

TROI

**An Experimental Study on a Steam Explosion with Corium Melt
in the TROI Facility**

150

TROI

70:30) UO₂ ZrO₂ (,

5 ~ 10kg ,

5 .

250kN ,

7.0MPa ,

Abstract

In the TROI experiments, the characteristics of a steam explosion have been studied using the melt of the real reactor material (corium) and water. In these experiments, the mixture of UO₂ and ZrO₂ (corium, 70:30) was used as a molten reactor material, and the mass of the material was 5 ~ 10kg. Total 5 experiments have been performed at atmospheric pressure and at room temperature. Steam explosions occurred three times and did not occur twice among the experiments. The data acquired in the tests were static pressures and temperatures in the pressure vessel and the interaction vessel. Also, in case of a steam explosion, dynamic pressures in the interaction vessel and dynamic loads to the bottom were obtained. In case of a steam explosion, a dynamic pressure reached 7.0MPa and a dynamic load was measured to be 250kN. The size of debris after a steam explosion was very fine compared with those without a steam explosion. However, the concentration of hydrogen which is thought to suppress a steam explosion was found to be negligible.

1.

TM-2

(quenching) , 가

(steam explosion) .

[1], [2, 3, 4], [5, 6], [7, 8], [9]. JRC-Ispra FARO/KROTOS TROI TROI 가 ZrO₂ [10, 11], 가

2. TROI

TROI 1 212°C 20 (>3000K) 가 가 water jacket 가 가 150kW, 50kHz 가 가 가 가 (cold crucible induction heating method) Lebedev Institute of the Academy Science of the USSR [12]. finger 가 (fingers) finger 가 finger 가 [13].

가 가 가 1 2 grey body (emissivity ratio: 1.0) (3100°C) emissivity ratio 1.2

$$\frac{1}{S} = \frac{1}{T} - K \ln(g) \quad (1)$$

, S, T, K, g, emissivity ratio 2000°C Emissivity ratio 1.18

grey body TROI-11 3100°C
4150K

(1) 1000 ~ 2000°C

K-type 가
(Piezoelectric pressure transducer, PCB Piezotronics Inc., Model 112A, maximum range: 69MPa 6.9MPa)가
(Druck Co., Model PMP4060, maximum range: 35bar)가
VXI system(Agilent Technology)

가 CCD
Phantom V4.0 512×512 pixel 1000 frames/sec CCD
가 200cc 가 가

3. TROI

TROI TROI-9 TROI-13 5
UO₂ ZrO₂ 70 : 30 TROI-9 TROI-13
2

3.1. TROI-9

TROI-9 14.23kg UO₂ ZrO₂ ()
4.325kg , 90cm
UO₂ , 2 3200K 가
3 0.01MPa 가 4
70K 5
가 7K
, ZrO₂ 가 [10]. ZrO₂
가 1 ~ 5cm , 2 6
가 1cm , 60% 가 2 ~ 5mm
가 FCI 35ppm
814ppm FCI 0.54g
가 FARO
가 [5], TROI FARO
가 TROI 2.5% 가

3.2. TROI-10

TROI-10 TROI-9

8.675kg , 67cm 13.7kg , DAS

7 , 가 3800K 8

0.012MPa 가 , 0.13MPa 가 가

9 / 2

15 , 가 17K

/ 가 10

10 30K 가

TROI-9 , TROI-9

11

TROI-9 가

1502ppm , 90ppm

0.98g , 0.49mole,

3.3. TROI-11

TROI-11 TROI-10 , DAS

9.185kg , 67cm 13.7kg

12 ,

TROI-10 4150K ,

13 0.122MPa

가 가 , TROI-10

TROI-10 14

가 , 50K

TROI-10 ,

15

10 가 20K ,

16 UO₂ ,

17

31ppm, 18ppm ,

가

가

3.4. TROI-12

TROI-12 TROI-9, 11 , TROI-10
 , 13.7kg 8.360kg
 , 67cm
 18 18(a) 가
 , 18(b)
 가 , 18(c)
 18(d) 19
 3800K
 가 가
 20 1.0MPa
 1ms 16ms 21
 220kN 22 0.12MPa ,
 TROI-10 23 12K
 , TROI-10 24
 22K 25
 , TROI-10
 33ppm, 1239ppm

3.5. TROI-13

TROI-13 TROI-12
 , 13.7kg 7.735kg
 , 67cm 26
 , TROI-12
 가 Zr , Zr
 가 가
 가 3500K 가
 가 2600K , 3500K
 27 7.0MPa TROI-
 12 가
 , 28
 , load cell 250kN
 , 15ms TROI-12 29
 , 가 23K 30
 24K 가 IVT104 가
 가 31

, TROI-12

TROI-12

188ppm

165ppm

가

5.

