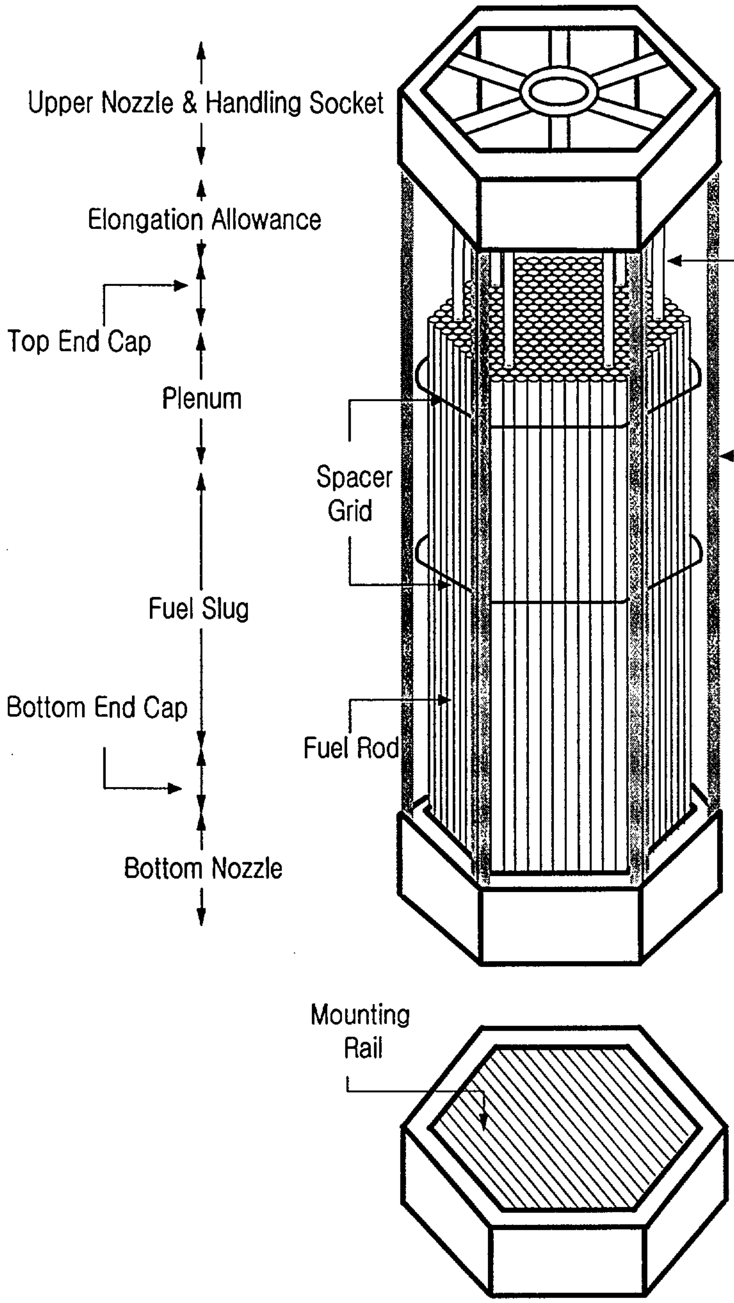


Figure 3. HYPER Blanket Assembly along with Key Section View.

6.2 Blanket rod

A typical configuration of the blanket rod is shown in Figure 4. Configuration and essential features that apply to the blanket rod of the reactor core system are as follows :

1) The blanket fuel shall be TRU-Zr alloy or or a dispersion fuel of (TRU-Zr)-Zr.

2) The blanket fuel should lead promptly and directly to a negative reactivity feedback.

3) The blanket fuel rod shall be made of sealed tubing containing actinide materials.

