THE ENCAPSULATED NUCLEAR HEAT SOURCE REACTOR CONCEPT FOR DEVELOPING AND FOR INDUSTRIAL COUNTRIES

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Abstract
The encapsulated nuclear heat source (ENHS) is a novel reactor concept in which the fission-generated heat is transferred from the primary- to the secondary coolant through a reactor vessel wall of a novel design. This enables the reactor module to have a very simple design, to be free of any mechanical connection to other power plant components, and to be simple to install and to replace. The ENHS is to be factory fueled and to deliver 125 MWth per module for 15 effective full power years (EFPY) without any on-site fuel handling. At the end of its core life the ENHS is to be replaced by a new ENHS module.

A study of the feasibility of the ENHS has been initiated in September 1999 under sponsorship of the DOE NERI program. It was found that using lead for the coolant, the ENHS can be designed to have 100% natural circulation and deliver 125 MWth to the secondary coolant through the reactor vessel wall with no more than 50 °C temperature drop. Use of cover-gas lift-pump can significantly reduce the volume and weight of the ENHS module. Feasible diameter and height of an ENHS module for 125 MWth are, respectively, 2.5 m and 20 m. Its weight for transportation, when loaded with fuel and solidified Pb, is less than 200 tons.

It was also found feasible to design simple, uniform composition, Pb-cooled cores to deliver 125 to 250 MWth for 15 EFPY with very small burnup reactivity swing; approximately 0.5%. The design domain for such cores has been defined.

Introduction
The encapsulated nuclear heat source (ENHS) is a novel reactor concept [1] that has been selected by the 1999 DOE NERI program as one of the “Generation - IV”

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reactors to be studied. The ENHS reactor features a high degree of modularity, relatively small and simple modules that are all factory manufactured and easy to install, high degree of passive safety, simplicity of operation and maintenance and long-life cores [1-4]. The ENHS constitute a totally new refueling concept: it is to be factory fuelled, inserted into an in-place power plant, run for 15 effective full power years (EFPY) without any refueling, and then replaced by another module.

One of the unique features of the ENHS is that the fission-generated heat is transferred from the primary coolant to the secondary coolant through the reactor vessel wall. This enables the reactor module to have a very simple design and to be free of any mechanical connections to the power plant components. The ENHS coolant need have a low vapor pressure at operating temperatures. Lead or Pb-Bi eutectic appears to be among the most promising.

The purpose of this paper is to briefly describe the ENHS concept and to summarize findings from a couple of studies completed since the inception of this NERI project. These studies are: (a) Exploration of the range of dimensions and weights of ENHS for 125 MWth that are to feature up to 50 °C primary-to-secondary temperature drop and up to 100% natural circulation. (b) Definition of the design domain of cores for the ENHS that enable 15 EFPY with close to zero burnup reactivity swing.

**Single ENHS Reactor Concept**

A very schematic description of one of many possible embodiments of a reactor concept having a single ENHS module is depicted in Figs. 1 and 2. The reactor consists of ten modules: one ENHS, three steam generators, three reheaters and three secondary coolant pumps. All these modules are inserted into the reactor pool; they are supported by a massive structural platform that is seismically isolated. There is no mechanical connection between the modules. This makes them relatively simple to install and to replace.

A schematic vertical cut through one concept of an ENHS module is shown in Fig. 3. This concept features 100% natural circulation. There are three walls to the ENHS reactor vessel – two structural walls and a confinement wall in between. The confinement wall provides the barrier between the primary and secondary coolants. The primary coolant gets from the riser into the downcomer channels that are formed between the inner structural wall and the corrugated confinement wall and gets back into the coolant plenum underneath the core. The secondary coolant gets from the pool into the space between the corrugated confinement wall and the outer structural wall and flows up in the channels located between the downcomer channels. The heated secondary coolant flows back to the pool near its top. Heat is conducted from the primary to the secondary coolants through the confinement wall. The confinement wall is corrugated in order to increase its surface area for heat transfer so as to keep the primary-to-secondary temperature drop at a reasonable value – taken in this work to be 50 °C.

