

Renewed Interest in Lead Cooled Reactors

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Contents: Prediction of nuclear power and waste increases – closed fuel cycle is needed Interest in LFRs in the US and in the EU Pros and cons of lead and LBE cooling Safety aspects of larger lead cooled systems

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Range and Median of Projected Nuclear Energy from SRES – Special Report on Emission Scenarios of IPCC – Drivers are energy needs in in developing countries, energy security in developed ones, climate concerns



Source: INPRO-1A

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EUROPEAN COMMISSION Joint Research Centre A Discontinuity for Nuclear Power: The Case of Innovation (IAEA-INPRO)





Cumulative Uranium Use in Different

SRES Scenarios, no re-processing assumed,



Source: Roegner, IAEA



Carbon Emissions in 2050 turn around in A1, A1T + B1 Scenarios



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Main advantages of breeding systems + reprocessing

- Only fast Pu or thermal U-233 breeders lead to sustainable nuclear power
- Only fast systems + epithermal MSRs can burn their own and also long-lived waste from LWRs
- Much less mining and milling necessary– good for the environment
- New pyro-reprocessing will probably also be cheaper and cleaner

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Efforts on LFR Development

- In the mid 90's Russia had started a large effort on the BREST designs of 300 and 1200 MWe but there appears to be no major funding anymore
- At ANL, LANL, LLNL there is a sizeable effort on the 400MWt STAR-LM modular design using natural circulation lead cooling
- In the EU a consortium has formed that aims at investigating the 600 MWe European Lead Fast Reactor (ELFR)
- Participants in the Expression of Interest (EoI) to the EC (European Commission, Research Directorate) are:



Nuclear Industries: Ansaldo (Italy), Empresarios Agrupados (Spain)Utilities:Electicité de France, (EdF)National Labs:SCK-CEN (Belgium); CNRS (France), ENEA, Italy;
FZK, Germany; REZ, Czechia; NRG, NetherlandsEU LaboratoriesJRC/IE, NetherlandsUniversities:CIRTEN (Italian University Group) and RIT, Sweden

The European Lead Fast Reactor (ELFR) will have around 600 MWe

Inlet temperature around 400 °C, outlet temp. 480 °C – very conservative values concerning corrosion and also good for low thermal stresses, low and wide vessel – due to seismic concerns

Due to the high inlet temperature it appears possible to achieve an efficiency of 42 % using a supercritical steam cycle

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LFR's and LBE-cooled reactors could meet all GenIV criteria

- Regarding economics both systems profit from the use of steam heat-exchangers in the primary pool and long burn-up times
- But lead is an order of magnitude cheaper than LBE and there is no question about its availability
- The ELFR with 600 MWe may profit from the economy of size, probably many components can still be factory-made
- For the SVBR 75/100 LBE-cooled modular designs, IPPE Obninsk and Gidopress have compared economics cost with other reactors and a gas-fired plant (for some reason they had to base it on 1991 cost)



SVBR75/100 Economics – 8 year refueling interval

Reactor Type	SVBR 75/100	VVER 1500	VVER 1000	BN 1800	Steam - Gas Unit
Power, MWe	16 * 100	1479	1068	1780	325
No of Units	2	2	2	2	10
Efficiency, %	34.6*	33.3	33.3	46.2	44.4
Capital Invest= ment, \$/kWe	661.5	749.8	819.3	783.4	600
Electricity cost cent/kWh	1.46	1.85	2.02	1.56	1.75

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* higher for supercritical steam cycle --- Source: IPPE paper, ICAPP'03



For the same temperature the corrosion in pure lead is better than that in LBE



Fig. 1a: Thin protective crust on SS 1.970 in flowing lead - 1.9 m/sec, 550 °C, 3000 hrs (IPPE Obninsk / FZK)



Fig 1b: Unstable crust on SS 1.970 in flowing LBE - 1.3 m/sec 550 °C, 4300 hrs (FZK)



Other Pros and Cons of Pb vs LBE cooling

The lower prize of lead allows a generous use in the design which is good for increasing the heat capacity of the system and for shielding components in the primary pool

