EFIT: THE EUROPEAN FACILITY FOR INDUSTRIAL TRANSMUTATION OF MINOR ACTINIDES

Barbensi Andrea[a], Corsini Giovanni[a], Mansani Luigi[a], Artioli Carlo[b], Glinatsis Georgios[b]

[a]*Ansaldo Nucleare S.p.A., Corso Perrone 25, IT-16161 Genova, Italy, luigi.mansani@ann.ansaldo.it*
[b]*ENEA, Via Martiri di Montesole 4, IT-40129 Bologna, Italy, georgios.glinatsis@bologna.enea.it*

Within the EURATOM Sixth Framework Program, the EUROTRANS integrated project, funded by the European Community, is expected to provide a significant contribution to the demonstration of the industrial transmutation through the Accelerator Driven System route. The goal will be reached through the realization of a detailed design for an experimental facility of 50 to 100 MWth power which shows the technical feasibility of transmutation in an ADS (XT-ADS, and, the development of a conceptual design of a generic European Transmutation Demonstrator of several hundreds of MWth, to be realized in the long term to generate electric energy. For this conceptual design, called EFIT (lead-cooled European Facility for Industrial Transmutation), fuelled with Minor Actinides (U-free fuel), the main design options to overcome the limits of previous ADS projects, particularly as concerns the economic aspects, maintaining meanwhile the high safety level and guarantee high reliability and low investment risks, have already been identified.

The preliminary version of EFIT, designed on the basis of the experience acquired in the previous PDS-XADS project, is presented. The use of pure lead instead of LBE as the primary coolant, the higher power density and primary temperatures are the features for compactness and efficient energy generation.

I. INTRODUCTION

In the frame of the project IP EUROTRANS[1] of the 6th Framework Programme (FP) of the European Union (EU), 51 European Organizations have the strategic R&D objective to pursue an European Transmutation Demonstration (ETD). The aim of the 4-years lasting program, funded by the European Community, is twofold:

- Develop the conceptual design of an European Facility for Industrial Transmutation (EFIT) with a pure-lead cooled reactor of several hundreds MW with considerable Minor Actinides (MA) burning capability and electricity generation at reasonable cost. The design will be worked out to a level of detail which allows a study cost estimate.
- Carry out the detailed design of the smaller XT-ADS[2] (eXperimental Transmutation in an Accelerator Driven System (ADS)), as irradiation facility to be constructed in the short-term. The XT-ADS is also intended to be as much as possible a test facility for the main components and for operation of EFIT, at the lower working temperatures allowed by the use of the Lead-Bismuth Eutectic (LBE) as the primary coolant and spallation target material.

EFIT is being designed as a transmutation demonstrator, loaded with MA fuel. It is intended to become operational many years after the XT-ADS (around 2040) and therefore to profit of the experience gained from the running European Research an Development (R&D) programs on fuel and materials and of the operation of the XT-ADS, which is to be built and operational in the near future (about eight years from the start of the IP_EUROTRANS project).

II. THE EFIT PROJECT

EFIT is an industrial-scale transmutation facility, the characteristics of which are efficiency of transmutation, simple operation and maintenance, and high availability in order to achieve effective MA transmutation and electric energy generation at reasonable cost. The EFIT description is given below by main design areas.

II.A. Core

The core design approach is as follows. Starting from the Pu and MA vectors, which are the nuclides deriving from reprocessing the spent fuel of Light Water Reactor (LWR) used for the U-free fuel of EFIT, a preliminary ratio of MA nuclides to all nuclides is determined that brings about a burn up reactivity swing of a few hundreds pcm/cycle or less ($\Delta K \approx 100$ pcm/cycle) without burning or breeding Pu. For the case of $\Delta K \approx 0$ and Pu breeding ratio ≈ 1, this means that reactor operation, intended as combined operation of sub-critical core and spallation neutron source, takes place at constant proton beam current over each cycle and that, at the end of each fuel cycle, the new fuel can be fabricated by adding fresh MA only to the reprocessed fuel of the previous cycle. The requirement of nearly zero burn up reactivity swing is dictated by the wish not to have to heavily rely on the proton beam for the generation of extra spallation neutrons for burn up reactivity swing compensation and this gives the designer the freedom to tailor the accelerator for a narrower range of proton beam current and to avoid over sizing. The choice of Pu breeding ratio ≈ 1 implies that Pu is required for the first fuel only, a feature that limits to a minimum Pu handling and does not contribute to pile-stocking in times of surplus of Pu, considering also that Pu can be advantageously fissioned in (possibly new-generation) fast reactors, all facilities that are predictably less expensive than EFIT. To obtain high transmutation rates and Pu breeding ratio ≈ 1 an content in Pu of 45.7%, defined as the ratio (in weight) between the amount of its nuclides and the sum of them with MA (= total fuel), has been used.