Figure 4 shows a horizontal cut through a corrugated confinement wall. The corrugated wall channels are stiffened against buckling by vertical bends (not shown in
Fig. 4). Horizontal rings that are welded to the tips of the corrugations provide additional stiffening. They also act as spacers between the confinement wall and the inner and outer structural-walls. The axial distance between these spacers is approximately 1m. In addition to their structural function, the spacers are to avoid “rubbing” of the thin confinement wall against the adjacent structural walls and to assure that the space between the base of the corrugations and the structural walls will be large enough to avoid formation of “pockets” of stagnant coolant.

![Diagram of ENHS module reactor](image)

**Fig. 1** A schematic vertical view of a single ENHS module reactor

![Diagram of ENHS module reactor](image)

**Fig. 2** A schematic top view of the single ENHS module reactor pool. The number of steam generators, reheaters (if used) and pumps is yet to be determined.

Illustrations of possible corrugation dimensions are given in Tables 1 and 2 that are discussed in the following section. The downcomer flow channel formed by the corrugated wall is rectangular with a cross-section of (Downcomer depth) x (Down-
comer width). The corrugations of Fig. 4 pertain to Case 9.2.1; they are of an extremely large aspect ratio. Smaller aspect-ratio corrugations can also be used (Tables 1 and 2).

![Diagram of ENHS design](image)

**Fig. 3** A schematic vertical cut through an ENHS design having 100% natural circulation. Confinement wall having vertical corrugations extends to below the core level. Not to scale.

An alternate ENHS concept being considered is depicted in Fig. 5. It uses a cover-gas lift-pump that circulates the cover gas from the plenum above the coolant level in the ENHS and injects it into the coolant in the riser through nozzles located at a certain level above the core*. The cover gas bubbles reduce the effective density of coolant in the riser, thus increasing the head for coolant circulation. The circulator is envisioned to be located above the reactor pool, outside of the ENHS. Thus, no moving mechanical parts and no electrical parts associated with coolant circulation are located inside the ENHS.

There are very few components inside the ENHS reactor vessel. In particular, it does not include intermediate heat exchangers (IHX), decay heat removal systems (DHRS), and mechanical or EM pumps. Its confinement wall serves as the IHX and

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* A cover gas lift pump for circulation of liquid lead coolant was first proposed by ANSALDO7 for accelerator driven system. The use of steam lift pumps for circulation of secondary lead coolant was proposed earlier by one of the co-authors et al. [8-10].
part of the DHRS. Neither primary nor secondary coolants are pressurized. They exert nearly balancing hydrostatic pressure on the relatively thin confinement wall.

As presently perceived, the ENHS will be manufactured and fuelled in the factory and shipped to the site as a sealed unit with solidified Pb or Pb-Bi filling the vessel up to the upper level of the fuel rods. Upon insertion to the reactor pool hot Pb (or Pb-Bi) is to be pumped into the ENHS vessel. This hot Pb, along with the hot Pb in the pool, will melt the solid Pb at the lower part of the vessel.

At the end of its life, presently perceived to be 15 EFPY, the ENHS will be removed from the reactor pool and stored on site until the decay heat will drop to a level that will let the Pb (or Pb-Bi) solidify. Before solidification, the coolant will be extracted from the upper part of the ENHS above the level of the fuel rods. The ENHS with the solidified Pb will then serve as a shipping cask.

Currently, the Control and Shutdown Systems (C&SS) used in the 4S reactor [5, 6] have been adopted for the ENHS. The C&SS consists of a single neutron absorber assembly located centrally in the core and six reflector drive mechanisms that move the six radial reflector segments. The shutdown assembly is securely latched in place during shipping and reactor installation. The shutdown rod includes an electromagnetic latch that does not engage until the startup temperature is achieved, about 350°C. At this point the rod can be withdrawn and held out until permanent shutdown is required.
Normal operational shutdowns can be accomplished with the reflectors as needed. The reactor is brought critical by a hydraulic system that moves the reflectors at 1 mm/sec to compensate for the negative temperature coefficient of reactivity. At the full power position, the reflectors are stopped from further upward movement by mechanical stops whose movement is established by high-reliability gear drives. These drives restrict the rate of movement of the reflectors to approximately 1 mm/day. This movement compensates for the burn-up reactivity effect. There is no feedback to this drive mechanism. It is anticipated that the power level can be controlled over a wide range simply by using steam pressure and feed-water flow control. In summary, the reactor control is envisioned to be very simple and fully automated: a combination of axial movement of the radial reflector surrounding the core and passive control by temperature feedback.