TROI-9

TROI-13

- (UO₂ : ZrO₂ = 70 : 30)

TROI-9

TROI-13

- 7.0MPa

250kN

- FCI

가

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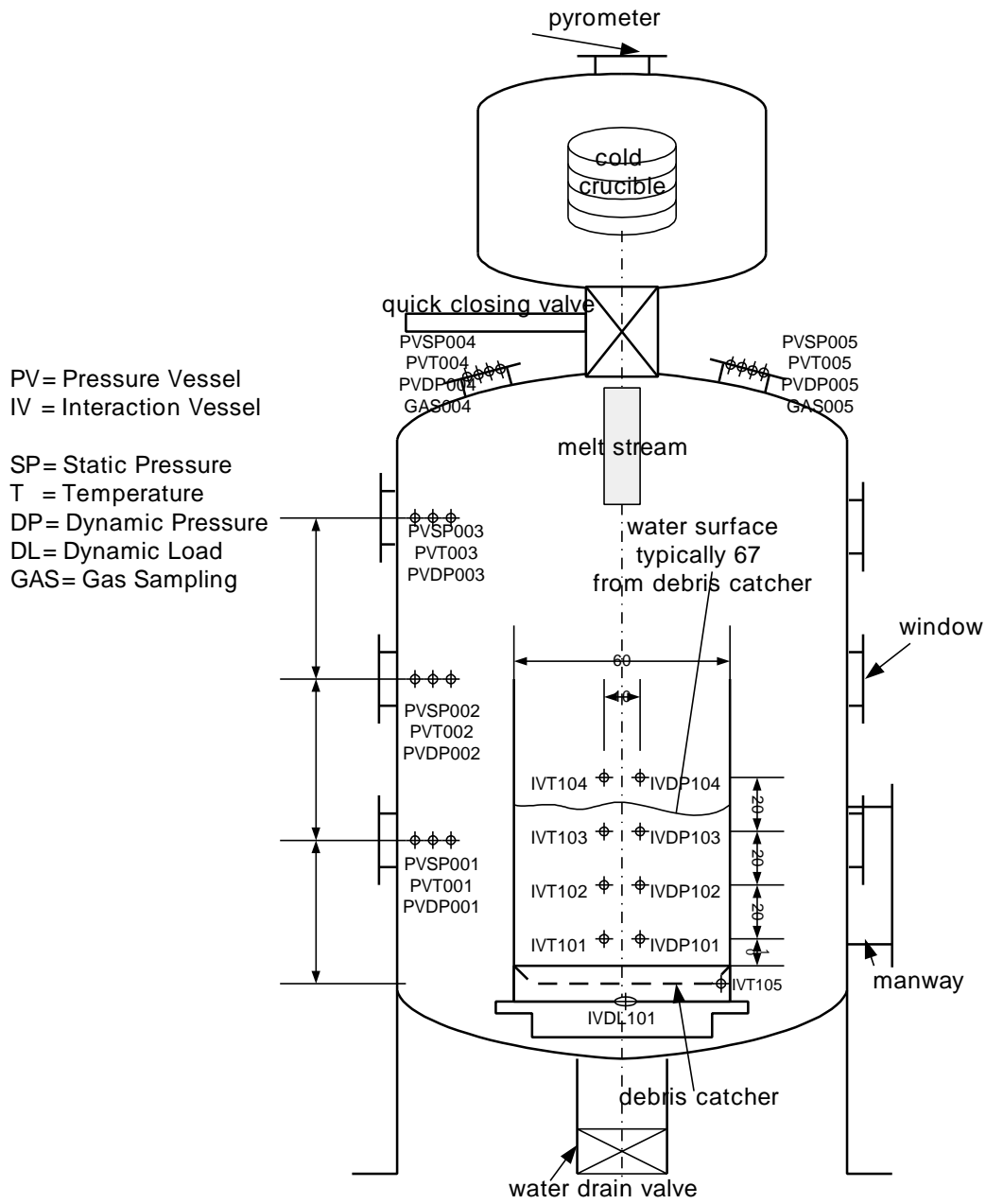
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11. , “ ZrO_2 UO_2/ZrO_2 FCI ”, (2001).
12. V. I. ALEKSANDROV, V. V. Osiko, A. M. Prokhorov and V. M. Tatarntsev, *Synthesis and crystal growth of refractory materials by RF melting in a cold container*, Chapter 6, Current topics in materials science, Vol. 1, edited by E. Kaldis, North-Holland publishing company (1978).
13. S. W. Hong, B. T. Min, J. H. Song, H. D. Kim and J. K. Choi, “A Study on the Melting and Release of Refractory Materials using Induction Skull Melting,” *Proceedings of the Second Japan-Korea Symposium on Nuclear Thermal Hydraulics and Safety*, Fukuoka, Japan (2000).