The EFIT core is being designed[3] for a thermal power of about 400 MW, aiming at performance and radial power flattening. In order to flattening the radial power distributions a 3 fuel zone core has been selected. In the intermediate zone is placed fuel with 50% MgO matrix content and suitable pin diameter and pitch (to maximize the power density and to minimize the core pressure losses). In the inner zone the fuel content is lowered increasing the MgO content up to 57% and in the outer zone is placed fuel with the same composition of intermediate zone but with increased pin diameter to increase the total fuel amount. This permits to work with a high maximum and average power density (max for each homogeneous zone 98.7, 94.5 and 95.6 W/cm^3 and homogeneous average 70,7 W/cm^3 = 303.1 W/cm^3 for the fuel material) and, as a consequence, high burn up (about 78,3 MWd/kg). This result can be obtained while respecting present technological limits such as the maximum allowable temperature for pellet (about 1380°C) and clad (550°C) integrity. The specific burning rate (mass of fissioned MA per TWh generated energy) is around 42 kg MA/TWh, "42-0 approach"[3]. The fuel content in Pu selected keeps the reactivity swing, along the fuel cycle, as low as few hundreds pcm (200 pcm). The selected U-free oxide fuel in a MgO matrix (a metallic ^{92}Mo matrix is retained as backup option) has permitted to obtain a MAs and Pu burn up of 13.9% and 0.7% respectively for the 3 year cycle, see Fig. 1.

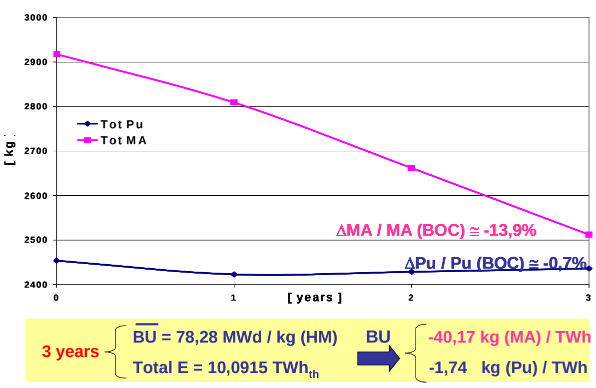

Fig. 1. MA and Pu evolution during the fuel life.

Fig. 2. shows the radial flux distribution (at middle core elevation) for BOC and EOC. The external neutron source is provided through the spallation process where protons of 800 MeV energy impinge on a Pb target. About 23 neutrons (instead 3.10 neutrons / fission event) have being obtained for each proton. The spatial, energy and angular distributions of the source neutrons is obtained by MCNPX[4] code.

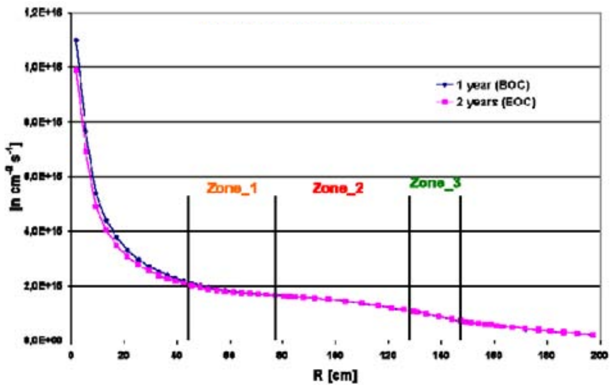

Fig. 2. Radial flux profile at BOC and EOC.

The whole system (target and core) has been modeled by MCNP code in a very detailed 3D model for BOL, BOC and EOC calculation, while the burn up history has been evaluated with ERANOS[5] codes system having in input the neutron source from MCNPX code (source defined as made up of neutrons born in the system with energy less than 20 MeV).

The EFIT core is made of 180 hexagonal Fuel Assemblies, with 169 pins (168 fuel pins) each; the active length is 90 cm, the equivalent inner and outer radius are 43.7 cm and 151.5 cm respectively.

Because EFIT is an hybrid reactor controlled by the spallation neutrons, it must be ensured that the core remains always sub-critical, without having to rely on shutoff or control rods. The margin to criticality is an important requirement for the core definition that leads, eventually, to define core size and reactor power.