Fig. 5  A schematic vertical cut through an ENHS with a cover-gas “lift-pump”. Outer structural wall does not have a special shield. Corrugated confinement wall extend to below the core level. Not to scale.

Each of the six reflector segments is presently perceived to be a 15 cm thick cavity that is as long as the active-fuel region. At the shutdown position the cavity level coincides with the active fuel level. The highest reactivity-state of the core is obtained with the cavity withdrawn from the vicinity of the active fuel region; Pb (or Pb-Bi) surrounds the core. The reactivity worth of each reflector segment is less than half a dollar. Hence, a severe reactivity insertion accident is inconceivable. Rather than one cavity
per reflector segment, it might be preferable to design the reflector container to have many small compartments or to be filled with a foam-like material that is compatible with Pb and that is not good at slowing down and at scattering neutrons. This will reduce the probability of Pb filling the cavity and making it an ineffective reactivity control mechanism in case of a breach in the container wall. Tungsten-based reflector is also being considered as possible alternative to the cavity reflector.

The path for decay heat removal is from the primary coolant through the corrugated confinement wall into the secondary coolant and through the pool wall into a passive air-cooled reactor vessel emergency cooling system (RVECS). The ENHS is characterized by a very large surface area per MW\textsubscript{th} of decay heat removal from both the primary- to the secondary coolant, and from the secondary coolant to the RVECS. In addition, the ENHS is characterized by a large thermal inertia due to the large inventory of the primary and secondary Pb. Both features are expected to make the ENHS highly passively safe.

The number of steam generators, reheaters and pumps to be used in the single ENHS module reactor of Figs. 1 and 2 is yet to be optimized. In fact, it may be decided not to use at all reheaters that are being heated by the secondary coolant. This can simplify the energy conversion system design but will somewhat reduce the energy conversion efficiency. The reason for showing the reheaters in Fig. 2 is to indicate that it is straightforward to incorporate them in the ENHS reactor. This can not be done in most other reactor design concepts.

**ENHS Module Design Possibilities**

A preliminary scoping study was performed to identify the required dimensions of the ENHS module for 125 MW\textsubscript{th} and its corresponding weight. The design goal of this study was to get a primary-to-secondary coolant temperature drop of approximately 50 °C with and without a lift-pump.

Following is a list of assumptions used for this scoping study:

1. Thermal power is 125 MW.
2. Average linear heat rate is 120 w/cm. In a later part of the study we reduced the average linear heat rate to 80 w/cm.
3. Core support plate thickness is 0.3 m.
4. Cavity height below core support plate is 1 m.
5. Fission gas plenum length above fuel is 75% of the fuel length.
6. Cover gas cavity height is 1 m.
7. Vessel bottom and top base thickness is 0.5 m.
8. Effective coolant layer around core is 3 cm.
9. Core barrel thickness is 1 cm.
10. Coolant layer outside of core barrel is 1 cm.
11. Reflector thickness is 15 cm.
12. Reflector drive guide wall thickness is 2 cm.
13. Shield thickness is 51.5 cm.
Assumptions “5”, “8” through “13” are based on the 4S reactor design by Toshiba [5,6].
14. Outer structural wall thickness is 3 cm.
15. Space between corrugations and structural walls is 1 cm.
16. Core coolant inlet/outlet temperature is 420/540 or 400/560 °C.
17. Maximum clad temperature is represented by the outer clad temperature calculated at the core outlet, assuming the average linear heat rate of “2”. This follows ANL Stage 1 modeling [11].
18. The effect of lift-pump on generating head for Pb circulation is accounted for parametrically by assuming an effective reduction in the Pb density above the gas injection level.
19. The confinement wall thickness is 4 mm. This thickness appears adequate for 15 years of operation.
20. An estimate for the primary-to-secondary temperature drop is $\Delta T_c + 2 \Delta T_{film}$ where $\Delta T_{film}$ is the film temperature drop in the primary side.
21. The downcomer flow channels are rectangular in shape. Their hydraulic-diameter was assumed to be the narrow dimension of the channel. This is a conservative approximation.