1. Sensor description in TROI tests

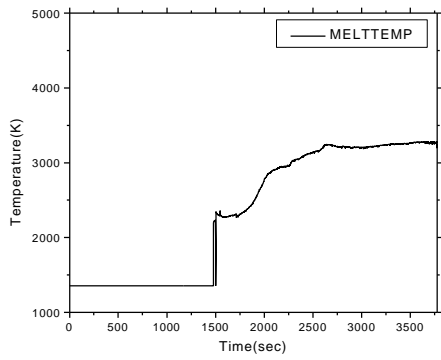
Parameter	Sensing location	Sensor description
Coolant temperature	IVT101 ~ IVT104	1mm, Thermocouple
Dynamic pressure in the coolant	IVDP101 ~ IVDP104	PCB model 112A <60MPa
Dynamic load at the test section bottom	IVDL101	PCB model 210B50 <50000 lb _f
Atmosphere temperature in the pressure vessel	PVT001 ~ PVT005	1.6mm, Thermocouple
Transient pressure in the furnace vessel	FVSP1	Druck model PMP4060 <35bar
Transient pressure in the pressure vessel	PVSP002, PVSP003	Druck model PMP4060 <35bar
Dynamic pressure in the pressure vessel	PVDP004, PVDP005	PCB model 112A <20MPa

