Study on the Effect of Heatup Rate on Rupture Temperature Model of SPACE Code

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Introduction

❑ Fuel Cladding Rupture Model of SPACE

- Based on NUREG-0630 model which is a function of hoop stress and heatup rate
- Instant heatup rate is sensitive to time step size and change of cladding temperature
- Considering complex thermal-hydraulic behavior during LOCA, instant heatup rate may be unstable, so that prediction of rupture temperature would be wrong.

❑ NUREG-0630 Model

$$T_R = 4233 - \frac{20.4\,S}{1+H} - \frac{8.51\times 10^6\,S}{100(1+H)+2790\,S}$$

T_R : rupture temperature (K)
S : engineering hoop stress (kpsi)
H : heatup rate ratio, max(0, min(heat rate / 28 K/s))

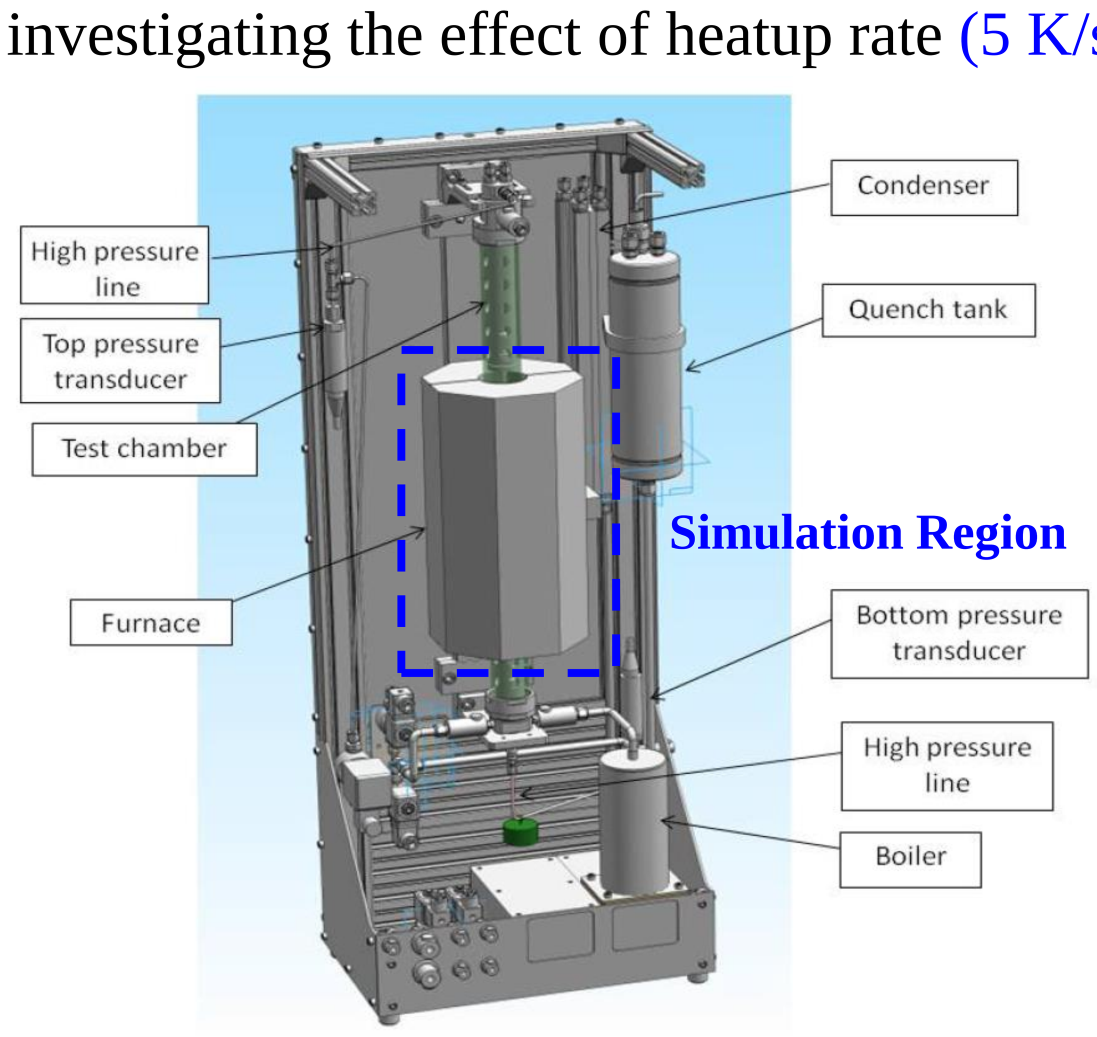
❑ Effect of FFRD on Rupture Model

- Fuel crumbling will reduce gap size, increase gap conductance and change cladding temperature.
- In code simulation, instant change of cladding temperature due to fuel crumbling will affect the heatup rate seriously.
