Proposal of Safety Criteria for MSRs
（In Comparison with LWRs）

THORIUM ENERGY CONFERENCE 2010

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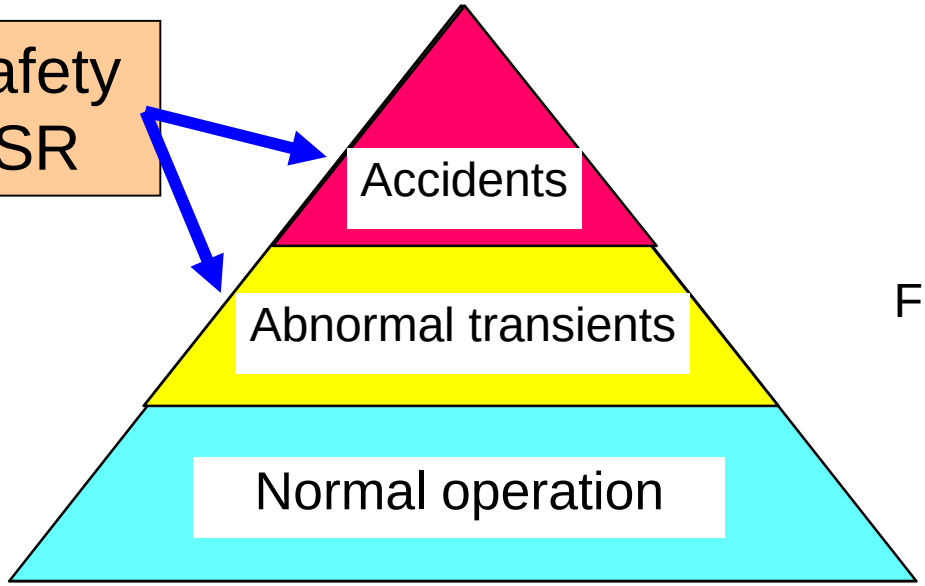
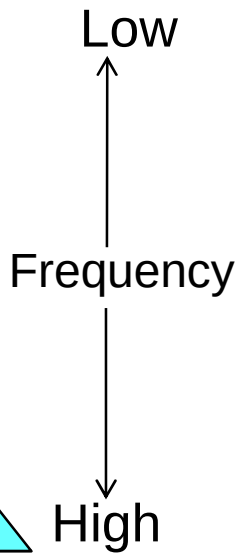
Objective of this study

To establish safety criteria for MSR





Accidents	Events beyond abnormal transients
Abnormal transients	Anticipated events to occur once or more during the plant service life Initiated by a single equipment malfunction, or a single operator error
Normal operations	Reactor shutdown or startup, besides operation at power

Safety criteria for abnormal transients in LWRs

Objective：To keep re-startup capability

①Minimum DNBR or MCPR shall not be violated.
②Fuel cladding shall not mechanically fail.
③Maximum fuel enthalpy shall be less than the limit.
④Reactor system pressure shall be less than the limit.

①～③: To keep fuel integrity

①：DNBR>1.17 for PWRs, and MCPR＞1.07 for BWRs
②：Plastic strain of fuel cladding tube＜１％
③：Maximum fuel enthalpy＜170cal/g・UO2 （un-irradiated）

④: To keep primary system integrity

Reactor system pressure shall be less than the 1.1 times of the maximum operating pressure.

Safety criteria for abnormal transients in MSRs

- In MSRs, fuel is molten salt, thus no criteria for fuel failure.
- Molten salt has high boiling temperature, low vapor pressure and no possibility of boiling, thus criteria of ①③④ can not be applied.
- Is it reasonable to apply the same criteria for fuel cladding to reactor vessel and piping of MSRs?