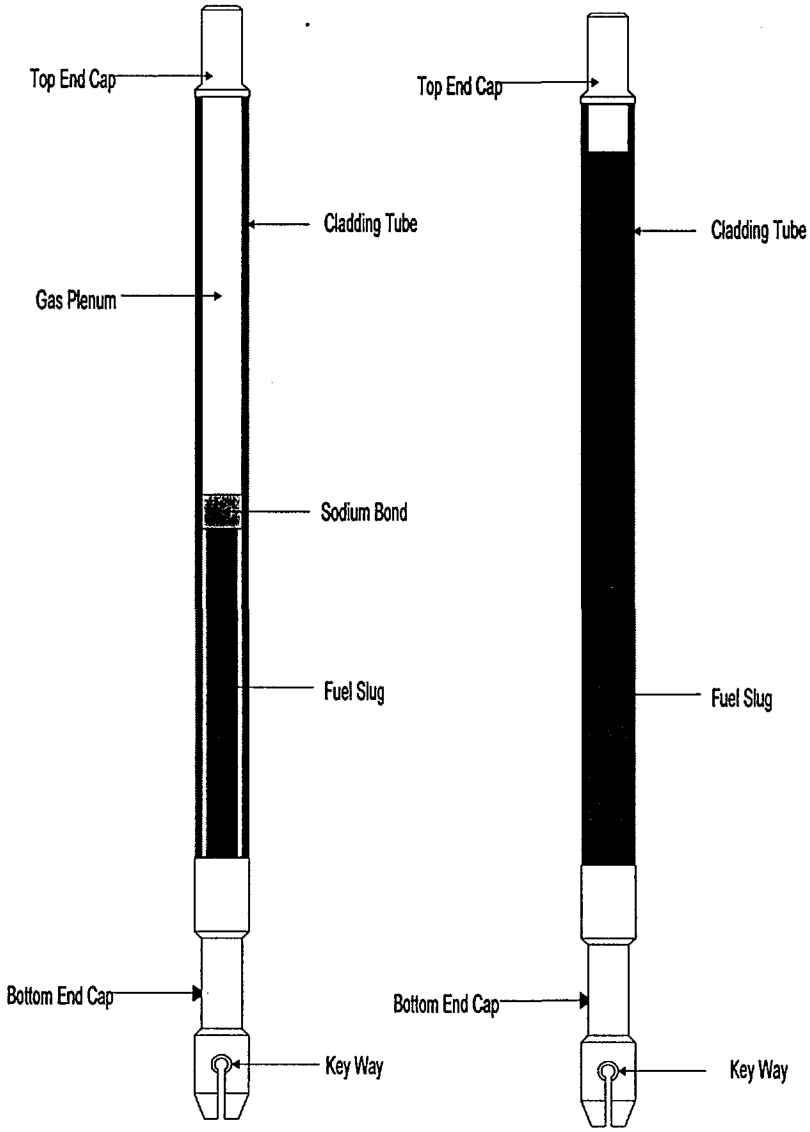
4) In case of alloy fuel, the blanket fuel slug shall be immersed in sodium for thermal bonding with the cladding.

5) The cladding shall provide structural integrity for the blanket rod and serve to separate the blanket fuel from direct contact with the coolant, thereby preventing the fission products from entering the primary coolant.

6) A fission gas plenum shall be located above or below the blanket fuel slug and sodium bond as a reservoir for gaseous fission products produced during irradiation.

7) The blanket fuel rods shall be equipped with a spacer to maintain the clearance between rods.

8) The blanket rod should provide axial shielding, typically at the bottom end, to protect the core support structure from fast neutron damage.



(a) alloy type (b) dispersion type

Figure 4. Schematic of the HYPER Blanket Fuel rod.

6.3 Blanket assembly

Configuration and essential features that apply to the reactor core subsystem of the reactor system are as follows:

1) The handling head of the assembly can be of the female type, depending on the design of the fuel-handling machine and owing to better self-alignment capability.

2) Flow tube structure shall be designed such that it supports the mass of the blanket assemblies, directs coolant to their rod bundles, and prevents hydraulic lift-off of the assemblies.

