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Melt-Based Breeder Pebbles: Effect of Cooling and Analysis of Droplet Formation

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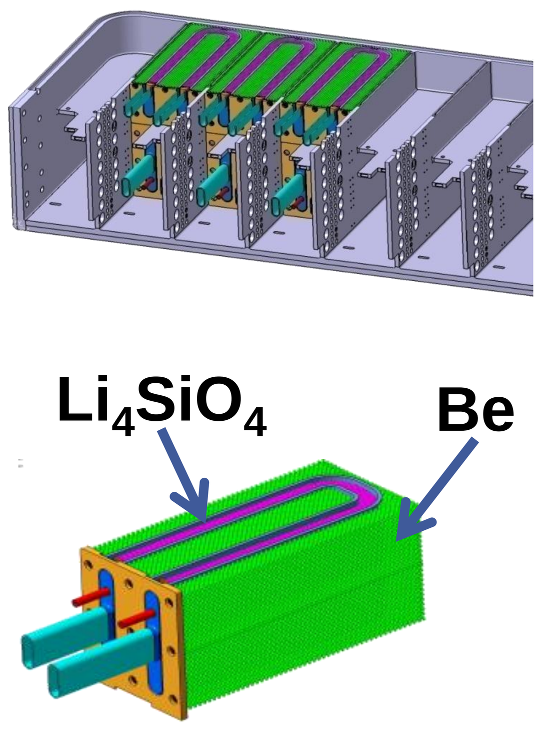
The Helium Cooled Pebble Bed (HCPB) blanket concept proposed by the European Union for ITER is made up of several breeder units containing two distinct pebble bed zones. One zone encloses beryllium pebbles as neutron multipliers and the other encloses lithium orthosilicate as ceramic tritium breeders. A purge gas, composed of helium and hydrogen, is used to remove the generated tritium.

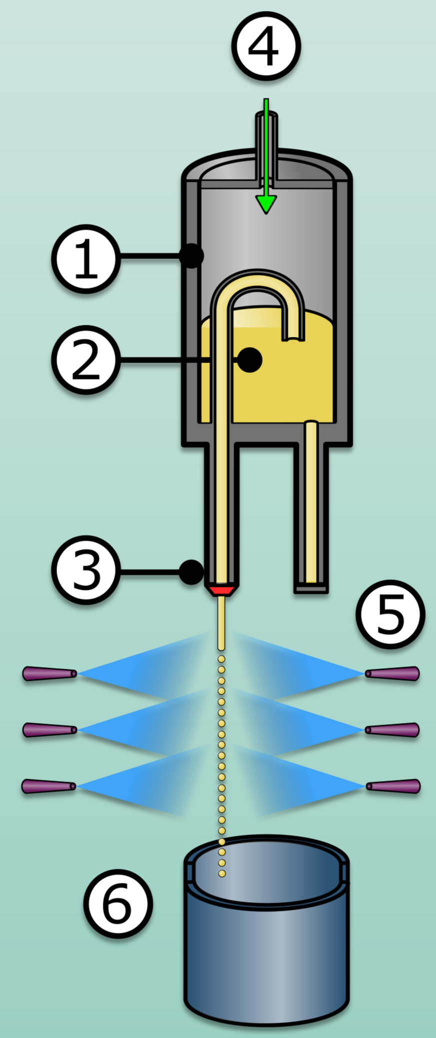


The design of the closed fuel cycle, including tritium production and extraction, is essential to the overall efficiency of the reactor. Although the pebbles have no structural function, they still need to be able to withstand forces originating from thermal expansion as well as neutron irradiation. It is critical that the pebbles do not fragment and disintegrate while in operation, reducing the efficiency and stability of the pebble bed.