- To avoid such an undesirable situation, time-averaged heatup rate model has been developed and implemented into SPACE.

Experimental Data

❑ NRC-Studsvik LOCA Test 192

- provides experimental data with well-controlled cladding wall temperature which is required for investigating the effect of heatup rate (5 K/s).



Apparatus of NRC-Studsvik test

Time-averaged Heatup Rate Model

$$\frac{\int_0^T W(t)\frac{\Delta Tc}{\Delta t}dt}{\int_0^T W(t)dt} = \frac{\int_0^T \frac{\Delta Tc}{\Delta t}dt}{\int_0^T dt} \cong \frac{\sum_{i=0}^{N}\left(\frac{\Delta Tc}{\Delta t}\right)_i \Delta t_i}{\sum_{i=0}^{N}\Delta t_i} = \frac{\sum_{i=0}^{N}\Delta Tc_i}{\sum_{i=0}^{N}\Delta t_i}$$

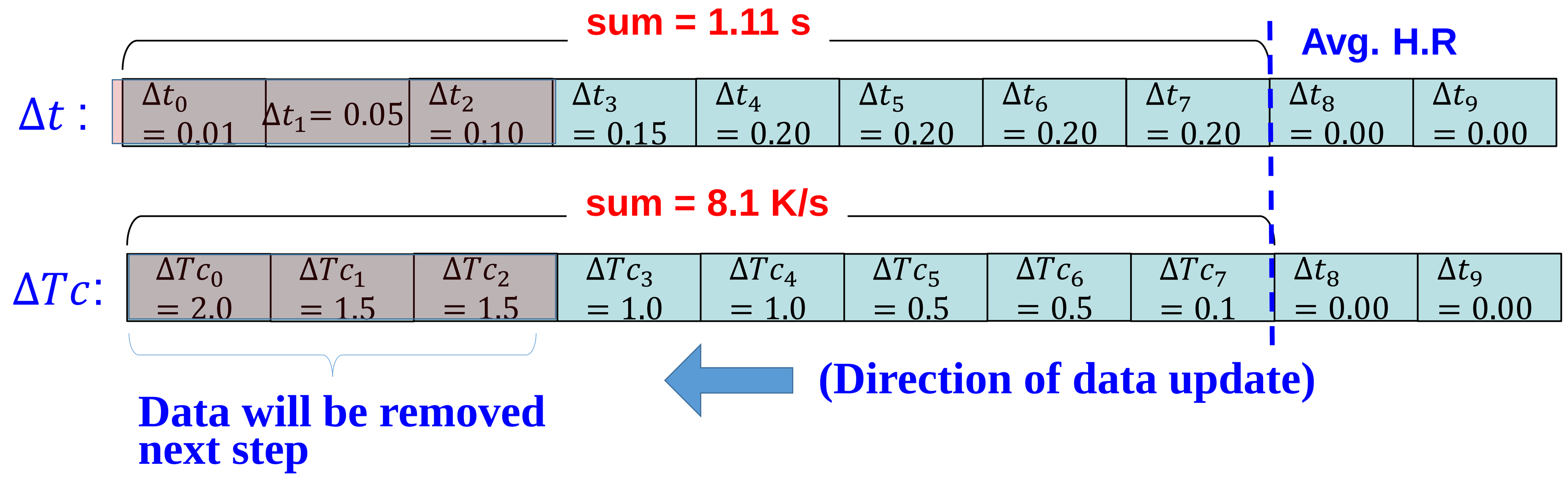
$(W(t) = 1)$

ΔTc_i: change of cladding temperature at i[th] step
Δt_i: time step size at i[th] step

$$N = \frac{2}{max.time\ step\ size}$$: Number of elements of array

❑ Example of Time-averaged Method

- $max.\Delta t = 0.2\ s$, time interval for determining H.R = 1 s (number of elements, $N = 10$)