Table 1 Selected Characteristics of ENHS Modules of Type A

<table>
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<tr>
<th>Case No.</th>
<th>Core height (m)</th>
<th>Core Pitch (cm)</th>
<th>Core Riser length (cm)</th>
<th>Down-comer depth (cm)</th>
<th>Down-comer width (cm)</th>
<th>Max. clad temp. (°C)</th>
<th>Total upper lower RV radius (m)</th>
<th>Total RV height (m)</th>
<th>Core down-comer total Pb weight (kg)</th>
<th>Core Pb veloc. (m/s)</th>
<th>Down-comer Film DT (K)</th>
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The core dimensions used for this scoping study have not yet been fully optimized. For a given core height, fuel rod diameter and average linear heat-rate, there is only one pitch (or a very narrow range of pitches) that will give the desirable flat $k_{eff}$ variation with burnup. The definition of these cores is addressed in the following section.

Shielding of the structural components has not been designed, as yet. The shield needed for the ENHS structural wall is likely to be considerably thinner than the 51.5 cm borrowed from the 4S reactor design [5, 6]. In fact, the ENHS structure may not need at all a special shielding against radiation damage. This is because the ENHS lifetime is constrained by the peak fast neutron induced damage to the clad, and the peak
damage rate to the structural components outside the core is smaller than the peak damage rate to the clad.

Tables 1 and 2 present design and performance characteristics of different ENHS. Table 1 pertains to the ENHS of the type shown in Fig. 3 (Type A). Table 2 pertains to an ENHS that differs from that depicted in Fig. 3 in a couple of ways: (a) Its corrugated confinement wall starts from a level that is 2 m above the top of the core. (b) The inner structural wall radius 2m above the core coincides with that of the core barrel (Type B).

Each entry line (“Case”) in Tables 1 and 2 represents an ENHS module in which the combination of the design variables enables the primary coolant to have 100% natural circulation and to transport 125 MWth to the secondary coolant with close to 50 °C temperature drop. The design variables of the study are the five parameters at the left-hand side of the tables: downcomer channel dimensions, riser length, core height and pitch (i.e., core fuel rod lattice pitch). Additional design variables are the core inlet/outlet temperatures and the lift-pump induced effective Pb density in the riser. The other parameters given in the tables are derived.

It is observed that the flow channels formed by the corrugations of the confinement wall need have a relatively large aspect ratio: typically 2 cm wide in the azimuthal direction and an order of magnitude wider in the radial direction. Despite of the narrowness of these channels and the relatively small flow velocity, the Pb flow will be turbulent.

The primary conclusion from the results of the two scores of cases summarized in Tables 1 and 2 is that it is feasible to design an ENHS for 125 MWth with 100% natural circulation, 4 mm thick confinement wall and primary-to-secondary temperature drop not exceeding 50 °C. Another important conclusion is that using a cover gas

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lift pump it is possible to significantly reduce the ENHS module height, diameter and, hence, weight. It appears that an ENHS can be designed to have a diameter of ~2.5 m, a height of ~20 m, and a total weight of ~400 tons. With the Pb level limited to the upper level of the fuel rods, the total transportation weight of the ENHS is estimated to be ~200 tons. Such a module can be transported fully assembled and fuelled from the factory to the site using existing transportation and lifting means.

Use of cover gas lift pump also provides more flexibility in the selection of the core dimensions for the ENHS and in the startup and load following capability of the ENHS.

A detailed layout of representative ENHS designs has recently been initiated. It appears that we have practical design solutions to major feasibility issues such as how to fabricate and install the confinement wall, how to seal it, and how to accommodate the differential thermal expansion of the structural and confinement walls. Also recently initiated is a thorough structural analysis of the ENHS vessel design. Preliminary results indicate that 4 mm will be an acceptable thickness for the confinement wall.

**Core Design Domain for ENHS**

One goal of the ENHS is to have a long life core without refueling or fuel shuffling. Another goal of the ENHS is to have this long-life core with a nearly zero burnup reactivity swing. This section summarizes our findings concerning the feasibility of designing a nearly zero burnup reactivity swing core to operate for 15 EFPY.

The design variables of this study are the core height, fuel rod diameter, clad thickness, lattice pitch-to-diameter ratio (p/d), initial plutonium weight percent, total core thermal power and average linear heat rate. Of these, the fuel rod diameter and clad thickness were fixed at 1 cm and 0.1 cm, respectively. The fuel is a metallic alloy of U-Pu with 10 weight % Zr; its density is assumed to be 75% of the nominal density. The uranium is depleted to 0.2 \(^{235}\text{U}\) and the Pu initial composition is typical to that from LWR spent fuel. The clad is represented by stainless steel having 64.8 \(^{\text{Fe}}\) Fe, 17 \(^{\text{Cr}}\) Cr, 14 \(^{\text{Ni}}\) Ni, 2.8 \(^{\text{Mo}}\) Mo and 1.5 \(^{\text{Mn}}\) Mn. In reality, lower Ni contents steel will be used with the Pb coolant. Two power levels and two average linear heat rates have been considered: 125 and 250 MW\(_{th}\), and 80 and 120 w/cm.