3) Blanket assemblies shall be positioned in a flow tube to channel the coolant flow and provide a degree of isolation of the assembly from adjacent assemblies to protect the blanket elements, and to restrict failure propagation.

7. Seismic Requirements

The blanket assemblies shall be designed as seismic category I[1]. The assemblies shall be designed to permit continued operation through OBE (operating basis earthquake) seismic events. The blanket fuel assemblies shall be seismically qualified to a design basis earthquake of TBD (0.22g) horizontal ground acceleration. The assembly and the components shall maintain their structural integrity during and after design basis earthquake. The seismic qualification of the blanket fuel assemblies shall be limited to verifying structure soundness only, i.e., stress encountered during a design basis earthquake shall be less than 70 % of the yield limit.

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1) Seismic category I : structures which have safety related functions

8. Structural Requirements

8.1 Blanket rod

Ferritic-martensitic steel has been chosen as the reference cladding material for the HYPER blanket fuel because of its demonstrated low-swelling characteristics at neutron fluence of interest to the HYPER program.

The structural design requirements for the blanket rod are determined by cladding integrity aspects. These requirements are explicitly embedded within the operational and reliability requirements. Appropriate limits to cladding cumulative damage fraction (CDF) and cladding strain provide the structural evaluation criteria to assure satisfaction of the high level reliability and performance requirements defined in the prior sections.

8.2 Blanket assembly

The structural design requirements for blanket assembly are explicitly embedded within the operational and reliability requirements. The structural material characteristics are determined by the "Nuclear Systems Materials Handbook" and the "Alloy Properties Databook". Appropriate limits to assembly dilation and bowing, and restraint contact forces provide the structural evaluation criteria to assure satisfaction of the high level reliability and performance requirements defined in the prior sections.

Dilation of the hexagonal assembly is an important factor during the operational lifetime of fuel assemblies in the core. It is caused by the irradiation-enhanced creep, void swelling and thermal gradient of the hexagonal array material. Excessive assembly dilation should be minimized to accomodate removal from the core and storage where the grid size of the storage basket is limited. Therefore, it is important to determine the hexagonal assembly dilation behavior to guide the design and in-core management of the fuel assemblies in a way that excessive assembly deformation can be avoided.

9. Environmental Requirements

The effects of environmental factors can cause substantial changes in the response and failure properties utilized by the Code. In extreme circumstances the environmental effects may change the material properties to the extent that the premises upon which the design process is based may be rendered invalid. A normally ductile material may exhibit characteristics that are associated with brittle materials. Clearly, the effects of the environment must be considered in the design process.

There are at least three different types of environmental effects :

(1) loss of structural material by erosion or corrosion,

(2) introduction of failure modes not explicitly addressed by code design rules (such as stress corrosion), and

(3) modification of mechanical and physical properties (such as a loss in fatigue strength or a loss in creep rupture strength).

9.1 Objective

The objective should be to assure that the minimum levels of assured structural integrity provided by the Code rules or a benign environment remain intact during the specified service lifetime. That is, that the minimum levels of assured structural integrity established by the Code rules and limits for service in a relatively benign environment(air) should be maintained in the actual service environment.

9.2 Environmental effects

9.2.1 The compatibilities of sodium-materials and LBE-materials

The largest problem areas in the compatibility field are metallic mass transfer, carbon transfer, mechanical property effects, sodium cleaning, and sodium-water reaction studies. The solution aspect of mass transfer produces wall thinning and changes in surface composition, principally at the hot end of the fuel cladding; the deposition aspect can cause heat transfer fouling and, in the case of activity transfer, access limitations. Carbon transfer is more penetrating and can significantly affect mechanical properties of structural and cladding materials. The effect of sodium environment on the long-term creep and fatigue behavior of structural alloys must be determined. Damaging interactions with impurities carried by sodium may limit the potential use of refractory alloys as fuel cladding.