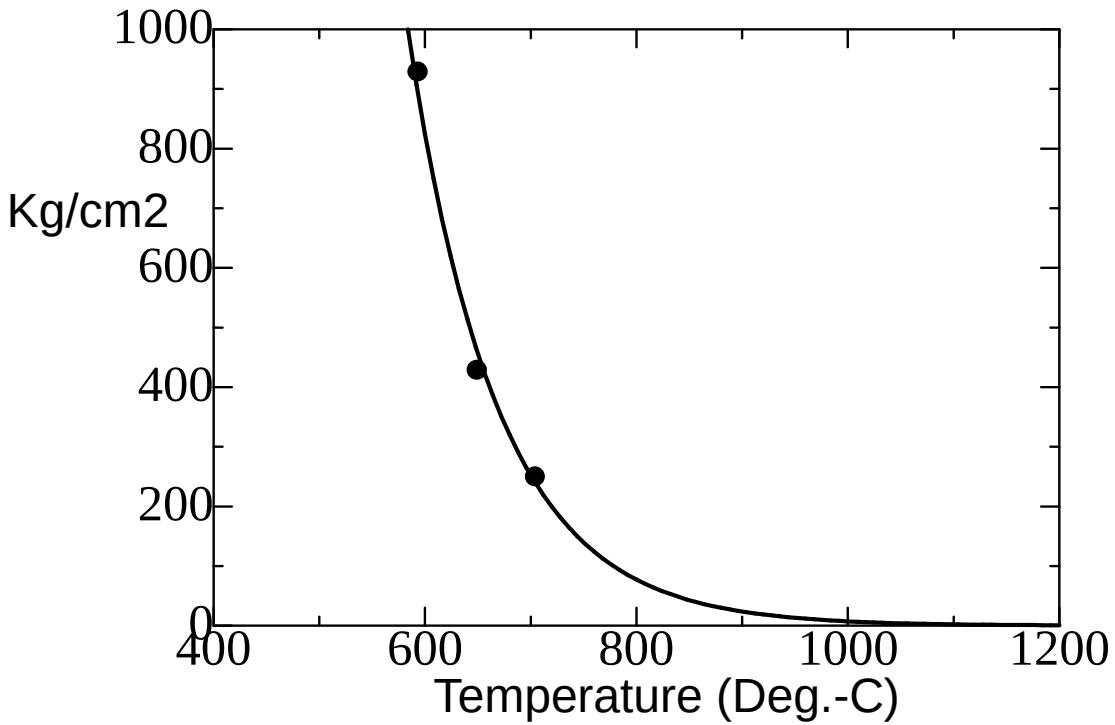
ORNL-4541（Conceptual design of MSBR）defines maximum allowable stress as ＜250Kg/cm2 @704 Deg.-C for Hastelloy-N

However, this criteria is valid for long term operation.

For a short time period, the allowable limit could be relaxed.

Maximum allowable stress of Hastelloy-N

- There are no data for beyond 704 Deg.-C.
- The limiting temperature may be around 1,000 Deg.-C?