2. Initial condition & results for TROI tests (SE=Steam Explosion)

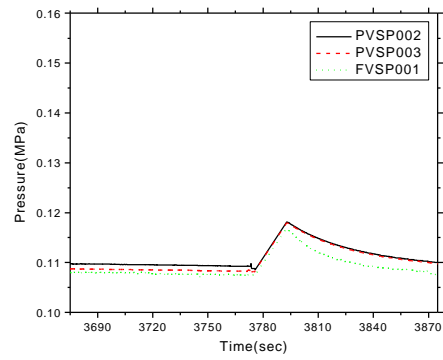
	TROI test number	Unit	9	10	11	12	13
Melt	Initial Charge Composition	[w/o]	67/32/1	69/30/1	69/30/1	69/30/1	69/30/1
	UO ₂ / ZrO ₂ / Zr						
	Temperature	[K]	3200	3800	4150	3800	2600
	Charged mass	[kg]	14.23	13.7	13.7	13.7	13.7
	Initiator mass	[kg]	0.1	0.1	0.1	0.1	0.1
	Released mass	[kg]	4.325	8.675	9.185	8.360	7.735
	Initial jet diameter	[m]	-	-	-	-	-
	Free fall in gas	[m]	2.5	2.5	2.5	2.5	2.5
Test Section	Water mass	[kg]	254	189	189	189	189
	Initial Height	[cm]	90	67	67	67	67
	Final height	[m]	-	-	-	50	55
	Cross section	[m ²]	0.283	0.283	0.283	0.283	0.283
	Initial temperature	[K]	296	298	296	293	292
	Sub-cooling	[K]	77	75	77	80	81
Pressure Vessel	Initial pressure(air)	[MPa]	0.1	0.117	0.111	0.11	0.108
	Free volume	[m ³]	8.032	8.032	8.032	8.032	8.032
Results	Maximum PV pressurization	[MPa]	0.01	0.012	0.01	0.008	0.016
	Time to reach peak	[sec]	18	2.5	3	2	<1
	Maximum PV heat-up	[K]	70	17	50	14	23
	Time to stabilize	[sec]	15	15	20	<7	<1
	Maximum water heat-up	[K]	6	48	20	17	24
	Time to reach peak	[sec]	18	3	12	<1	<1
	Steam explosion		NO	SE	NO	SE	SE
	Dynamic pressure peak	[MPa]	-	?	-	1.0	7.0
	Duration	μsec	-	-	-	1ms	1ms
	Impulse	kN	-	-	-	210	250
	Duration	μsec	-	-	16ms	15ms	
Debris	Total	[kg]	4.325	8.675	9.185	8.360	7.735
	>6.35mm	[kg]	0.09	0.435	1.49	0.295	0.620
	4.75mm ~ 6.35mm	[kg]	0.4	0.725	1.365	0.390	0.245
	2.0mm ~ 4.75mm	[kg]	2.6	3.39	4.8	3.385	2.675
	1.0mm ~ 2.0mm	[kg]	0.815	2.025	1.25	1.715	1.225
	0.71mm ~ 1.0mm	[kg]	0.18	0.64	0.235	0.580	0.540
	0.425mm ~ 0.71mm	[kg]	0.14	0.705	0.04	0.805	0.965
	<0.425mm	[kg]	0.1	0.755	0.05	1.190	1.465
H ₂ gas	Before/After the interaction	[ppm]	35/814	90/1502	31/18	33/1239	188/165
	Mass	[g]	0.54	0.98	0.012	0.82	0.11



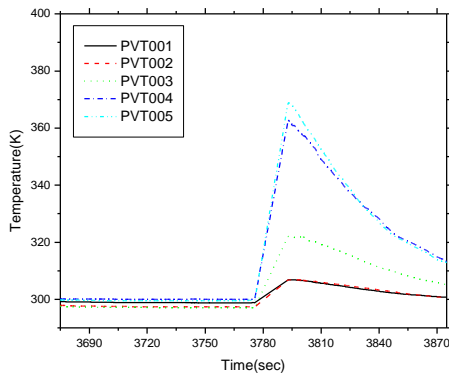
1. Schematic diagram of TROI facility



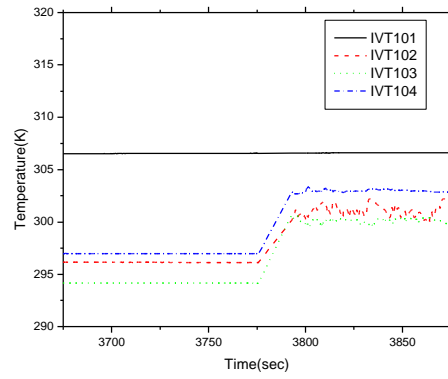
2. Melt temperature in TROI-9 test



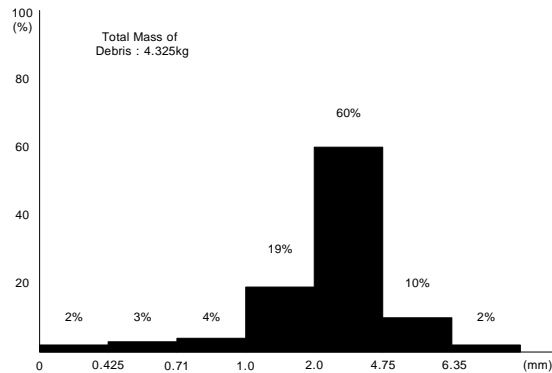
3. Static pressures in the pressure vessel in TROI-9 test



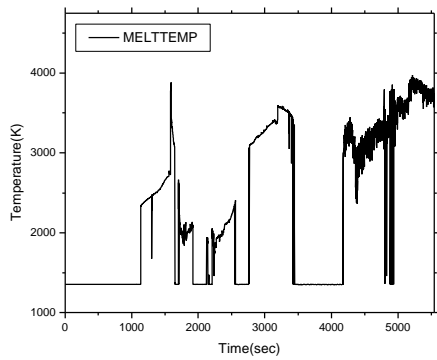
4. Temperatures in the pressure vessel in TROI-9 test