The polonium generation in the lead is 10 000 times lower – much less radioactivity in the coolant, the volatile Po in the gas plenum is less and the source term in a highly unlikely severe accident will be less (I and Cs are probably getting absorbed by Pb or Pb/Bi)

Accidental freezing of lead is less of a problem since it shrinks on freezing. LBE expands slightly – but IPPE Obninsk developed an approach to cope with LBE freezing



Pros and Cons of Pb vs. LBE, continued

The main advantage of LBE cooling is the 80 reactor-year experience in Alpha submarines and the extensive ADS research on design, LBE corrosion an thermo-hydraulics in the EU

High melting point of lead is a is a disadvantage – but one has to manage fuel handling remotely also in LBE; massive accidental lead freezing due to a low decay heat will not lead to a bad accident since low decay heat can be removed by conduction and the ex-vessel air cooling

Regarding proliferation concerns, which are anyways lower in heavy metal-cooled systems due to their long burn-up periods, the high temperature (and weight) of stored subassemblies will be a deterrent



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Safety Aspects of a 600 MWe LFR



STAR-CD Grid for 1420 MWt self-designed LFR. Vessel Height 11m, Vessel Diameter 12 m, Simple Flow Path – up through the riser and down through HX and downcomer

Guard Vessel + Air Cooling Ducts surround Vessel



Emergency Decay Heat Removal with RVACS in Station Blackout with scram – Vessel 12m Diameter, 11m tall



Grace time to reach maximum 2 days + temperature peak 100K below limit for fast creep for AISI 316 at the existing principal stress

Maximum natural circulation velocity in core. Initial max. core velocity w 2.5 m/sec. Late velocity near vessel wall in downcomer 7 cm/sec



Emergency Decay Heat Removal, cont'd – Vessel Diameter 10 m and height 11 m



With a smaller vessel (10 m diam) the max. wall temperature is within 50 K of the fast creep limit for AISI 316 and actual stresses. Heat-up at full power without cooling is 1.4K/sec

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Inlet blockage in a single subassembly of the Ansaldo ADS design (11 KW/m) leading to a 15% flow reduction.

This is a limiting case leading to some cladding melting in the upper part of the bundle

Larger linear power will allow smaller blockages. Wrapperfree core would help



2-JUL-04 **TEMPERATURE** ABSOLUTE **KELVIN** |TER = 4430|LOCAL MX= 1686. LOCAL MN= 573.0







Conclusions

- Breeding systems + more reprocessing needed in <u>the not too far</u> future if nuclear can take off as predicted by SRES
- A Lead Cooled Fast Reactor has very good prospects and a prototype could be realized relatively soon.
- The technology can be largely based on that of LBE. More corrosion tests are needed to confirm its superiority to LBE and its possible upper temp. limits
- The investigation of leaking steam HXs is needed. For a simple coolant flow approach this is very important. JRC/IE works on a design allowing only rising steam bubbles



Conclusions, last

- The emergency decay heat removal for a 1420 MWt LFR is possible with a simple flow approach and and 11 m tall and 12 m wide primary pool. Need for more investigations on RVACS fins and selective coating
- Investigations of unprotected accidents needed.
 Prospects are good since heat-up at full power without cooling only 1K / sec
- Decision between mid-sized LFR and more modular LFR should depend on both safety and economics. Modular prototype could be similar to final design



Electricity for all and let's keep our planet cool!

Thanks a lot for your attention





Joint Research Centre Range of future primary energy demand from SRES – Special Report on Emission Scenarios of IPCC



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Small Japanese LBE-cooled Fast EUROPEAN COMMISSION **Joint Research Centre** Design (53MWe) for Expanding Market – LSPR Long Life Safe Simple Small Portable Prolif. Res.





- Prevention of corrosion in the whole primary pool:
 - IBRAE Institute in Moscow has CFD code to check oxygen content and velocities everywhere
 - Corrosion experiments on large pieces of equipment
- In-service inspection:
 - thinner vessel of low-pressure system allows more easy detection of faults from vessel outside
 - Ultrasonic device for viewing under sodium is adapted for HLM
 - HXs and pumps should be withdrawable
- Long-lived radioactivity in HLM coolant is due to beta radiation of Bi-208 and Bi-210m
 - Re-use of HLM coolant, Pb and Bi possibly resistant to seawater