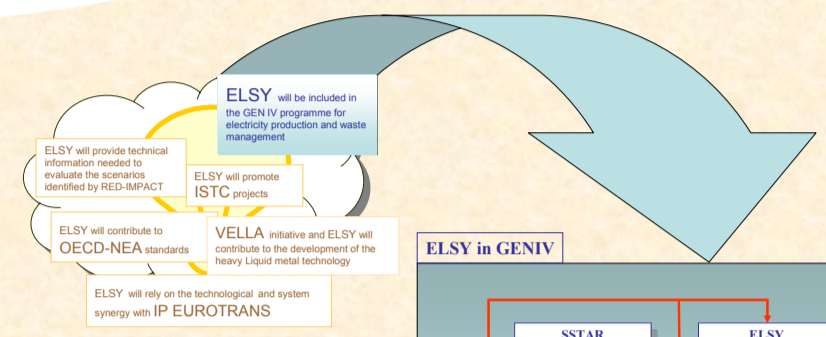




ELSY Interaction with other European Projects



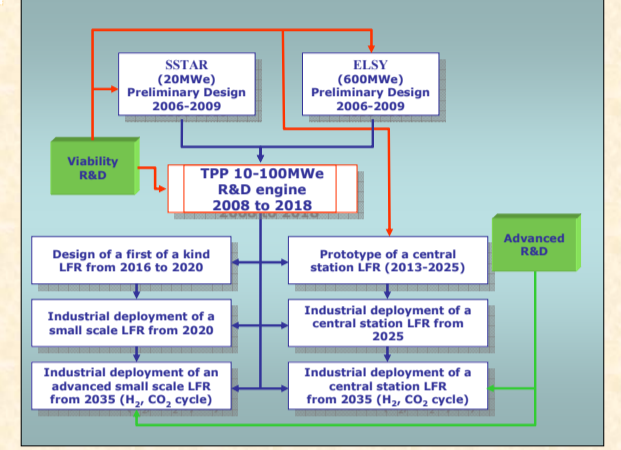
PROJECT OBJECTIVES

The GIF (Generation IV International Forum) members have evaluated plant designs and systems on the basis of four goal areas and eight specific goals. The LFR has been selected for its potential, but the consortium proposing this LFR project (ELSY) are of the opinion that none of the LFR projects presented so far fully exploits the potential of the LFR, although single LFR-peculiar features may be embodied in each of them. Even BREST, that may be considered the most advanced LFR design so far, in particular for the neutronic aspect, is deemed deficient in several important areas such as reparability of the primary system.