The fuel assembly is assumed to have 217 rods in an hexagonal array. The central assembly site is reserved for a safety rod assembly. There are no control rods. The fine reactivity tuning is done using the radial reflector. The reflector assembly includes a voided container that is 15 cm thick and as long as the fuel section in the core. The minimum reactivity worth of the reflector is obtained when the cavity level coincides with the fuel level in the core. The maximum reactivity worth is obtained when the cavity is all below the core, so that Pb surrounds the core. Each fuel rod has a fission gas plenum above the fuel section; the plenum length is taken to be 75% of the fuel section length.

The core design is subjected to a couple of constraints: the peak fuel burnup should not exceed 150 GWD/tHM, and the peak fluence of E > 0.1 MeV neutrons
should not exceed $4 \times 10^{23} \text{ n/cm}^2$. Other restraints on the core design are: (a) Maximum fuel length is 4 m. (b) Minimum $p/d$ is 1.15.

The calculations are done using MCNP [12] and ORIGEN-2 [13] managed by the MOCUP code [14]. MCNP calculates $k_{\text{eff}}$, zone-wise fluxes, relative power and effective one group averaged cross sections for use in ORIGEN-2. ORIGEN-2 calculates the change in the isotopic composition as a function of time. The results reported below were obtained by performing the MCNP calculations once every year of reactor full power operation.

Figure 6 defines the combination of core height and $p/d$ ratio that have nearly zero burnup reactivity swing for 15 years of full power operation. The two curved plots shown in the figure each represents a family of cores for a given total power output – 125 MW$_{th}$ for the left-hand plot and 250 MW$_{th}$ for the right-hand plot. The core diameter is uniquely defined by the core height, $p/d$ value, fuel rod outer diameter (1.2 cm, in the present analysis), average linear heat rate (80 w/cm) and core thermal power. The bottom boundary is the criticality constraint. The dashed line saying “Minimum critical height for $dk_{\text{eff}} = 1.0\%$ temperature reactivity loss” defines the minimum height of cores whose reflector reactivity worth is 1.6%. As the unreflected cores of Fig. 6 are designed to have $k_{\text{eff}} = 0.994$ when at room temperature, the room temperature $k_{\text{eff}}$ of the reflected cores is 1.01. The 1.0% excess reactivity is to compensate for the burnup reactivity swing. If the burnup reactivity swing is limited to 0.5%, the dotted line will move downwards, increasing the core design domain.

Of the family of acceptable cores defined by Fig. 6, the 2m high core having a $p/d$ of 1.3 appears attractive. The corresponding $p$ is 1.56 cm. Its fuel has 11.4 weight % Pu. This core enables designing relatively compact ENHS modules, as illustrated by Case 9.2.5 of Table 2. By designing the ENHS central absorber to compensate for the reactivity swing from room temperature up to 350 °C, as done in the 4S reactor [5, 6], the 1.5 m high core having $p/d$ of approximately 1.34 will become acceptable; its reflector reactivity worth will be able to compensate for the burnup reactivity swing.

An illustration of the burnup reactivity swing is given in Fig. 7. It pertains to the 2m high core having a $p/d$ of 1.30 of Fig. 6. $k_{\text{eff}}$ varies by not more than ~0.5% over 30 years of EFYP of operation! The fluctuations in $k_{\text{eff}}$ are stochastic; they are due to the use of the MCNP Monte-Carlo code for calculating $k_{\text{eff}}$. The optimal $k_{\text{eff}}$ versus burnup profile may be somewhat different from that of Figure 6; either flatter or having a slightly negative slope. In the latter case, the reactivity loss is to be compensated by the constant automatic creeping movement of the reflector.

The cores defined in Fig. 6 (by the two curved lines) all reach the peak fast neutron fluence constraint after ~15 EFYP. For a 1cm fuel rod diameter (inner), this constraint limits the linear heat rate to 80 w/cm. The resulting peak burnup is ~105 GWD/THM.