The operating subcriticality level has been chosen in accordance to the following requirement:

- the reactor core shall be designed so that it remains subcritical under all plant conditions, namely Design Basis Conditions (DBC) and Design Extension Conditions (DEC).

Subcriticality is a safety requirement of paramount importance, since the ADS has to be designed without shutoff or control rods. Analyses of the 80 MW LBE-cooled eXperimental ADS (XADS), a previously designed ADS[6], have determined the range of the effective multiplication factor (K_{eff}) for normal operation, transient and accident conditions. The maximum K_{eff} for the XADS core at full power and Beginning of Life (BOL) has been determined as 0.97, a value that strictly holds for the XADS only. For EFIT, the determination of the K_{eff} range that ensures the compliance with the subcriticality requirement is still outstanding. This determination will not be a *da-capo* design activity, however, since the same core design approach can be adopted and the results of XADS, adjusted occasionally in consideration of the EFIT peculiarities, can be reasonably assumed as starting data for the iteration process.

It is assumed that a margin of 0.016 ΔK to criticality, a figure that includes allowance for measurement errors, be required at DBC, akin to standard practice for light water reactors. K_{eff} shall hence not exceed 0.984 at any time during DBC. It is further assumed that a thinner margin is acceptable for DEC, owing to their postulated very low frequency, and that K_{eff} shall not be greater than 0.95 during Refuelling or Target Unit removal for replacement. Fig. 3. illustrates these safety criteria showing that at no time Keff shall move into the red regions, which represent the margins to criticality allocated to the three mentioned conditions. The green region covers the range of K_{eff} allowed for normal operation. The yellow regions cover the excursion ranges of K_{eff} predicted by the transient analyses for DBC and DEC respectively. Because completion of design is outstanding and the transient analyses will follow, both regions are depicted, but not figured out. As starting point for the design K_{eff} = 0.97 has been preliminary assumed for EFIT as the maximum value for the nominal full power conditions (upper limit of the green region).

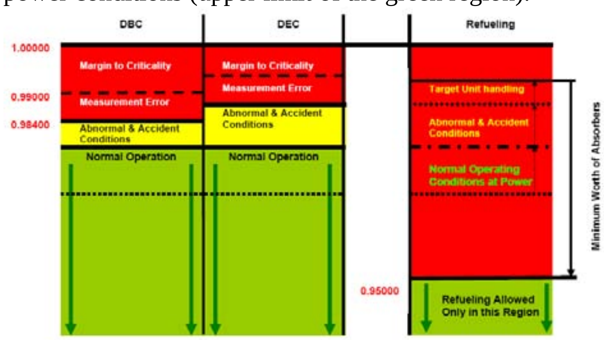

Fig. 3. Safety Criteria (required subcriticality margins) for DBC, DEC, Refueling and Target Unit Handling

II.B. Target Unit

The Target Unit constitutes the physical and functional interface between the accelerator complex (LINAC[7] type accelerator has been chosen for EFIT) and the core of EFIT. The spallation neutrons are generated in the Target Unit by interaction of the high energy proton beam with lead as the liquid target, which is kept in forced circulation inside the Target Unit. The Target Unit is a slim mechanical component of cylindrical shape, positioned co-axially with the reactor vessel and the core and hung to the reactor roof. Because it serves also as inner radial restraint of the core, the outline of its outer shell fits the inner outline of the core. Its main component parts are the Proton Beam Pipe, the Heat Exchanger and the two axial-flow pumps arranged in series in the vertical legs of the loop, upstream and downstream the target region, respectively (Fig. 4.). The proton beam travels *in vacuo* and the mid point of its penetration depth (estimated 43 cm for a proton beam energy of 800 MeV) in the target lead matches the mid plane of the core. The target lead transfers the deposited energy to the primary lead via the heat exchanger of the target unit.