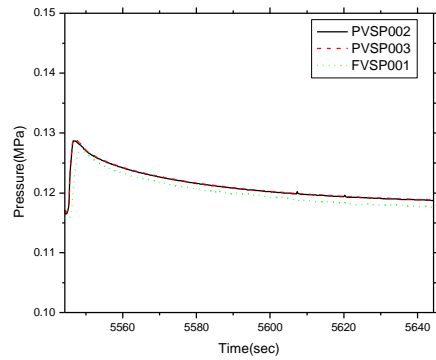
5. Temperatures in the interaction vessel in TROI-9 test



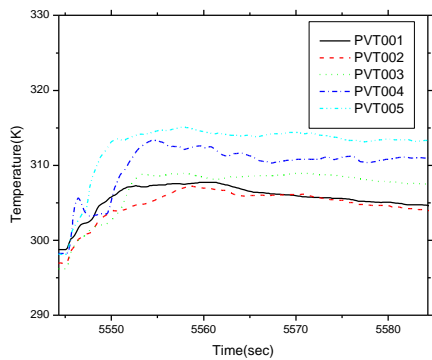
6. Sieved debris distribution in TROI-9 test



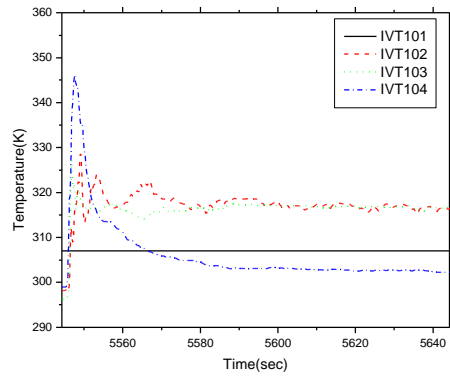
7. Melt temperature in TROI-10 test



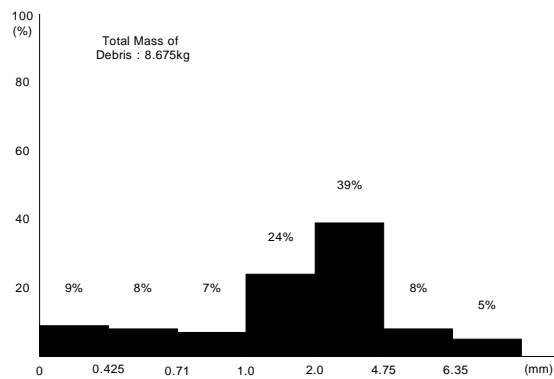
8. Static pressures in the pressure vessel in TROI-10 test



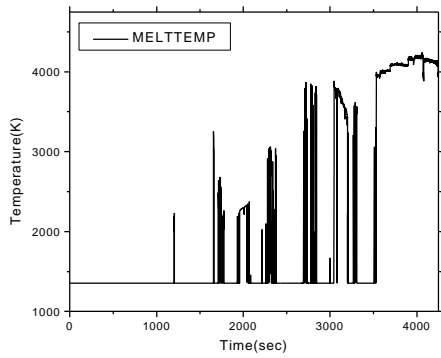
9. Temperatures in the pressure vessel in TROI-10 test



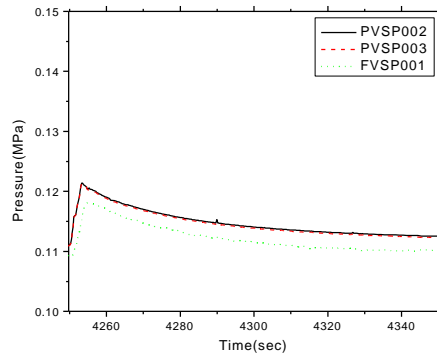
10. Temperatures in the interaction vessel in TROI-10 test