It is concluded that lead-cooled cores can be designed to operate for 15 EFYP without any refueling operation and to have a very small burnup reactivity swing. Details about the neutronic characteristics of these cores can be found in reference [15].
Fig. 6  Design domain of 80 w/cm cores for ENHS featuring nearly zero burnup reactivity swing. Peak fluence constraint limits life to ~15 EFPY.

Fig. 7  $k_{\text{eff}}$ evolution with operating time of the 2 m high core having a p/d of 1.3. Fuel inner/outer diameter is 1.0/1.2 cm.
Suitability for Developing and Industrial Countries

The ENHS appears to be very suitable for developing countries and for countries having widely spread population and no central electricity grid. This is due to the following features: (1) High proliferation resistance as a consequence of the following combination of features: (a) Use of uranium enriched to < 20% \( ^{235}U \) as the fuel. (b) Once-for-life core. (c) No refueling operations throughout life; fuel is loaded in the factory and never taken out on site. (d) Possibly, using the ENHS as an interim spent fuel storage cask. (2) High degree of modularity with all the modules factory manufactured and easy to install. (3) Extremely simple to operate and simple to maintain.

Multi ENHS module reactors might be economically attractive also for industrial countries due, primarily, to the high degree of modularity, short construction time, the possibility of gradually increasing the installed capacity, high capacity factor and low O&M costs. In addition, the development cost for commercialization is expected to be a small fraction of that of a single-core large reactor. Several schemes were considered for incorporating multi-ENHS modules within the nuclear power plant (NPP). These schemes include the following: (1) Four ENHS modules within one secondary coolant pool of the diameter the pool of the PRISM reactor. (2) Eight or more ENHS modules within one secondary coolant pool that has an elongated, possibly rectangular, cross section made of thermally insulated concrete. Such a pool design concept is being proposed for a single core, high power, BREST reactor [16]. Steam generators, superheaters, possibly reheaters and secondary coolant pumps are also inserted into the secondary coolant pool. Each of these components is a relatively small module, supported from a seismically isolated platform that covers the pool. There is no mechanical connection between the modules, so it is relatively simple to install and replace each of these components. In case of some failure in one of the modules, it will be probably most economical to replace it with a new module. If economically justified, the failed module could be fixed “off line” and used as a spare.

Concluding Remarks and Discussion

Using lead for the coolant, the ENHS can be designed to have 100% natural circulation and deliver 125 MW\textsubscript{th} to the secondary coolant through a 4-mm thick confinement wall with no more than 50 °C temperature drop. In fact, there is a good synergism between the requirements for limiting the primary-to-secondary temperature drop to 50 °C and between the requirement for 100% natural circulation. Preliminary structural analysis indicates that 4 mm is an adequate thickness for the confinement wall. This analysis continues.

Cover-gas lift-pump appears very promising for the ENHS; it can significantly reduce the volume and weight of the ENHS module and increase its operational flexibility and stability without introducing into the module any rotating components or electrical components. Feasible diameter and height of an ENHS module for 125 MW\textsubscript{th} are, respectively, 2.5 m and 20 m. Its weight for transportation, when loaded with fuel and solidified Pb is less than 200 tons. Hence, it appears that the ENHS could be trans-
ported from the factory fully assembled and fuelled.

The design domain has been defined for Pb-cooled cores that can deliver 125 to 250 MW\textsubscript{th} for 15 EFPY with very small burnup reactivity swing: approximately 0.5\%. What limits the core life is the radiation damage to the clad. The radiation damage constraint limits the average linear heat-rate of a core that is to operate for 15 EFPY to 80 w/cm. Had 10 EFPY been acceptable life for the ENHS, its core could have been designed for an average linear heat rate of 120 w/cm. The peak burnup of these cores is approximately 100 GWD/tHM.

It turns out that there is a good match between the core height and pitch-to-diameter values required for providing the desirable neutronic characteristics and between the requirements for 100\% natural circulation. Thus, it is possible to design an ENHS that has long life with close to zero burnup reactivity swing to also have 100\% natural circulation.

In summary, so far we found no “show stopper”; satisfactory solutions were found for all the feasibility issues considered. The ENHS continues to be a promising concept for Generation IV reactors.

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**References**