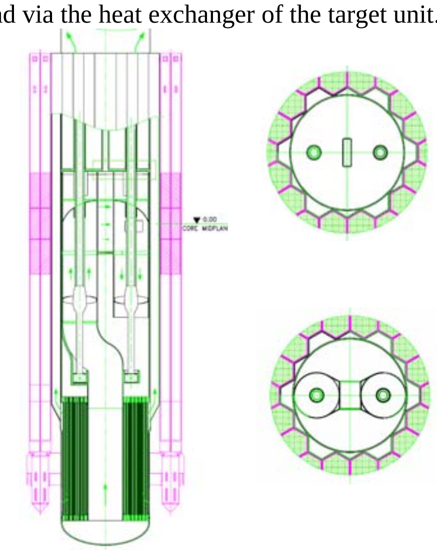

Fig. 4. Target Unit

The spallation products are kept confined in the Target Unit. Neutron back-streaming through the beam pipe is minimised by the small cross section and shape of the vacuum pipe and the narrow clearances of the mechanical structure, in order to limit the associated dose rate and the activation of the structures above the reactor roof. Because the heat source is at the top of the loop and hence a natural circulation is not possible, lead circulation is forced by means of two axial-flow pumps in series, fed by independent power supplies, in order to ensure circulation by at least one pump in case of failure of the companion pump. Limitation of erosion is ensured by a speed of lead of less than 2 m/s, except for the blades of the propellers for which the higher relative speed requires erosion-resistant construction materials. Promising candidate materials are programmed for testing in the frame of R&D activities. This material issue is common to the propeller blades of the primary pumps.

II.C. Primary System

The configuration of the primary system is pool-type, similar to the design adopted for most sodium-cooled reactors and for the previous XADS[8] design (Fig.s 5 to 8). All the primary coolant is contained within the Reactor Vessel, a cylindrical shell with hemispherical bottom head and top Y-piece, both branches of which terminate with a flange. The conical, outer branch is flanged to, and hangs from, the Annular Structure anchored to the civil structure of the Reactor Cavity, whereas the inner branch supports the reactor upper closures. Temperature and temperature gradient of the outer branch of the Y-piece can be kept low by adequate thermal insulation.

Key components for reactor operation at power are the Primary Pumps (PP) and the Steam Generators (SG). Four identical groups of these components are provided, each comprising two SGs, one PP in-between, piping for hot coolant circulation and a Casing at the SGs top, that encloses the coolant and direct it to the SGs. Thus the hot coolant region within the Reactor Vessel is rather small, being delimited by the Inner Vessel, the four PPs, suction and discharging piping and of the four regions enclosed by the four Casings. The cross section of the Casings is kidney-shaped, because the component groups are located in the annular region between Inner Vessel and Reactor Vessel. The free level of the hot pools inside the Casings is higher than the free level inside the Inner Vessel, whereas the free level of the cold pool is in-between the two hot pool levels, the different heads depending on the pressure losses across primary circuit component.

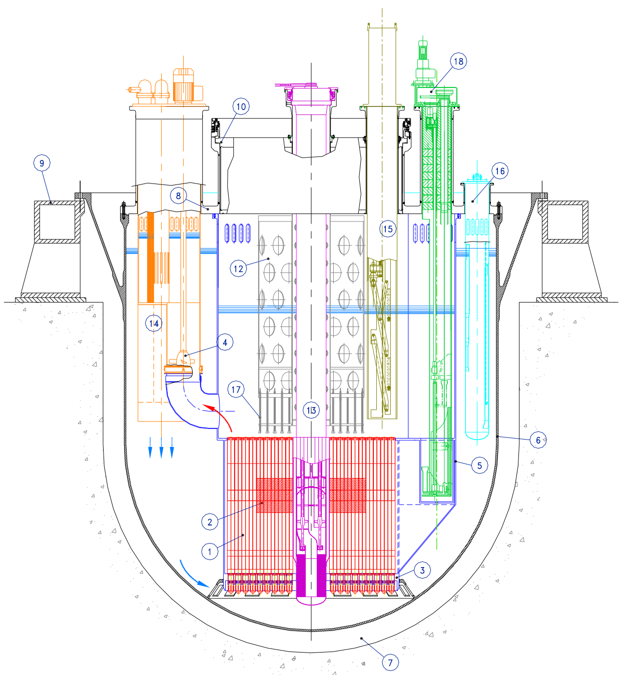

Fig. 5. EFIT Primary system assembly: vertical section
(1 Reactor Core, 2 Active Zone, 3 Diagrid, 4 Primary Pump, 5 Cylindrical Inner Vessel, 6 Reactor Vessel, 7 Reactor Cavity, 8 Reactor Roof, 9 Reactor Vessel Support, 10 Rotating Plug, 12 Above Core Structure, 13 Target Unit, 14 Steam Generator, 15 Fuel Handling Machine, 16 Filter, 17 Core Instrumentation, 18 Rotor Lift Machine, 19 DRC Dip Cooler)

Decay Heat Removal (DHR) is provided by four independent loops filled with organic, diathermic fluid, that dissipate the decay heat to the atmosphere by natural convection. Detailed description of the safety-grade DHR is provided in Section II.D.