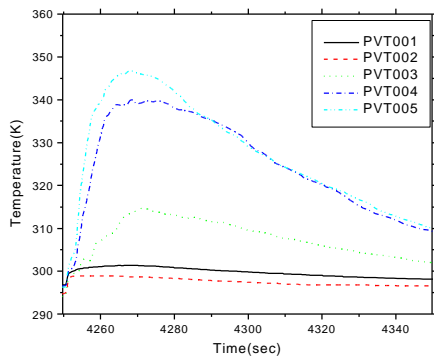
11. Sieved debris distribution in TROI-10 test



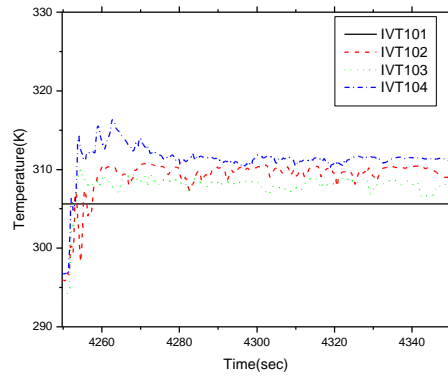
12. Melt temperature in TROI-11 test



13. Static pressures in the pressure vessel in TROI-11 test



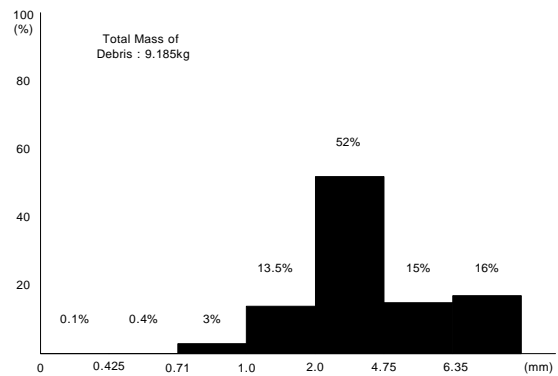
14. Temperatures in the pressure vessel in TROI-11 test



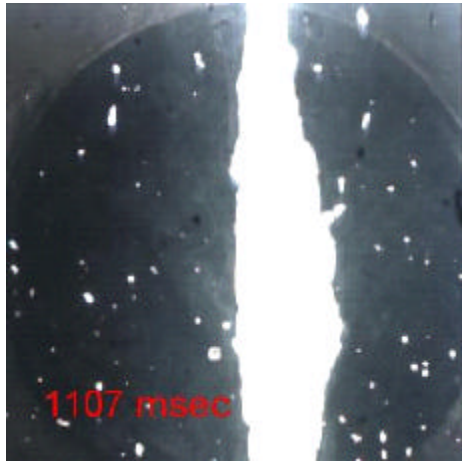
15. Temperatures in the interaction vessel in TROI-11 test



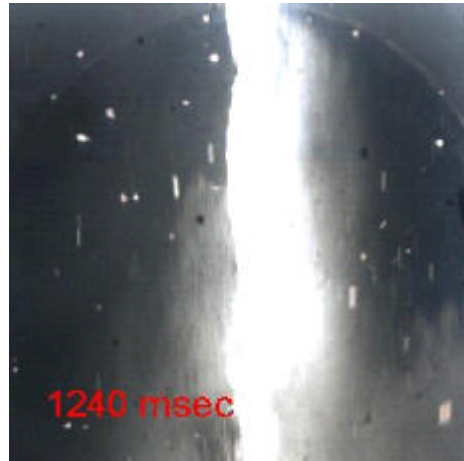
16. UO2 pellets in the debris in TROI-11



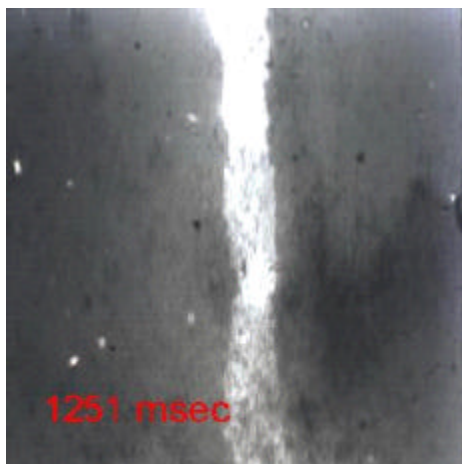
17. Sieved debris distribution in TROI-11 test