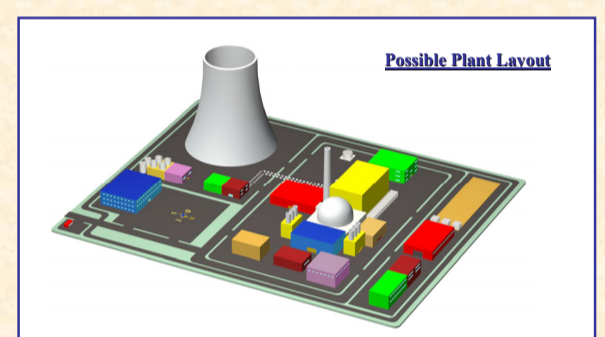
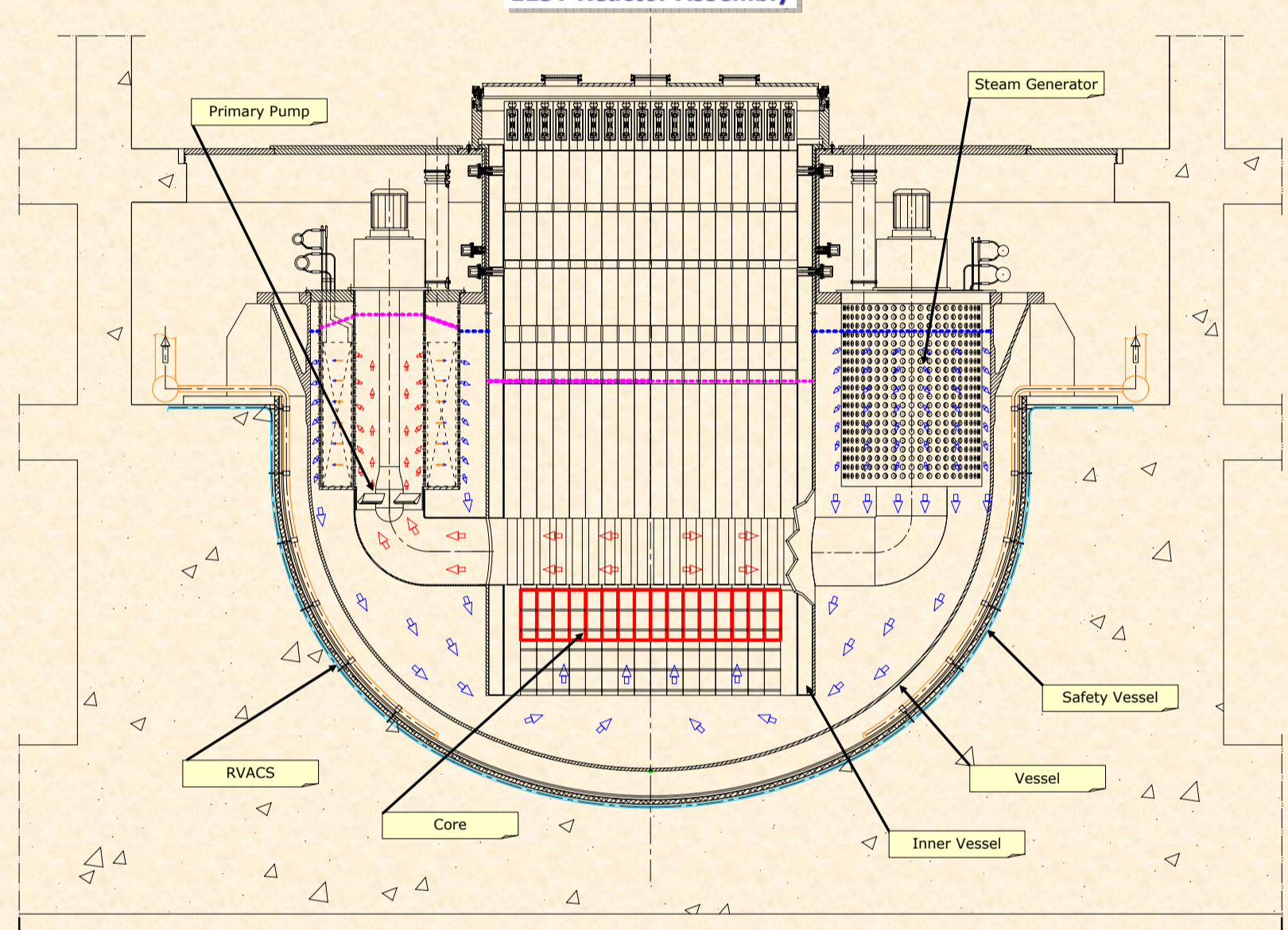
The ELSY consortium intends to design an LFR system that complies with all GEN IV goals and gives assurance of investment protection. This will be achieved by specific engineered solutions that exploit the very favourable molten lead features. These features may facilitate the plant design, but they require innovation, owing to the very different characteristics of molten lead with respect to better-known coolants such as sodium or water. Thus, the experience acquired by the consortium in designing sodium or water-cooled reactors and also the experience gained from the ongoing ADS development are the basic premise for the analysis of the candidate solutions for the LFR.

The main solutions, that the involved organisations propose in order to comply with the goals, are based either on the lead-inherent properties or on specific engineered solutions. It will be noted that they are preliminary and likely to be optimised in the course of the project in order to better comply with the goals. A concluding report on the compliance of ELSY with GEN IV requirements is to be issued at completion of the ELSY project.