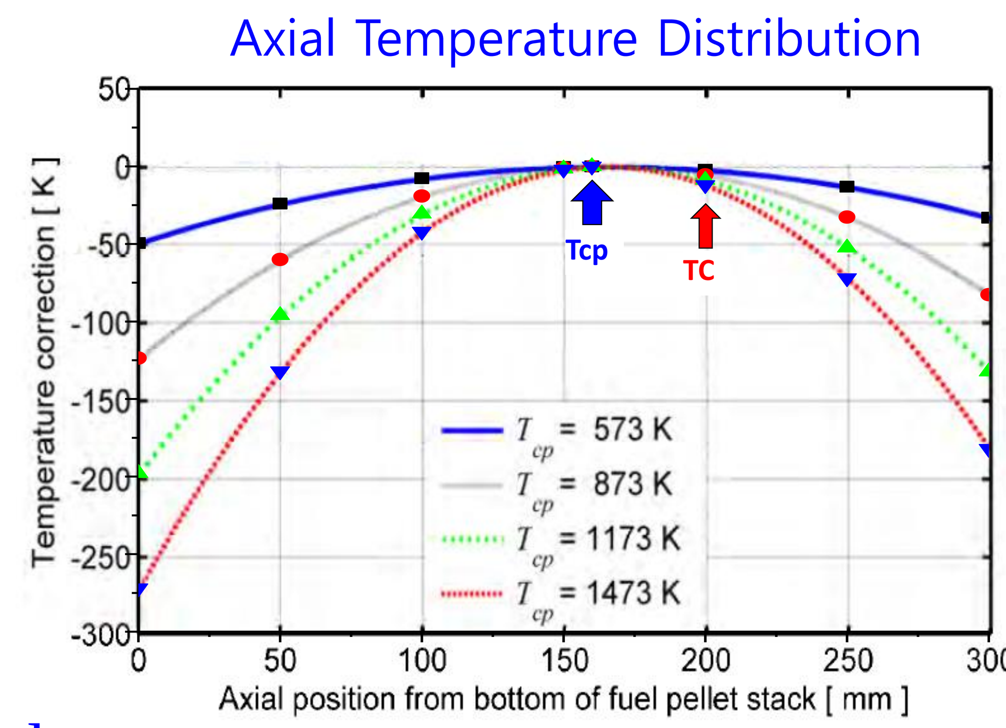


$$Avg.HR = \frac{\sum_{i=0}^{N}\Delta Tc_i}{\sum_{i=0}^{N}\Delta t_i} = \frac{8.1\ K}{1.11\ s} \cong 7.3\ K/s$$