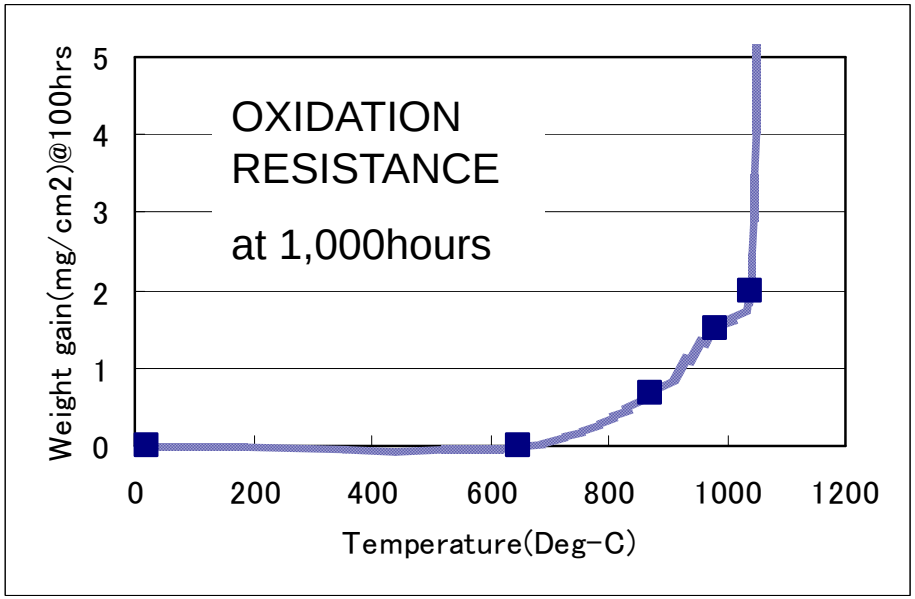


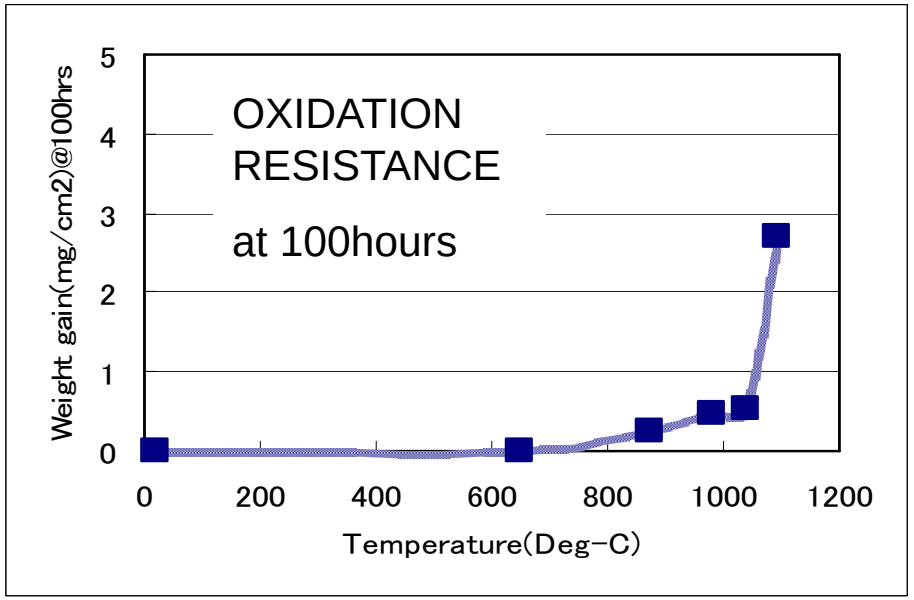
Ref.1)
http://www.haynesintl.com/pdf/h2052.pdf

- The reactor vessel for MSR is not a “pressure vessel”, and no pressurization transient will occur, thus loss of strength of the material could be the limiting condition.

Criteria for oxidation of Hastelloy-N

- ASME Pressure vessel standard defines the allowable oxidation.
- Maker's report says that **if** oxidation is a limit, about 1,000 Deg.-C may be the limit.
- The primary loop of MSR is enclosed with inert gas (:nitrogen gas), thus no oxidation will occur.
- Hence, no criteria from the oxidation standpoint is applicable.