ELSY in GEN IV



ELSY Reactor Assembly



ELSY Parameters	
Power	600 MWe
Thermal efficiency	40 %
Primary coolant	Pure lead
Primary system	Pool type, compact
Primary coolant circulation (at power)	Forced
Primary system pressure loss (at power)	~ 1,5 bar
Primary coolant circulation for DHR	Natural circulation + Pony motors
Core inlet temperature	~ 400°C
Core outlet temperature	~ 480°C
Fuel	MOX and consideration also for nitrides (with and without MA)
Fuel cladding material	TR1 (aluminized)
Fuel cladding temperature (max)	~ 550°C- 600°C
Main vessel	Austenitic stainless steel, hanging, short-height ~9m
Safety vessel	Anchored to the reactor pit
Steam generators	N° 8, integrated in the main vessel
Secondary cycle	Water-superheated steam at 180 bar, 450°C
Primary pumps	N° 8, mechanical, integrated in the SG, suction from hot collector
Internals	Removable
Inner vessel	Cylindrical
Hot collector	Small-volume, enclosed by Inner Vessel
DHR	3 independent, redundant and diverse DHRs, 4 loops each = RVACS
Seismic design	2D isolators supporting the reactor building

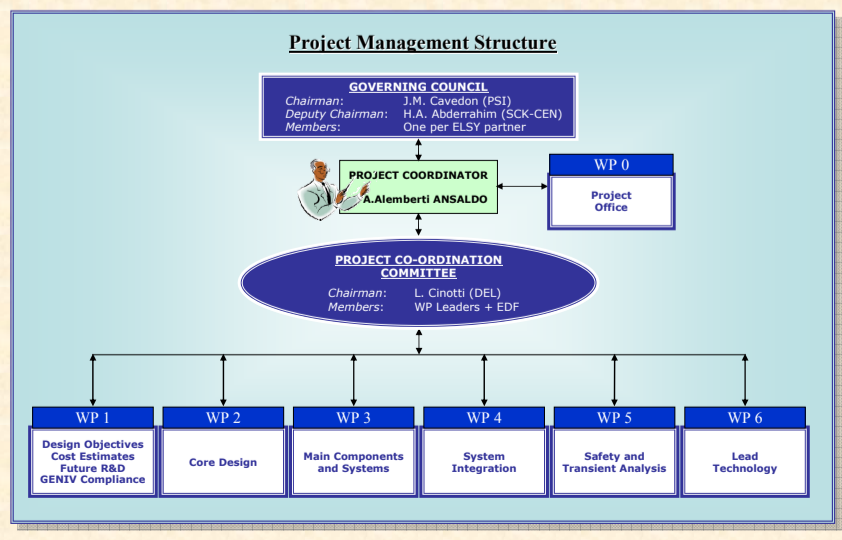
SUSTAINABILITY	
<b>Resource utilization</b> Because lead is a low moderating medium it is possible to maintain a fast neutron flux even with a large amount of coolant in the core, with efficient utilisation of accumulated Pu, and strong reduction of uranium consumption without aiming at fast doubling times. The design will have the objective of a Breeding Ratio of about 1. For this objective, the advantage of having high-density U-Pu nitride fuel will also be evaluated.	<b>Waste minimization and management</b> A fast neutron flux per se significantly reduces the waste generation. Furthermore the capability of the system to safely burn recycled minor actinides inside the ELSY core will be studied, because Pu and MA recycling in a closed fuel cycle is recognized as appropriate for waste minimization.
<b>Lead inherent features</b> Lead is a low moderating medium. Lead has low absorption cross-section. Core with fast neutron spectrum even with important coolant fraction.	
<b>Specific solutions</b> Breeding Ratio close to 1	Presence of Minor Actinides

Main solutions proposed for ELSY in order to comply with the Goals of Generation IV