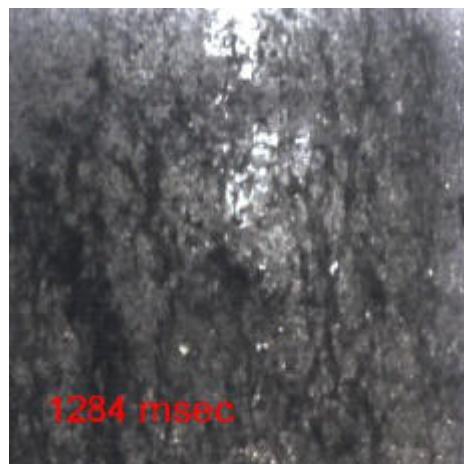
(a)



(b)

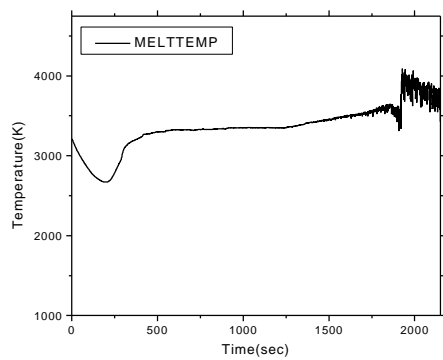


(c)

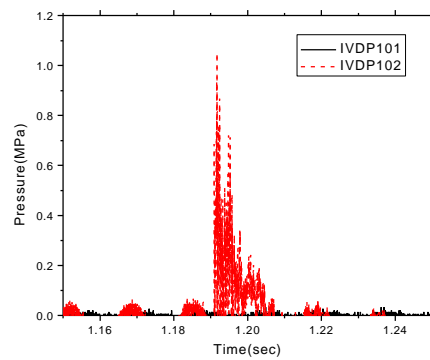


(d)

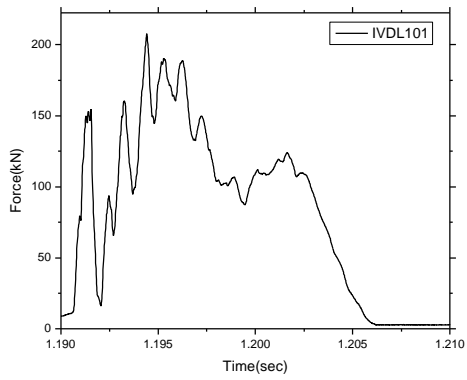
18. Photographs of steam explosion process



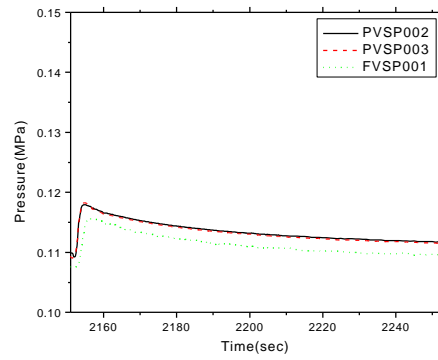
19. Melt temperature in TROI-12 test



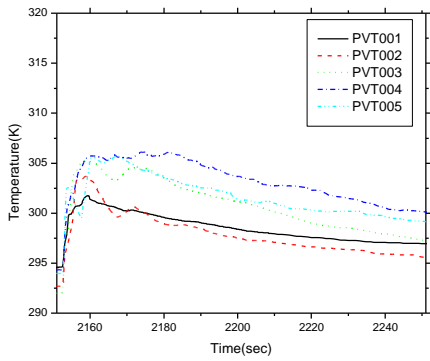
20. Dynamic pressures in the interaction vessel in TROI-12 test



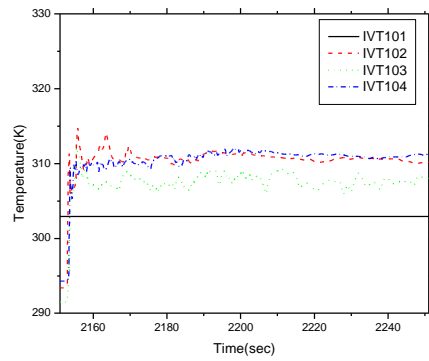
21. Dynamic load onto the interaction vessel in TROI-12 test