Pebble Fabrication

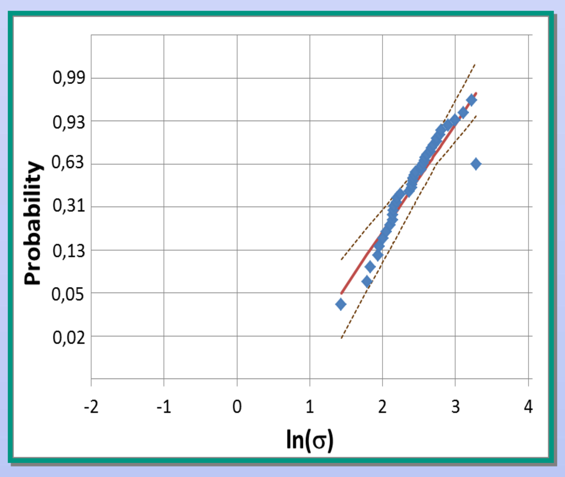
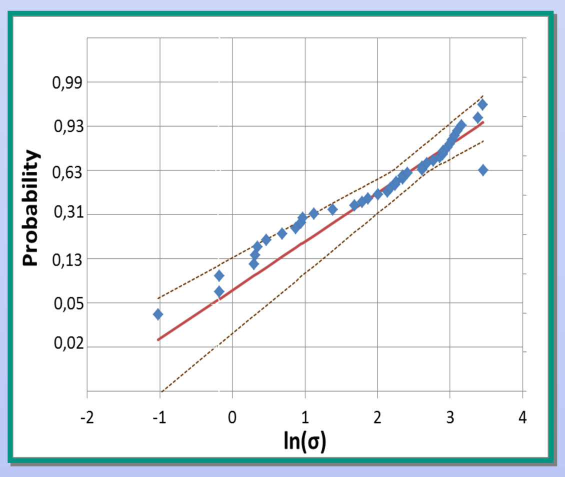
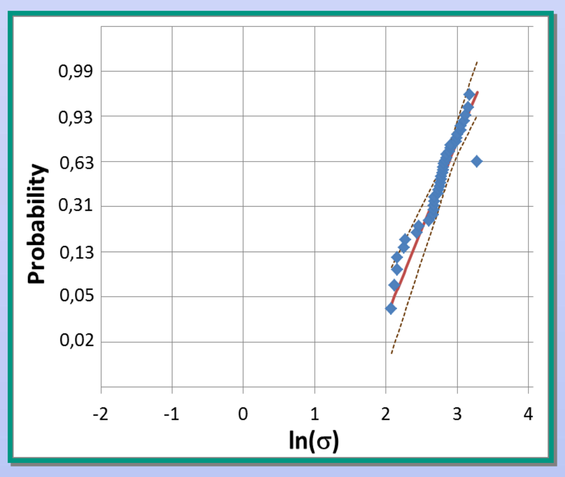
A melt-based process is used for the production of ceramic pebbles composed of **lithium orthosilicate**, Li_4SiO_4, with additions of **lithium metatitanate**, Li_2TiO_3.

1. Crucible temperature: **1300-1400 °C**
2. Precursors: **LiOH, SiO_2** and **TiO_2**
3. Nozzle diameter: **400 µm**
4. Filling tube and inlet for **400 mbar** synthetic air
5. LN_2 **spray cooling** method
6. LN_2 **quench** method



Weibull Analysis

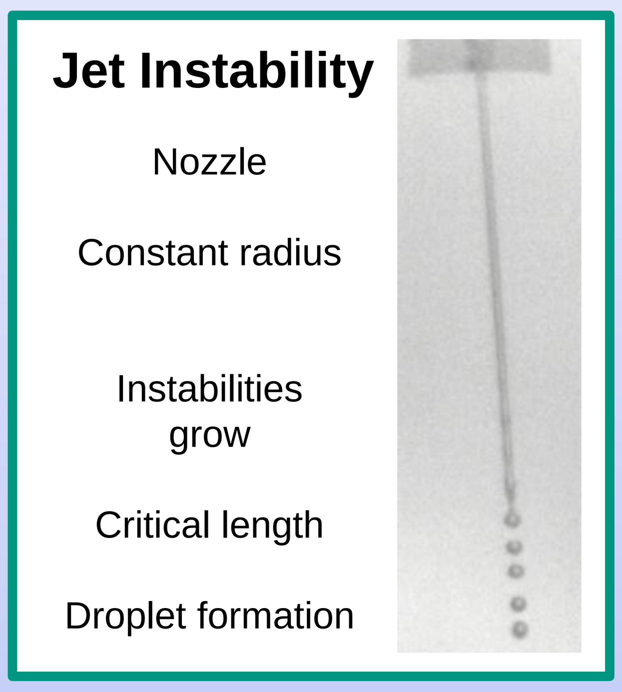
The strength distribution of ceramics follows a **continuous Weibull probability distribution**. The distributions generate a Weibull modulus which is typically used as an indication of the production **process stability**. Crush-loads are related to the **size of defects** such as cracks and pores that arise during production. The larger the modulus, the lower the amount of variation in the crush-loads implying that there are less random factors present in the process.

	Quench Method	14m Fall Tower	LN_2 Spray Method
Weibull Plot			
Weibull Modulus	m = 2.51	m = 1.10	m = 3.91

The highest Weibull modulus for the production of ceramic pebbles is achieved using the **liquid nitrogen spray cooling method**. This method also increases the overall strength by approximately 20%.

Droplet Formation

The process uses the principles of the **Rayleigh-Plateau instability** of a falling liquid jet to form droplets which then solidify to form pebbles. The instabilities originate from minute **external disturbances** which increase exponentially as the waves move further away from the nozzle. Eventually, when the pinched area becomes small enough, the jet will rupture causing the **formation of droplets,** which become spherical due to surface tension.



It can be assumed that an increase in the operating pressure will cause an increase in the **turbulence** around the nozzle and hence more **variation in the velocity** of the jet.

- At 200 mbar, the majority of the pebbles are produced in the 750 µm range consistently throughout the batch.
- At 400 mbar, many oversized pebbles are formed due to the fusion of unsolidified droplets moving at different velocities.
- At 1200 mbar, the pebbles are ejected at approximately 3 times the speed of those produced at 200 mbar. This causes a more violent 'pinching' during formation, resulting in many more pebbles smaller than 500 µm.