The Safety Vessel, surrounding the Reactor Vessel, is essentially a liner anchored to the reactor vault, with back cooling; in case of reactor vessel leak, the resulting primary coolant free level stabilizes above the top of the core as well as of the SGs and DHR heat exchangers to preserve the core cooling function.

Unlike previous designs, the primary system features pure lead as the coolant, which is characterized by good nuclear properties and no fast chemical reaction with water and the organic diathermic fluid of the safety-grade DHR system. There is a significant experience on metal-cooled fast reactors that is the result of past and current work on sodium-cooled fast reactors (e.g. Superphenix) and, in addition, a substantial effort is also being carried out in the use of the LBE technology in sub-critical reactors. It is a natural development to select pure lead as a coolant for EFIT since it is much cheaper, more abundant, and presents a substantially lower radiological concern than LBE. Lead tends to retain hazardous radio-nuclides, even in the event of a severe accident involving extensive fuel damage. Moreover the rate of Polonium production is 3-4 orders of magnitude lower than in case of LBE. Further, heavy metals have the advantage that, in the hypothetical case of a core disruption accident, core compaction scenarios, which might cause the insertion of large amounts of reactivity in a short time, are unlikely.

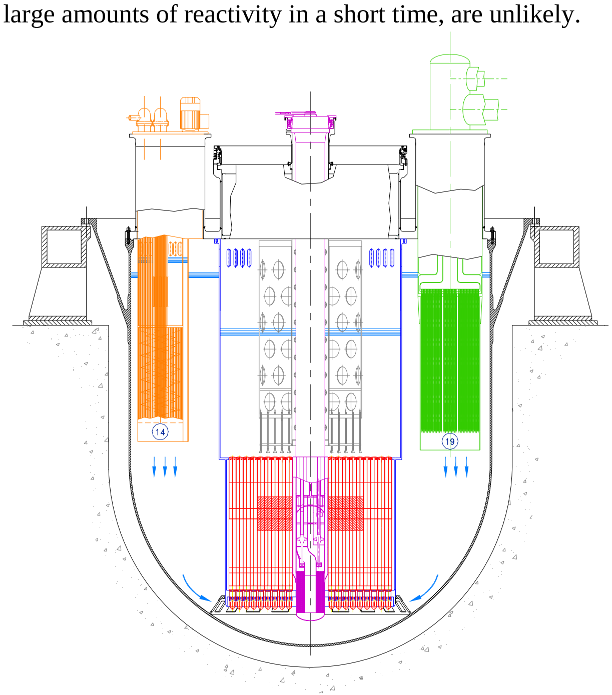

Fig. 6. EFIT Primary system assembly: vertical section

The pool design has important beneficial features, verified by the experience of design and operation of sodium-cooled fast reactors. These include a simple low temperature boundary containing all primary coolant, the large thermal capacity of the coolant in the primary vessel, a minimum of components and structures operating at the core outlet temperature. Whenever the sodium experience does not appear applicable to the specific tasks of EFIT, however, solutions are being worked out that, though being innovative in the nuclear field, are not new to the industrial practice.

The operating temperatures are: 400°C at core inlet (to have sufficient margin from the risk of lead freezing) and 480°C at core outlet. The core outlet temperature is chosen taking into account, on the one hand, the corrosion risk of structures in molten lead environment that increases with temperature (the current limit for candidate structural materials protected from corrosion by oxygen dissolved in the melt is about 500°C) and, on the other hand, considering that the outlet temperature cannot be too low because the associated increase of coolant flow rate would bring about unacceptable erosion of the structures. The proposed operating temperatures are, hence, a compromise between corrosion/erosion protection and performance.