For fuel cladding materials, the combination of thin wall, high temperature, and high stress creates different compatibility problems. Radiation and thermal effects may prove more limiting to stainless steel cladding than the compatibilities of sodium-materials and LBE-materials.

Several distinct problems arise from metallic mass transfer: corrosion reduces wall thickness of fuel cladding and other in-core structures and releases radionuclides to the sodium. Preferential removal of elements promotes precipitation and phase changes (ferrite layer) in stainless steel and may set up activity gradients that cause carbon and nitrogen transfer. The degradation of properties of stainless steels at high temperatures will be aggravated by any loss of effective load-carrying section thickness.

9.2.2 Irradiation

Changes in material properties may occur due to environmental effects. In particular, fast neutron irradiation above a certain energy level ($E > 0.1$ MeV) may result in significant increase in the brittle fracture transition temperature and deterioration in the resistance to fracture at temperatures above the transition range.

Since an ADS(accelerate driven system) is operated in the high neutron irradiation environment, HYPER core shall have a concept of shielding end cap and ferritic-martensitic steel solid end cap, and so on by the above criterion.

9.2.3 Corrosion

Material subject to thinning by corrosion, erosion, mechanical abrasion, or other environmental effects shall have provision made for these effects during the design or specified life of the component by a suitable increase in or addition to the thickness of the base metal over that determined by the design formulas. Material added or included for these purposes need not be of the same thickness for all areas of the component if different rates of attack are expected for various areas.

9.2.4 Mechanical design criteria

Forces resulting from the flow of coolant or mechanical wear during any mode of normal operation or event shall not cause deformations (including fuel geometry disruption) that could prevent sufficient core cooling. The reduction of the yield strength due to environmental effects can significantly reduce the Code's design margin for failure modes. The effect of the service environment on the 0.2% offset yield strength should be limited to a 10% reduction of the original value at all service temperatures. The loss in yield strength should be evaluated over the entire temperature range of service. Since gross plastic deformation and plastic ratchetting involve the entire cross-section, the reduction in yield strength due to the service environment should be determined on a cross-section-averaged basis.

- Enhancement of the yield strength due to the effect of the service environment would reduce the design margin in the Code elastic creep-fatigue evaluation procedure.
- The design limits and procedures should be reviewed to assure

that the intended design margins remain intact when the environment produces a 10% change in the yield strength.

9.3 Blanket rod and assembly

9.3.1 Flow blockage prevention

The reactor internals and blanket assemblies shall be designed to minimize the potential for flow blockage or flow restriction sufficient to exceed fuel damage limits in one or more by loose parts or by core assembly loading errors sufficient to cause blanket rod failures.

The design shall consider service temperatures, service degradation of material properties, creep, fatigue, and etc. under normal operating and accident conditions.

9.3.2 Environmental and dynamic effects design bases

Blanket fuel assembly and its components which are important to safety, shall be designed to accommodate the effects of and to be compatible with the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents.

9.3.3 Operation condition

The blanket assemblies that will be surrounded by the primary cooling system sodium shall have sufficient corrosion resistance during its resistance time. Their environmental conditions shall be as follows:

- Medium : sodium or LBE
- Coolant flow velocity : TBD
- Pressure : TBD
- Temperature : up to 510 ℃ (bulk outlet)
- Max. fast neutron fluence : $<$TBD ($4.0\times10^{23} n/cm^2$)($E>0.1MeV$)

9.3.4 Fresh blanket fuel

The fresh blanket assemblies will be located in a storage area under the following conditions:

- Medium : air
- Pressure : 1 atmospheric
- Temperature : 10 to 50 ℃
- Humidity : 95% max.

9.4. Blanket fuel storage, handling and radioactivity control

9.4.1 Blanket fuel storage

Fresh blanket assemblies shall be located vertically in a storage area in air between 10 ℃ and 50 ℃ and with a relative humidity of 95 % maximum.

