# Investigation of Material Performance in Pb-Bi Cooled Reactors

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## Introduction:

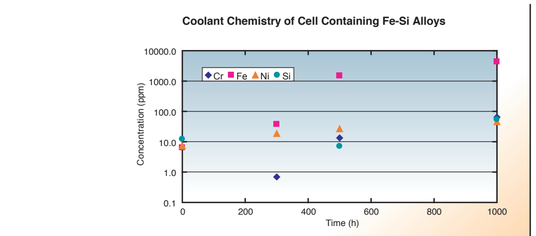
Tthe Idaho National Engineering and Environmental Laboratory is conducting research in Generation IV reactor technology. One of the proposed types of Gen IV reactors is a fast reactor cooled by a Lead Bismuth Eutectic (LBE). Recent investigation has focused on the material performance in three major areas: the interaction layer, tensile strength, and dissolution. Two simultaneous corrosion experiments were conducted in carbon steel pipe cells at 600(C for 1,000 hours. One cell housed Fe and Fe-Si alloys while the other contained Fe-Si-Cr alloys to determine the role of Si and Cr in Fe during LBE exposure. At times of 300, 500, 700, and 1,000 hours, corrosion coupons and bath samples were removed from the system to examine time dependence of material performance.

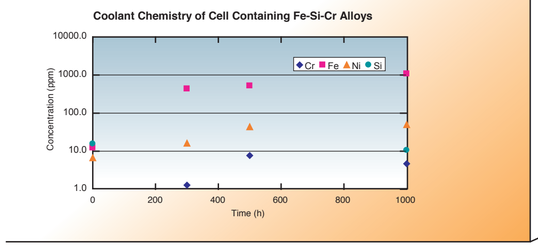
## Advantages of LBE Cooled Reactor

- Lead, in pure form, will melt at approximately 325°C, but when combined with bismuth, the melting point drops to 125°C.
- No volume change occurs with solidification.
- With a high vaporization point near 1750°C, higher operating temperatures (800-1000°C) can be attained, in turn, increasing the power efficiency.
- Ability to couple with hydrogen generation plant.
- LBE is non-reactive with water and air, thus reducing the likelihood of fires similar to those associated with liquid sodium coolants.
- It is an excellent shielding material for beta and gamma radiation.
- The LBE hardens the neutron spectrum and increases refection properties, as a result diminishing the need for a blanket even while breeding.

## Coolant Chemistry

Inductively Coupled Plasma-Atomic Emission (ICP) analysis was used to quantify the concentrations of Fe, Si, Cr, and Ni within the LBE as a function of time. Fig. 4 present this data along with the theoretical solubility limits in parenthesis in the legend. The solubility of Si in LBE has not been widely studied.




## Interaction Layer

Si and Cr contained with in the alloys diffuse to the surface and react with residual oxygen in the system thus creating a protective oxide layer. With time, this layer tends to grow on and into (via grain boundaries) the base material. If the oxide becomes too thick and is disrupted, it can spall off leaving an unprotected surface to be further oxidized. Figs. 2 and 3 show the grain boundary penetration and spallation of a layer, respectively.

Fig. 2: Grain boundary attack of LBE on a Fe-Si-Cr alloy

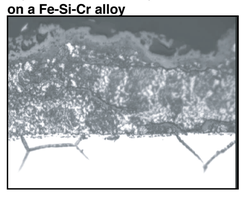
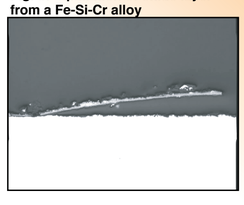
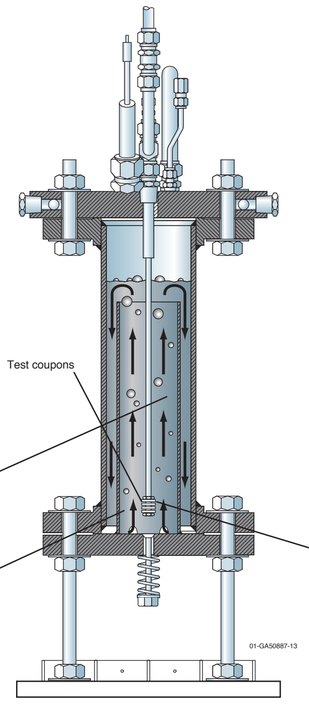


Fig. 3: Spallation of oxide layer from a Fe-Si-Cr alloy



INEEL experimental corrosion cell




## Corrosion Cell Features:

- Off-the-shelf material fabrication
- Gas injection (UHP Ar) via lance
- Isothermal conditions
- Tensile bars bolted to inner shroud
- Multiple lances containing corrosion coupons
- Max temperature: 700°C
- Total weight while running: 120 kg

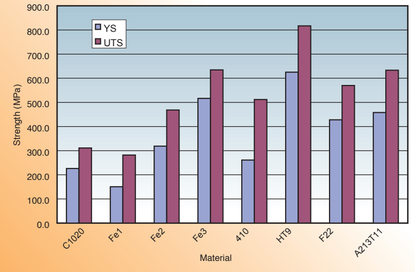
## Tensile Strength

Tensile specimens were exposed for 1,000 hours at 600°C to determine if liquid metal embrittlement occurs. The materials and compositions are listed in Table I. The first four columns were in the Fe-Si cell and the last four were in the Fe-Si-Cr cell. Each of the samples was pulled at a constant rate and the stress-strain curve, yield strength, and tensile strength were recorded. The yield and tensile strength for each material are shown in Fig. 1.

Table I: Compositions of alloys and steels submitted for tensile testing

| Element | C1020 | Fe | Fe2 | Fe3 | HT9 | 410 | F22 | A213T11 |
|---|---|---|---|---|---|---|---|---|
| C | 0.200 | | | | 0.200 | 0.136 | 0.110 | 0.080 |
| Nb | | | | | | | 0.004 | |
| Cr | | | | | 12.000 | 11.820 | 2.200 | 1.500 |
| Cu | | | | | | 0.060 | 0.170 | 0.060 |
| Mn | 0.330 | | | | | 0.460 | 0.450 | 0.490 |
| Mo | | | | | 0.100 | 0.010 | 0.960 | 0.520 |
| Ni | | | | | 0.550 | 0.130 | 0.220 | 0.040 |
| P | 0.013 | | | | | 0.015 | 0.007 | 0.019 |
| S | 0.008 | | | | | 0.002 | 0.002 | 0.007 |
| Si | 0.010 | | 2.500 | 3.820 | | 0.400 | 0.200 | 0.580 |
| Sn | | | | | | 0.010 | | 0.007 |
| V | | | | | 0.300 | | 0.007 | 0.001 |
| W | | | | | 0.500 | | | |
| Fe | Balance | Balance | Balance | Balance | Balance | Balance | Balance | Balance |

Yield and Tensile Strength of Materials Tested after LBE exposure at 600°C for 1,000 Hours




## Conclusions:

- Fe concentration in the LBE exceeded the solubility limit due to constant bath stirring from gas injection that kept Fe and $Fe_3O_4$ suspended in the LBE.
- Tensile tests and examination of fracture surfaces indicate a lack of liquid metal embrittlement.
- Interaction layer is providing insights into Fe-Si and Fe-Si-Cr performance in LBE.

03-GA50677-15