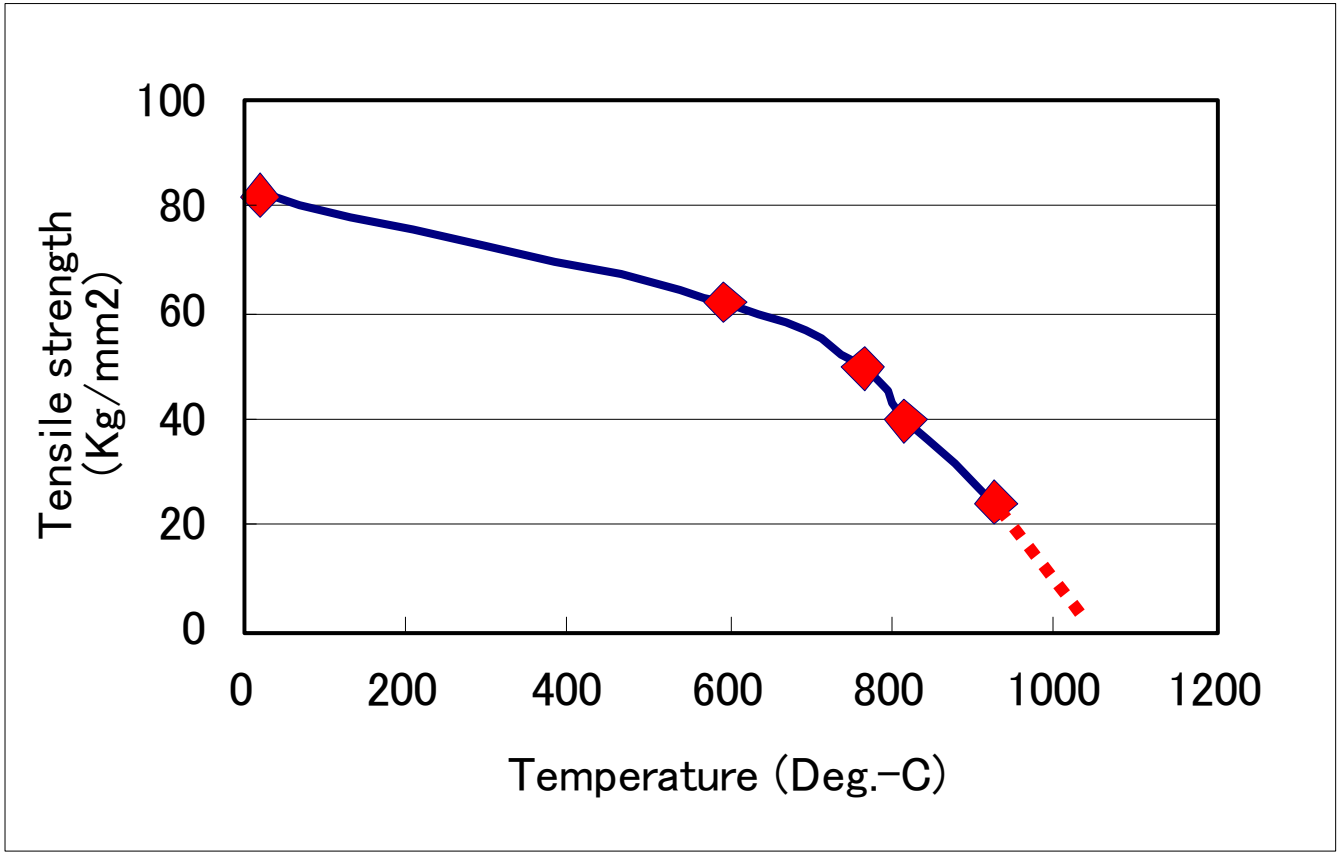


Ref.1 data

Tensile Strength of Hastelloy-N

In general, tensile strength is used as a strength of metals.