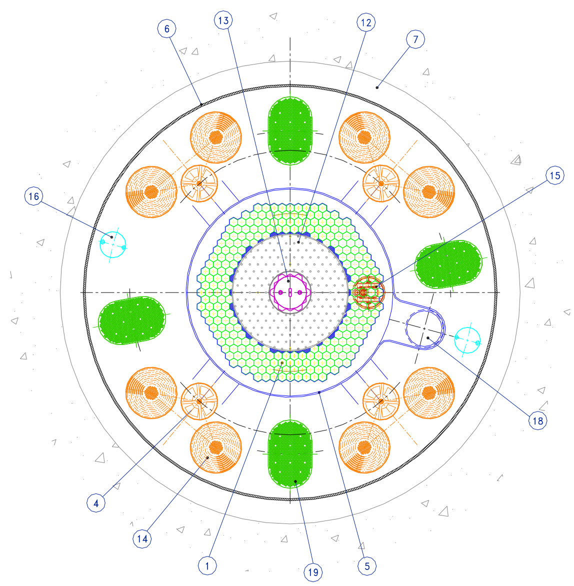

Fig. 7. Primary system assembly: Horizontal section over the core

The reactor vessel is designed to operate at the colder temperature of 400°C, and therefore corrosion protected even assuming that the oxygen activity control within the melt be temporarily lost. All other reactor internals will have to rely, with margin, on dissolved-oxygen control, whereas fuel cladding shall be aluminized for improved corrosion protection. With a core mean outlet temperature of 480°C it is possible to limit the cladding temperature to 550°C Increasing the cladding temperature largely over 550°C would mean taking an unjustified risk, even crediting the research results of the promising technology of Fe-Al alloy surface coating.

The primary circuit is designed for effective natural circulation, i.e. relatively low pressure losses and driving force brought about by the core mid plane elevation arranged wide below the mid plane of the steam generators or, in case of emergency decay heat removal, the mid plane of the DHR dip coolers.

The speed of the primary coolant is kept low by design (less than 2 m/s), in order to limit the erosion. Wherever this cannot be complied with, e.g. at the tip of the propellers blades, the relative speed is kept lower than 10 m/s and appropriate construction materials are selected for qualification (among them, the machinable Ti_3SiC_2).

Protection of structural steel against corrosion is ensured, in general, by controlled activity of oxygen dissolved in the melt and additional coating for the hotter structures. Wherever stagnation of the primary coolant is predicted, e.g. within dummies, provisions ensure a minimum coolant flow.

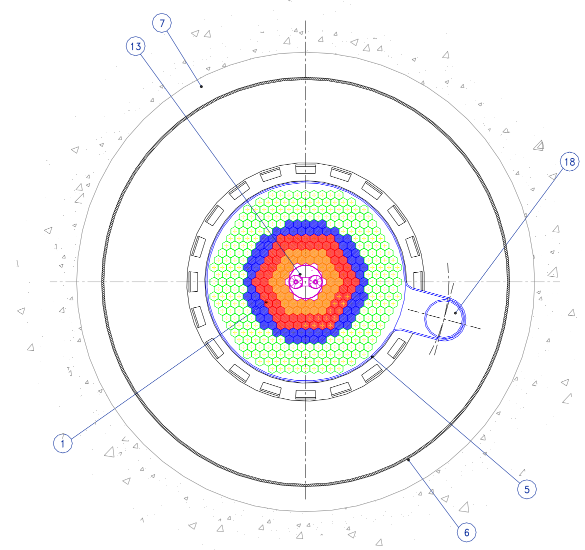

Fig. 8. Primary system assembly: Horizontal section at core elevation

Other components within the Reactor Vessel and design choices worth to be mentioned (Fig. 5.) are as follows:

- Cylindrical Inner vessel, hung to the reactor roof, welded directly on the Diagrid; 4 welded elbows as fittings of the suction pipework of the PP, with mechanical piston seal at the vertical upper ends.
- Diagrid, shaped as a thick disc welded to the bottom end of the Cylindrical Inner vessel.
- Core lateral restraints: a) outer restraints are the cylindrical shell, welded to the bottom head of the reactor vessel, that prevents the Diagrid from excessive lateral swinging, and the upper disk plate,

that is welded to the Cylindrical Inner Vessel. b) inner restraint is the outer shell of the Target Unit, which fits the inner outline periphery of the core.

- Above Core Structure: integral with rotating plug.
- Rotating plug: thick metal plate on ball-bearings with inflatable seals, co-axial to the core.
- Reactor Roof: thick metal plate bolted to inner branch of the Y-piece forming the upper part of the reactor vessel.
- Component for in-vessel fuel handling: one machine with extendible arm, on the rotating plug.
- DHR Direct Reactor Cooling (DRC) dip coolers: 4 independent and redundant in-vessel, bayonet-tube heat exchanger; organic diathermic fluid as the coolant; natural convection circulation (detailed description provided in Section II.D).
- Lead purification: two in-vessel gravitational filter units.
- Corrosion protection: dissolved oxygen activity control for formation and self-healing of a compact oxide layer, and Fe-Al alloy coating of the hotter structures.
- Ruptured Fuel Cladding detection system.