Simulation Results

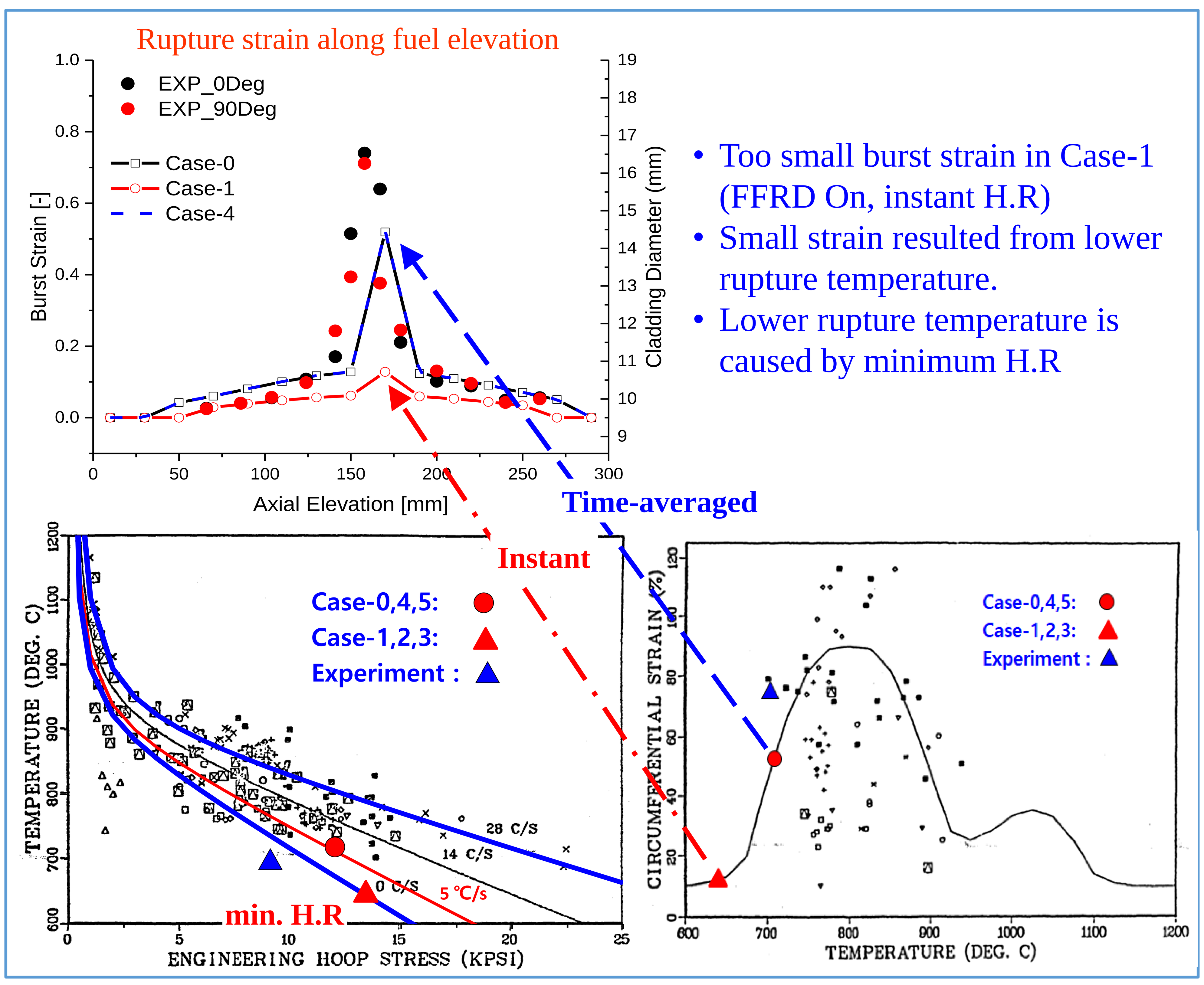
❑ Simulation Cases

Case	FFRD	Option	Duration (s)
0	N/A	instant	-
1	applied	instant	-
2	applied	average	0.1
3	applied	average	0.5
4	applied	average	1.0
5	applied	average	2.0



❑ Summary of Simulation Results

Parameter	Case-0	Case-1	Case-2	Case-3	Case-4	Case-5
Time (s)	1158.6	1150.7	1150.7	1150.6	1158.7	1158.7
Tc (K)	981.1	937.3	937.2	935.5	981.4	981.4
Tr (K)	981.1	920.9	921.0	921.2	981.4	981.4
HS (kpsi)	12.42	13.25	13.24	13.24	12.40	12.40
HR (K/s)	5.4	-125.5	-6.5	2.36E-3	5.4	5.4



- Too small burst strain in Case-1 (FFRD On, instant H.R)
- Small strain resulted from lower rupture temperature.
- Lower rupture temperature is caused by minimum H.R

Conclusions

- Fuel cladding rupture temperature model of SPACE is strongly dependent on the heatup rate at rupture and when fuel rupture occurs together with fuel crumbling which causes drastic change of heatup rate.
- Time-averaged heatup rate model was newly implemented into SPACE for accurate estimation of heatup rate and it agreed well with measured heatup rate and busrt strain
- Recommended time duration for averaging is 1 second for this test.