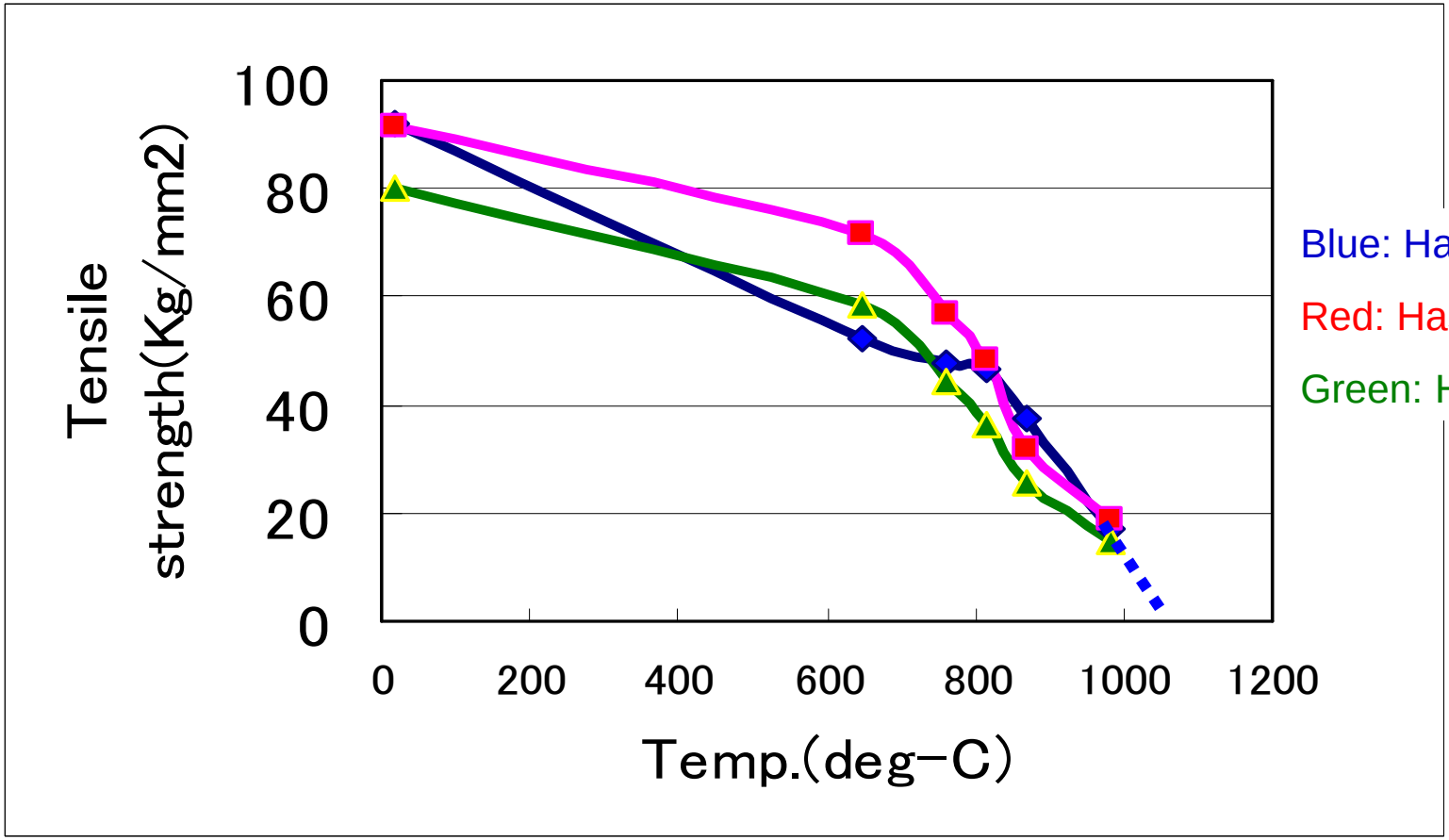
Based on the existing data for tensile strength, if it is extrapolated, the maximum allowable temperature could be about 1,000 Deg.-C.



Ref.1 data

Tensile strength of other Hastelloys

For other Hastelloys, the maximum allowable temperature could be also about 1,000 Deg.-C.



Ref.2) http://www.taihei-s.com/seihin13.htm

Another proposal of a criteria for abnormal transients in MSRs

- Assuming vessel temperature identical with fuel salt, the allowable fuel temperature should be less than the temperature which causes plastic strain of 1% during 1 hour under **the design load**.
- For example, 930 Deg.-C for outlet and 790 Deg.-C for inlet fuel salt for MSBR reactor vessel.
- Using Larson-Miller plot of Hastelloy-N (Ref.1), the limiting temperatures can be estimated.
- This is similar to that for fuel rod cladding criteria of LWRs.
- Violating this fuel temperature criteria, fuel salt must be drained to dump tank shortly.
- The dumps tank of MSRs can confine radioactivity, thus no radiation release will occur.

Safety criteria for Accidents in LWRs

Objective： Fuel failure is permitted, but large release of radioactivity shall not occur.

①Reactor is not damaged severely, and maintains coolable geometry.
②Fuel enthalpy must be lower than the limit.
③The reactor system pressure must be lower than 1.2 times of the maximum operating pressure..
④Maximum pressure of the containment boundary must be lower than that of the maximum design pressure.
⑤Severe radiation risk to the public near the reactor must be limited.

Safety criteria for accidents in MSRs

- In MSRs, no Design Base Accidents (DBAs) causing large radioactivity release will occur.
- Hence, safety criteria for DBAs should be investigated in the future
- Safety criteria for Severe Accidents, which are beyond DBAs, should be also discussed in the future.

Conclusion

- Against abnormal transients
  - The limiting fuel temperature to maintain tensile strength of Hastelloy-N; ≈1,000 Deg.-C.
  - Or, to limit the fuel salt temperature based on the plastic strain of 1% during 1 hour under design load; (≈For example, 930 Deg.-C for outlet and 790 Deg.-C for inlet fuel salt in MSBR reactor vessel.)
- Criteria against Design Basis Accident (DBA) and Severe Accident beyond DBA must be investigated in future.

Thank you for your attention!

Any questions/comments?