The lead coolant flow path is illustrated by lines with arrow heads in Fig. 5 and Fig. 6. Within the SGU/PP Assembly, hot lead is pumped into the enclosed pool above the PP and SG and driven shell-side downwards across the SG helical-tube bundles into the cold pool. At normal steady-state operation, the free level of the hot pool inside the casing is higher than the free level of the cold pool outside, that is higher, in turn, than the free level of the hot pool above the core enclosed by the inner vessel. In case of loss of service power to the level-keeping PP, there would be no need of large mechanical inertia to slowly coast down the pumps and continue for a while the forced circulation, because the available head would ensure the prompt onset of the natural circulation, and hence preserve the safety function of core cooling since the very beginning of the transient. The loss of a PP would bring about reverse flow in the affected sub-assembly and merely create a temporary core by-pass flow without seriously affecting the function of core cooling. Holes are provided on the upper part of the casing for creating a common, large reactor cover gas plenum and ensure overflow of surging coolant in case of SG tube rupture accident.

Removal of heat from the primary coolant of EFIT takes place by means of heat exchange between the primary lead coolant and water in eight identical SGs (see Fig. 6. and Fig. 7.) installed inside the Reactor Vessel. The steam generator is a vertical unit with an inner and an outer shell. The primary coolant flows downwards shell-side through the inner shell and the annulus between inner and outer shell. The tube bundle is made of U-tubes, the inlet legs of which are straight inside the inner shell. After the U-turn, the outlet tube legs are helical inside the annulus and become straight again at the exit. Lead and water flow co-currently in the inner shell and counter-currently in the annulus. Both tube plates are located above the free level of lead.

TABLE I. Primary and Secondary Systems parameters

Primary System Design Power (MW)	416
Present Core Power (MW)	395
Maximum Power from Spallation (MW)	11.2
Primary System Flow-rate (kg/s)	36000
Primary Coolant Target Flow-rate (kg/s)	1500
Core Flow-rate (kg/s)	34500
Fuel Assembly Flow-rate (kg/s)	33300
Dummy Assemblies Flow-rate (kg/s)	400
Absorber Elements Flow-rate (kg/s)	150
Core Bypass Flow-rate (kg/s)	650
Nominal Core inlet Temperature (°C)	400
Nominal Core mean outlet Temperature (°C)	480
Reactor Pressure (cover gas plenum) (MPa)	0.11
Secondary System Steam Pressure (MPa)	14
Secondary System Water/Steam Flow-rate (kg/s)	257
Feed-water Temperature (°C)	335
Steam Temperature (°C)	450
Steam Superheating (K)	116

II.D. Decay Heat Removal System

Two systems contribute to the DHR function in EFIT: the non safety-grade water/steam system; the safety–related DRC system. Following reactor shutdown, the non safety-grade water/steam system is used for the normal decay heat removal. In case of unavailability of the water/steam system, the DRC system is called upon.

The DRC System is composed of four identical loops (3 loops out of 4 are sufficient to perform the DHR intended functions), one of which is shown schematically in Fig. 9. The main components of the loop are: a molten lead-diathermic oil heat exchanger (dip cooler, DHX); an air-diathermic oil vapour condenser (AVC) with stack chimney.

The DHX is a bayonet tube bundle cooler immersed in the cold pool of the reactor with both tube plates located above the primary coolant free level. The AVC is an air cooler condenser with vertical finned tubes cooled by cross-flow atmospheric air driven by the natural draft provided by a stack chimney. Extra tubes are placed in front of the tube bundle that connect the lower header with the inert gas storage tank. The vapour is separated in the oil-vapour separator from the oil-vapour mixture rising from the DHX and fed to the upper header where it is distributed to the AVC tubes. The condensate runs by gravity into the lower header and eventually into the condensate drum where it mixes up with the hot oil and returns to DHX closing the oil loop. The inert gas that fills the AVC tube bundle and headers, during reactor normal operation, is pushed and confined by oil-vapour into the inert gas storage tank, during accident conditions when the DRC is called to operate.

Decay heat is removed by means of partial vaporisation of the oil in the DHX and oil vapour condensation in the AVC. Oil vaporisation and condensation take place at about 400°C, in order to maintain the primary coolant at a temperature of about 440-450°C.