The blanket fuel storage, handling, radioactive waste, and other systems which may contain radioactivity shall be designed to assure adequate nuclear safety under normal operation and design basis accident conditions. These systems shall be designed :

(1) to permit periodic inspection and testing of nuclear safety-related components.

(2) with suitable shielding for radiation protection.

(3) with appropriated containment, confinement or filtering systems.

(4) with a residual heat removal capability having nuclear safety-related function reliability and testability.

(5) to retain adequate fuel storage coolant inventory under accident conditions.

9.4.2 Prevention of criticality in fuel storage and handling

Criticality in the fuel storage and handling system shall be prevented by physical systems and processes, preferably the use of geometrically safe configurations.

9.4.3 In-vessel storage

The irradiated blanket fuel shall be kept in the core storage racks for one cycle until it has decayed enough to be transferred to the long-term storage bay.

In-vessel(reactor) storage of spent fuel and blanket assemblies equivalent to one reload batch (fuel and blanket assemblies replaced at a normal refueling outage) shall be provided.

On-site storage space shall be sufficient to completely unload the fuel and blanket assemblies from one reactor.

10. Reliability and Safety

10.1 Blanket rod

For the analysis of reliability and safety for the HYPER blanket fuel rod, different concepts shall be used between the DBEs (design basis events) and the BDBEs (beyond design basis events).

In the conditions of steady state and DBEs, the conservative analysis method shall be applied. The followings are the requirements on the evaluation of the fuel temperatures, reliability and integrity for the blanket rods :

1) It is required by the safety criteria for the HYPER designs to maintain blanket fuel integrity not only during normal operation but also during anticipated transients.

2) The +2 sigma environmental conditions and TBD (115%) overpower should be assumed at the prediction of fuel rod temperatures.

3) The cladding strains should be calculated using conservative equations for thermal creep and tensile properties, and considering the worst cases, such as hot channel fuel rod temperatures, peak fission gas release, and cladding thickness considering conservative wastage allowance.

4) The blanket rod cladding stresses should be calculated by the considerations of the worst case fission gas release and reduction of cladding thickness due to chemical attack.

In the case of BDBEs conditions, best engineering estimates (nominal analyses) shall be used to evaluate the events. It also shall be shown by the analyses that the fuel integrity is fully maintained during the BDBEs without exceeding fuel rod damage limits, and with having sufficient safety margins. The requirements on the evaluation of reliability and safety for blanket fuel rods during BDBEs are as follows :

1) The initial conditions of the BDBEs analyses should be used by the worst case of steady state conditions, such as end-of-life condition, hot spot temperatures and the worst case of fission gas release.

2) During BDBEs, the nominal values of the event conditions and property correlations may be used in the analyses of blanket rod integrity.

3) In the case of temperature conditions, 2 sigma value should be used to accommodate the uncertainties instead of nominal values.

10.2 Blanket assembly

The blanket assembly shall be designed and irradiated in a manner which avoids gross overpower operation, and which shall maintain the integrity of the blanket assembly with minimum release of radioactive material. Radioactivity releases from the blanket assembly will be minimized by design and operation to ensure that resultant radiation doses are as low as reasonably achievable, and that individual dose limits are not exceeded.

Although all major problems are currently being addressed, much research remains to be performed in order to establish the safety and reliability of the specific blanket concept to the burnups planned. The data base to support the blanket assembly to be used in the HYPER design needs to be developed. The data are needed to support the establishment of the fuel design limits and the fuel damage limits for licensing, and for the validation of the analytical tools for licensing evaluations.

11. Standard and Codes

Nuclear safety-related fuel assembly shall be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the nuclear safety functions to be performed. Where generally recognized codes and standards are used, they shall be identified and evaluated to determine their applicability, adequacy, and sufficiency and shall be supplemented or modified as necessary to assure a quality product in keeping with the required nuclear safety functions.