PROLIFERATION RESISTANCE and PHYSICAL PROTECTION	
<b>Lead inherent features</b> Use of a MOX fuel containing MA increases proliferation resistance. Use of a coolant chemically compatible with air and water operating at ambient pressure enhances physical protection. There is no need of a robust protection to avoid the risk of catastrophic scenarios, which can be initiated by acts of sabotage also from the secondary system from the DHR system because there is no risk of fire propagation. The independent, redundant DHR system operating under natural circulation enhances physical protection. There are no adverse viable scenarios of significant containment pressurization to be considered.	Primary coolant chemically compatible with air and water operating at ambient pressure
<b>Specific solutions</b> Use of a MOX fuel containing MA increases Proliferation Resistance. No blanket. Independent redundant DHR loops operating in natural circulation.	

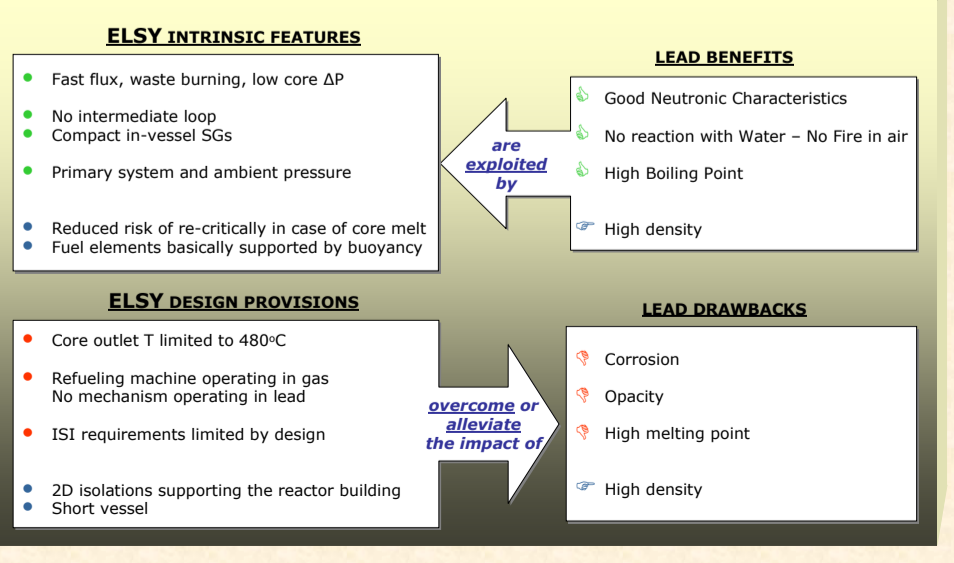
ECONOMICS	
<b>Life cycle cost</b> The cost advantage factors must include low capital cost, short construction duration, low fuel cost and low electricity production cost. The cost usefulness of MOX fuel in a fast spectrum has been already demonstrated in the case of the SFR, and the same conclusion should be applicable for the LFR. The consortium is confident that, owing to the favourable characteristics of molten lead, it will be possible to drastically simplify the solutions engineered for the SFR for application to the ELSY project and hence reduce the overnight capital cost, which is a major cost factor for the competitive generation of nuclear electrical energy. A strong simplified plant will be the base for reduced capital and operating cost.	<b>Risk to capital (Investment protection)</b> In some countries, the reduction of risk to capital is focused on the total capital cost that includes the financial exposure and it is of course quite low for small reactor modules that are therefore preferable from this point of view. In Europe the interest in the small modular units is understandably less, considering the larger dimensions of the Utilities with their experience in large investment programmes, often simultaneously involving several large-size units, and to the difficulty of finding the plant sites. Thus, in Europe, the reduction of the Risk to capital should be better focused on the investment protection. By nature, this goal is more difficult to achieve when dealing with a facility involving new technology. In view of the fact that plant life extensions have been granted to water-reactor plants under condition of replacing critical components, one may expect that similar plant life extension possibility may exist for LFR provided that all increased components are removable. This objective is a challenging one in the ELSY design.
<b>Lead inherent features</b> Lead does not react with water. Lead does not burn in air. Lead has a very low vapour pressure. Lead is cheap.	
<b>Specific solutions</b> Reactor pool configuration. No intermediate loops (necessary condition for economics). Compact Primary System. Simple design of the reactor internals. Supercritical steam (high efficiency).	Potential for all removable in-vessel components (to be evaluated and confirmed, as one of the challenge of the design activity).