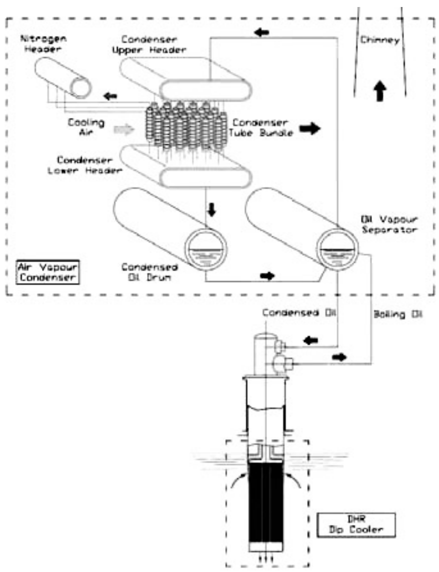

Fig. 9 Direct Reactor Cooling system

The higher boiling point of the oil with respect to the boiling point at atmospheric pressure is the consequence of superimposed pressure of inert gas (nitrogen, about 10 bar). The pressure is manually controlled by the operator in order to compensate for any significant system pressure variation due to the seasonal evolution of the ambient temperature.

DRC operation under normal operating condition. The dip coolers DHX are placed in the reactor vessel in the upper part of the cold collector, where the primary coolant presents a mild thermal gradient, owing to convection streams brought about by the heat losses from the hotter Internals. Both oil vapour separator and condensed oil drum in the lower part of the AVC are half filled of oil and half of a mixture of oil vapours and nitrogen, while tube bundle, upper header and nitrogen header are filled with nitrogen at the temperature of the atmospheric air. Since the oil in the DHX is prevented from vaporising at temperatures lower than 400°C by the superimposed pressure and the temperature difference between oil and lead in the DHX is a few K, oil is kept circulating at the flow rate brought about by the small density difference between hot and cold leg. Vaporization take place because of increasing lead temperature due to the heat losses from the hot internals. Condensation of oil vapour takes place in a short portion of the tube bundle entrance of the AVC because the heat losses are a few hundred kW. As a consequence, the DRC loops are almost idle during normal operating conditions. It will be noted that the removal of the heat losses keeps the thermal stratification in the upper part of the reactor vessel under control at such a low gradient that the design concept of cold reactor vessel is preserved and the associated thermal stresses during steady-state normal power operation are negligible (reactor vessel cooling function of the DRC).

DRC operation under emergency condition. In case of unavailability of the water/steam system, the DRC system is called upon to passively enhance its performance and remove decay heat to specification. At normal operating conditions, namely, all DRC loops are in operation with oil circulating at reduced flow rate. At start of the emergency condition, lead enters the DHX at higher temperature and flow rate, driven by the larger density difference between the cold shell-side leg and the hot outside leg, and oil starts to vaporise massively, speeded to circulate at higher flow rate by the large hydrostatic head between vaporizing and return legs of the loop. A recirculation ratio of more than four times the once-through vapour rate is achieved, having installed the oil vapour separator and condensate drum at the appropriate level above the DHX. The recirculation ratio is defined as the flow rate of liquid leaving the DHX compared with the vapour rate alone.

The vapor requires, to be condensed at the nominal rate, the whole AVC surface. In fact, owing to the increasing pressure, vapour floods the finned tubes while displacing the nitrogen gas. Vapour condensation takes place on the tube inner walls, and condensate runs down by gravity into the lower header and condensate drum, and mixes up in the separator with the oil rising from the DHX dip cooler. The sub-cooled, oil returns the DHX via the cold leg, closing thereby the natural recirculation loop of the oil. The displaced nitrogen gas enters the extra tubes placed in front of the tube bundle, and hence cooled by fresh air, rises up, being lighter than the oil vapour, and eventually, at steady state, is confined in the nitrogen header connected to the upper ends of the tubes. Any vapour entrained by nitrogen or evaporating from the oil free surface below, would condense and fall before reaching the header. The system pressure has increased, at steady state, because of the added mass of vapour, but the pressure increase has been kept limited by the large-volume header, and, hence, also the oil boiling point has remained almost unchanged. Thermal expansion of nitrogen, that would further increase system pressure and the oil boiling point, an occurrence that would affect the thermal stability of the oil and is therefore undesirable, does not occur, because the nitrogen header is kept at the temperature of the ambient air being hydraulically connected, but thermally isolated from the loop.

III. CONCLUSIONS

Design options and operating conditions of the main components of the Primary System of EFIT have been provided and described. The integration, in a pool type primary system, consideration the interfaces among sub critical core, target and beam pipe, SGs, PPs, DHR-DRC Dip Coolers, and Refueling System, has been illustrated. With the given reference components and primary system layout, the Partners involved in the IP-EUROTRANS project and in particular in the EFIT project can proceed with the analyses of key technical issues in the fields of core neutronics, materials, steady-state thermal-hydraulics and plant transient response, fuel, and later on with the cost estimate of EFIT.

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