Blanket fuel system is classified as safety-grade. The nuclear industry standard, ANSI/ANS-54.1-1989 was written to establish general design criteria (GDC) for large-loop and pool type LMRs as well as small modular reactors. The standard was developed with the emphasis placed on retaining the GDC wherever the criterion is applicable to the ADS design. Thus the design standard proposed by ANSI/ANS-54.1-1989, "General Safety Design Criteria for a Liquid Metal Nuclear Power Plant" may be specific guidance of the components design of the HYPER. These design criteria supplement the required design criteria contained in 10 CFR Part 50, Appendix A.

Any components in the reactor coolant pressure boundary (RCPB) in the HYPER shall be designed and constructed to be applicable sections of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code and Code Case. Because of the low operating pressure and high operating temperatures and because the RCPB components are fabricated of highly ductile stainless steel material, the potential for rapidly propagating failure of the RCPB is considered to be negligible.

The design of mechanical system and components includes specifying and complying with the analytical methods used for all components and components supports covered by the American Society of Mechanical Engineers, Boiler and Pressure Vessel Code Class 1, 2 and 3.

In the ASME code, Class 1 components and component supports are categorized as low-temperature components or elevated-temperature components, and are described by components operating conditions and design loading conditions, design stress and pressure limit, analytical and empirical methods for design of pumps and valves, and design and installation criteria for pressure-relieving device, components and piping supports.

12. Quality Assurance Programs

In this chapter, the applicant should provide a description of the QA program to be established and executed during the design of the blanket fuel system for HYPER. The QA program must be established at the earliest practical time consistent with the schedule for accomplishing the activity.

12.1 Quality assurance during design

12.1.1 Organization

12.1.1.1 Design documents including a preliminary safety analysis report (PSAR) should describe clearly the authority and duties of persons and organizations performing quality assurance (QA) functions of assuring that the QA program is established and executed or of verifying that an activity has been correctly performed.

12.1.1.2 Design documents should describe those measures which assure that persons and organizations performing QA functions have sufficient authority and organizational freedom to

(1) identify quality problems,

(2) initiate, recommend, or provide solutions, and

(3) verify implementation of solutions.

Design documents should describe the measures which assure that persons and organizations assigned the responsibility for checking, auditing inspecting, or otherwise verifying that an activity has been corrected performed report to a management level such that this required authority and organizational freedom, including sufficient independence from the pressures of production, are provided. Irrespective of the organizational structure, the design documents should describe how the individual or individuals with primary responsibility for assuring effective implementation of the QA program at any location where activities subject to the control of the QA program are being performed will have direct access to such levels of management as may be necessary to carry out this responsibility.

12.1.1.3 Design documents should describe the extent to which the applicant will delegate to other contractors the work of establishing and executing the QA program or any part thereof. A clear delineation of those QA functions which are implemented within the applicant's QA organization(s) and those which are delegated to other organizations should be provided in the design documents. The documents should described the method by which the applicant will retain responsibility for and maintain control over those portions of the QA program delegated QA functions are properly carried out. The PSAR should identify major work interfaces for activities affecting quality and describe how clear and effective lines of communication exist between the applicant and his principal contractors to assure necessary coordination and control of the QA program.

12.1.2 Quality assurance program

12.1.2.1 The QA program in the PSAR should cover each of the criteria in Appendix B to 10 CFR Part 50 in sufficient detail to permit a determination as to whether and how all of the requirements of Appendix B will be satisfied.

12.1.2.2 The safety related structures, systems, and components to be controlled by the QA program should be identified in the PSAR.

12.1.2.3 The PSAR should describe the measures which assure that the QA program is being established at the earliest practicable time consistent with the schedule for accomplishing activities affecting quality for the project, that is, the PSAR should describe how the QA program is being established in advance of the activity to be controlled and how it will be implemented as the activity proceeds. Those activities affecting quality initiated prior to the submittal of the PSAR, such as establishing information required to be included in the PSAR, design and procurement, and safety-related site preparation activities should be identified in the PSAR. The PSAR should describe how these activities are controlled by a QA program which complies with the statements in 10 CFR Part 50, Appendix B.