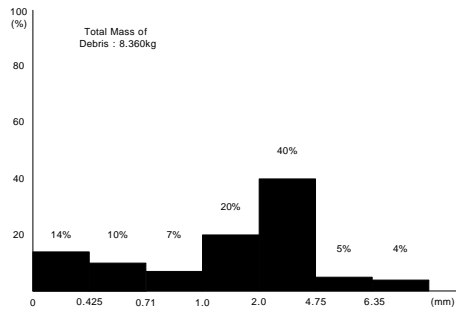
22. Static pressures in the pressure vessel in TROI-12 test



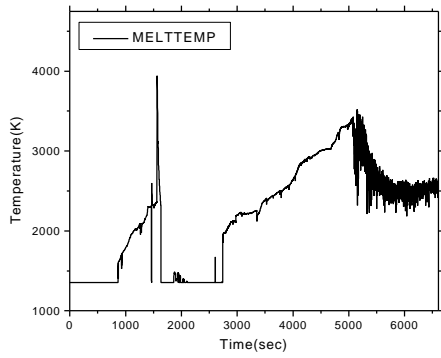
23. Temperatures in the pressure vessel in TROI-12 test



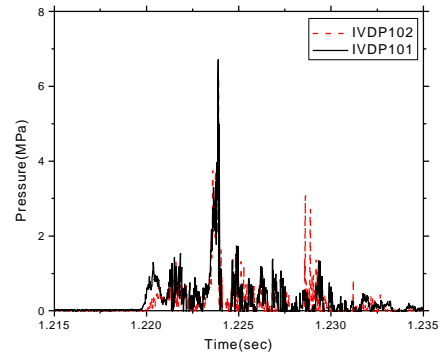
24. Temperatures in the interaction vessel in TROI-12 test



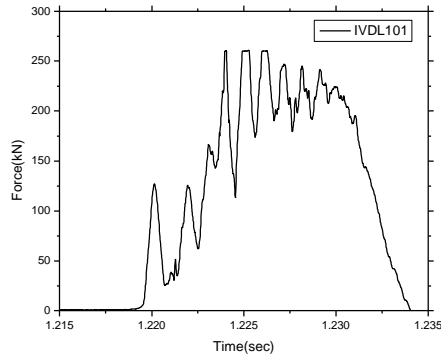
25. Sieved debris distribution in TROI-12 test



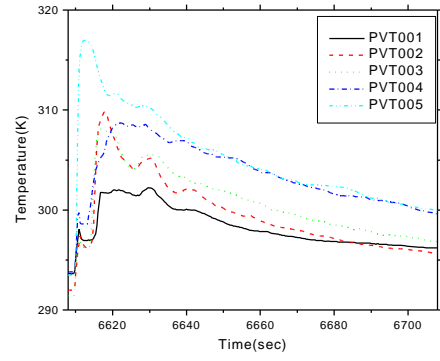
26. Melt temperature in TROI-13 test



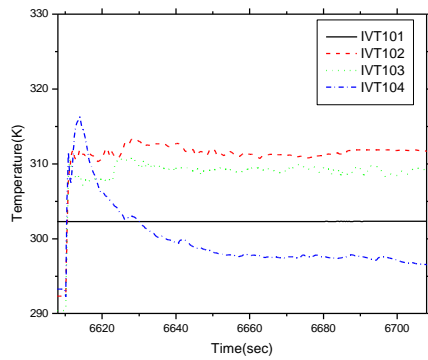
27. Dynamic pressures in the interaction vessel in TROI-13 test



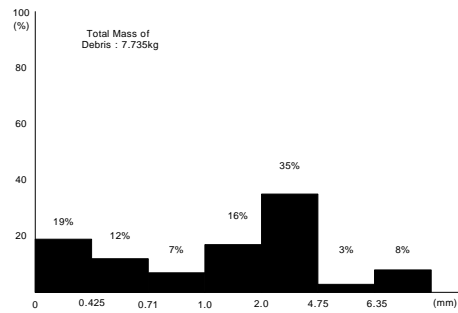
28. Dynamic load onto the interaction vessel in TROI-13 test



29. Temperatures in the pressure vessel in TROI-13 test



30. Temperatures in the interaction vessel in TROI-13 test



31. Sieved debris distribution in TROI-13 test