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Advantage of Molten Salt Coolant over other options

The fundamental breakthrough of using molten salt fuel in standard nuclear fuel assemblies does not require that the coolant removing heat from those assemblies is also a molten salt. Why did we choose to make it so?

Water was never really considered as an option. The requirement for high pressures and all the hazards that are associated would be incompatible with our design philosophy of seeking intrinsic safety.

Sodium is used in almost all fast spectrum reactors today. Neutronically it is excellent, with a very low neutron absorption and no long lived activation products. But while excellent from a nuclear physics viewpoint, in most other ways it is a problem.

- Sodium spontaneously and violently burns on contact with air
- Molten sodium and water form an explosive combination
- Sodium has a low heat capacity per unit volume so has to be pumped very fast through the reactor core
- Sodium has a low boiling point which creates hazard and means reactors must run at rather low temperatures

An alternative coolant, used extensively by Russia, is molten lead or lead/bismuth combinations. This is actually a very good coolant and we did seriously consider it. It was rejected for one main reason. In the event of catastrophic core damage causing rupture of many of the fuel tubes (terrorist explosives are the only plausible mechanism for this but we felt that could not be sensibly discounted) then the fuel salt would float on the molten coolant. We could not guarantee that there was no scenario where that floating fuel salt could not accumulate in a critical configuration and reach criticality. Molten lead coolants were therefore rejected.

That left molten salt coolants. These are actually extremely good coolants and it is strange that they have not been adopted before. They are however now being very seriously considered in a variety of conventional solid fuelled nuclear reactors. They have many advantages for any nuclear application.

- Chemical stability with no reactions with air or water
- Very high boiling points
- High heat capacity per unit volume allowing compact reactors with relatively low flow rates
- Adequate neutronic properties (not as good as sodium, but good enough)

But the deciding advantage for us was that in the event of catastrophic core damage, any fuel salt released would simply mix with the coolant, be diluted and rendered very safe. Our design principle is to seek intrinsic safety above all other factors and that more than any other factor drove our decision to use molten salts as coolants.

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What Coolant Salt?

There are many options for salts to be used as coolants. We rejected outright all salts containing lithium or beryllium (which are very popular in other molten salt reactors) because both produce substantial radioactive tritium in a reactor. That creates a radiological hazard which would have to be managed, and our design principle of achieving intrinsic safety instead of safety thanks to engineered safety systems ruled against that option.

For the fast spectrum reactor we chose to use a salt of 42% ZrF_4/10% NaF/48%KF. Zirconium is widely used in PWR reactors but has to be very highly purified to do so. This is because it invariably contains another element, hafnium, which is very similar chemically but a very strong absorber of thermal neutrons. Hafnium however is not a strong absorber of fast neutrons and we therefore chose to use unpurified (and therefore low cost) zirconium in our fast spectrum reactor.

This was not simply a cost saving exercise (though the low cost was welcome). While having hafnium in the coolant had only a minimal effect on the performance of the nuclear core, it resulted in the coolant salt between the core and the edges of the tank becoming a very effective neutron screen. As soon as neutrons slowed down by bouncing off the nuclei in the coolant, the hafnium absorbed them. The 1m of coolant around the core screened out 99.99% of neutrons escaping the core, eliminating the need for special neutron screens and preventing neutron damage to the metal structures of the reactor.

For the thermal spectrum reactor a different coolant was required since hafnium would destroy the cores reactivity. In principle, by using nuclear grade, highly purified zirconium we could have just used the same coolant. But that coolant would not then have been as effective a neutron screen and we would have needed a much larger reactor.

A much better option exists however. Thorium forms a tetrafluoride salt. A coolant comprising ThF_4 mixed with NaF and KF has suitable melting point and physical properties. This coolant has very interesting properties. It converts most of the neutrons that escape from the core into the fissile isotope uranium-233. It therefore converts the coolant into a breeding blanket.

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