12.1.3. Design control

12.1.3.1 The PSAR should describe the design control measures which assure that

(1) applicable regulatory requirements and design bases for safety-related structures, systems, and components are correctly translated into specifications, drawings, procedures, and instructions,

(2) appropriate quality standards are specified in design documents, and

(3) deviations from such standards are controlled.

12.1.3.2 The PSAR should describe the measures for applying design control to such aspects of design as reactor physics; stress, thermal, hydraulic, and accident analysis; materials compatibility; and accessibility for maintenance, in-service inspection, and repair and should describe measures for delineation of acceptance criteria for inspects and tests.

12.1.3.3 The PSAR should describe measures which assure verification or checking of design adequacy, such as design reviews, use of alternative calculational methods, or performance of a qualification testing program under the most adverse design conditions. The PSAR should identify the positions or organizations responsible for design verification or checking and should describe measures which assure that the verifying or checking process is performed by individuals or groups other than those who performed the original design, but who may be from the same organization.

12.1.3.4 The PSAR should describe measures for identifying and controlling design interfaces, both internal and external. and for coordination between participating design organizations. The PSAR should describe measures in effect between participating design organizations for review, approval, release, distribution, collection, and storage of documents involving design interfaces and changes thereto. The PSAR should describe how these measures will assure that these design documents are controlled in a timely manner to prevent inadvertent use of superseded design information.

12.1.4. Procurement document control

12.1.4.1 The design documents should describe measures assure that documents, and changes thereto, for procurement of material, equipment, and services, whether purchased by the applicant or by his contractors or subcontractors, correctly include or reference the followings as necessary to achieve required quality:

(1) Applicable regulatory, code, and design requirements.

(2) Quality assurance program requirements.

(3) Requirements for supplier documents such as instructions, procedures, drawings, specifications, inspection and test records, and supplier QA records to be prepared, submitted, or made available for purchaser review or approval.

(4) Requirements for the retention, control, and maintenance of supplier QA records.

(5) Provision for purchaser's right of access to suppliers' facilities and work documents for inspection and audit.

(6) Provision for supplier reporting and disposition of non-conformances from procurement requirements.

12.1.5 Instructions, procedures, and drawings

12.1.5.1 Design documents should describe measure that assure that activities affecting quality such as design, procurement, manufacturing, construction and installation, testing, inspection, and auditing are prescribed by appropriately documented instructions, procedures, or drawings and that these activities will be conducted in accordance with the documented instructions and procedures.

12.1.5.2 The PSAR should describe the system whereby the documented instructions and procedures will include appropriate quantitative (such as dimensions, tolerances, and operating limits) and qualitative (such as workmanship samples and weld radiographic acceptance standards) acceptance criteria for determining that prescribed activities been satisfactorily accomplished.

13. Other Requirements

Other requirements for blanket fuel assembly design, which are not defined by the above requirements, are described in this section. The additional requirements can contain several items such as the research activities, database of operational experiences, further safety features and the modified design concept. Testing and inspection of new blanket fuel is performed by the licensee to endure that the fuel is fabricated in accordance with the design and that it reaches the plant site and is loaded in the core without damage.

13.1 Fuel transfer

Fresh blanket assemblies are placed into a fuel transfer cask (FTC), and transported to the reactor module to refuel its core. With the gate valve on the transfer adaptor closed, the enclosure access doors are opened and the FTC is position within the enclosure and by the cask transporter connected to the gate valve. Fresh blanket assemblies are moved from the FTC to the transfer station within the reactor vessel by the cask bi-stem drive mechanism. Within the reactor, the assemblies are moved between the core, storage racks, and transfer station by the IVTM. Spent blanket assemblies are transferred from the core to in-vessel storage rack where they reside for one reactor operating cycle.