SAFETY and RELIABILITY			
<b>Operation will excel in safety and reliability</b> Molten lead has the advantage of allowing atmospheric pressure operation of the primary system. Lower dose to the operators can also be predicted, owing to its low vapour pressure and high capability of trapping fission products and shielding of $\gamma$ rays. In case of accidental air ingress, in particular during refuelling, oxidised lead can be reduced to metal by injection of hydrogen gas and the reactor operation can be safely resumed. The moderate $\Delta T$ between core inlet and outlet temperature reduces the thermal stress during transients, and the relatively low core outlet temperature reduces creep in the steels.	<b>Low likelihood and degree of core damage</b> It is possible to design fuel assemblies with a large coolant fraction as in the case of a water reactor. This results in a moderate pressure loss through the core not exceeding about 1 or 2 bar, in spite of the high density of lead, with associated improved heat removal by natural circulation and the possibility of innovative reactor layout such as Primary Pumps installed in the Hot Collector, a feature that, besides the described economic advantages, improves several aspects related to safety, such as: Moderate volume of Hot Collector and large volume of Cold Collector. DHR Coolers immersed in the Cold Collector. This favours the natural circulation and eliminates the interference between hot coolant stemming from the core and the cold coolant from the outlet of the DHR Coolers. Free-level of the Cold Collector, in normal operation, higher than the free-level of the Hot Collector. This, in case of Primary Pump Shutdown, favours a rapid transition from forced to natural circulation of the coolant and hence ensures adequate heat removal from the core during a transient. With lead as a coolant and a simplified flow path design, the natural circulation capability of the primary circuit is greatly improved. There is no need of fast safety-related actions for maintaining the coolant speed, with simplification of the Control and Protection Systems. The fact that molten lead does not react violently with air or water gives the designer some freedom in the choice of the liquid for the DHR coolers. In case of leakage of the Reactor Vessel, the free level of the coolant will be allowed by design, to drop to a level that ensures the coolant circulation through, and the safe heat removal from, the core. Any leaked lead would solidify and remain confined by the structures of the Reactor Pit continuously kept cold.	<b>No need for off site emergency response</b> Fuel deposition dominates over fuel compaction, thus reducing considerably the likelihood of the occurrence of severe re-criticality events in the case of core disruption. In fact the lead density, which is slightly higher than that of fuel, and convective streams make it rather difficult to construct scenarios leading to fuel aggregation with subsequent formation of a secondary critical mass in the event of postulated fuel failure.	
<b>Lead inherent features</b> Lead does not react with water. Lead does not burn in air. Lead has a very high boiling point; a very low vapour pressure and a high shielding capability for $\gamma$ radiation.	<b>Lead has:</b> - good heat transfer characteristics; - high specific heat and thermal expansion coefficient. Core design optimisation leads to inherently activated negative reactivity feedbacks.	<b>Lead density is close to that of fuel.</b> (Considerably reduced risk of re-criticality in case of core melt).	
<b>Specific solutions</b> Primary system at atmospheric pressure. Low coolant $\Delta T$ between core inlet and outlet.	<b>Large fuel pin pitch.</b> Decay Heat Removal (DHR) in natural circulation. Primary Pumps in the hot collector. DHR Coolers in the cold collector.		



**Conclusions**

The design provisions proposed for ELSY exploit the advantages of lead and overcome or alleviate the impact of the drawbacks.



Work Packages Leaders

WPO A. Alemberti (Ansaldo), WP1 K. Tucek (JRC/IE), WP2 E. Malambu (SCK-CEN), WP3 A. Orden (EA), WP4 L. Cinotti (DEL), WP5 D. Strauwe (FZK), WP6 P. Agostini (ENEA)

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