13.2 Fuel handling and Inspection

Inspection of fresh blanket fuel assembly should include the following activities. These inspection are performed remotely in the FHC (fuel handling cell):

1) Verify assembly identification by means of visual and mechanical examination of the assembly serial number and notches.

2) Visually examine to verify absence of dents, nicks, and/or gouges,

especially in the area of hexagonal corners, and the discriminator post.

3) Visually examine the top of a rod bundle and the inlet nozzle to verify the absence of foreign objects or material. A flow test using inert gas should also be performed to determine gross blockage in assemblies.

4) In the event that defects are observed during the examination, additional inspections should be performed which will include photographing surface defect and performing selective dimensional inspection of external defects for record purposes.

The assemblies will be transferred into the FHC after successful completion of prescribes inspections. Unacceptable core assemblies will be transferred into the FHC and later transferred to a reactor module.

13.3 Core assemblies receiving, storage, and shipping

The spent fuel assemblies located in the in-vessel storage positions are also included with the core unloading. At low level of decay heat, the blanket fuel assemblies are transferred directly to the FHC for storage, without active cooling, before being transferred to the central fuel cycle facility for reprocessing. Equipment and instrumentation are provided for cooling, assembly temperature monitoring, and leak detection. The assemblies can be transferred to the FHC without any in-vessel storage because of their low decay power.

The FSF includes the capability to receive, unload, inspect, and store fresh blanket assemblies before their loading into the reactor and to transfer spent core assemblies to a central fuel cycle facility. The main components or areas within the FSF for receiving, storage, and shipping of blanket assemblies are :

1) Storage for fresh and spent blanket assemblies located in the FHC.

2) Storage in the FHC for the unloading of one reactor core.

3) A fuel transfer cell that provides the means for transferring blanket assemblies between the FTC and FHC.

4) The receiving area where trucks are unloaded.

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Abstract (About 300 Words)

This document describes design requirements which are needed for designing the blanket assembly of the HYPER as design guidance. The blanket assembly of the HYPER consists of blanket fuel rods, mounting rail, spacer, upper nozzle with handling socket, bottom nozzle with mounting rail and skeleton structure. The blanket fuel rod consists of top end plug, bottom end plug with key way, blanket fuel slug, and cladding. In the assembly, the rods are in a triangular pitch array. This report contains functional requirements, performance and operational requirements, interfacing systems requirements, core restraint and interface requirements, design limits and strength requirements, system configuration and essential feature requirements, seismic requirements, structural requirements, environmental requirements, reliability and safety requirements, standard and codes, QA programs, and other requirements for the blanket fuel assembly of the HYPER.

Subject Keywords (About 10 Words) : blanket fuel, design criteria, fertile materials, HYPER, design limits, fuel integrity, fuel assembly, TRU-Zr alloy.

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초록(300단어 내외)

본 문서는 HYPER용 블랑킷집합체의 설계에 필요한 길잡이로써 전반적인 설계요건을 기술하였다. HYPER 블랑킷집합체는 블랑킷연료봉, 탑재선로, 간격체, 취급소켓이 부착된 상부노즐, 탑재선로가 부착된 하부 노즐, 노즐연결지지체로 구성된다. 블랑킷봉은 상부봉단마개, key way가 부착된 하단봉단마개, 블랑킷연료심 및 피복관으로 구성된다. 블랑킷집합체내의 블랑킷봉은 삼각배열로 다발을 이룬다. 본 보고서에는 블랑킷 연료집합체에 대한 기능적 요건, 성능 및 운전요건, 인접계통 요건, 노심 연계요건, 설계한계 및 강도 요건, 계통배열 및 필수특징적 요건, 지진시 요건, 구조적 요건, 환경적 요건, 신뢰도안전 요건, 표준 요건, QA 요건 및 기타 요건 들을 기술하였다.

주제명 키워드 (10단어 내외) : 블랭킷연료, 설계기준, 친핵분열성물질, HYPER, 설계한계, 연료건전성, 연료집합체, TRU-Zr 합금.