

TROI 가

An Effect of Corium Composition Variations on Occurrence of a Steam Explosion in the TROI Experiments

150

TROI 가

		UO <sub>2</sub>	ZrO <sub>2</sub>	0 : 100, 50 : 50,
70 : 30, 80 : 20	87 : 13	10 kg	.	가 0 : 100
zirconia			, 50 : 50	
				70 : 30
		가	steam spike	가
				가
	80 : 20			
	steam spike	가		
가	87 : 13			, UO <sub>2</sub>
	steam spike	mush zone		가
				가

Abstract

Recently series of steam explosion experiments have been performed in the TROI facility using corium melts of various compositions. The compositions (UO<sub>2</sub> : ZrO<sub>2</sub>) of the corium were 0 : 100, 50 : 50, 70 : 30, 80 : 20 and 87 : 13 in weight percent and the mass of the corium was about 10kg. An experiment using 0 : 100 corium (pure zirconia) caused a steam explosion. An experiment using 50 : 50 corium did not cause a steam explosion while a steam spike occurred in an experiment using 70 : 30 corium which was the eutectic point of corium. A steam spike is considered to be the fact that a triggering of a steam explosion occurred but a propagation process does not occur so as to cause a weak interaction. However, the possibility of a steam explosion with this composition can not be ruled out since many steam explosions occurred in the previous experiments. In the two experiments using 80 : 20 corium, a steam spike occurred in one experiment but no steam explosion occurred in the other experiment. However, the triggerability of a steam explosion with this composition is not clear since few steam explosions occurred in the previous experiments. And no steam explosion occurred in an experiment using 87 : 13 corium of which urania content was the greatest among the experiments performed in the TROI facility. From this, the possibility of a steam explosion or a steam spike is appeared to be high in the non-mush

zone. It is considered that an explosive interaction could easily occur with the eutectic composition. Since the solidification temperature around the eutectic point is low, the melt is likely to maintain its liquid state at the time of triggering so as to cause an explosive phenomenon.

## 1.

가 . . . . . [1],  
 [2, 3, 4], . . . . . [5, 6, 7],  
 [8, 9, 10] . . . . .  
 ,  
 [11]. ANL ZREX [4] JRC-Ispra FARO/KROTOS  
 zirconia zirconia  
 [5, 6, 7] TROI [12, 13, 14, 15, 16, 17] zirconia  
 가 . TROI  
 가

## 2. TROI

TROI 1 . . . . . , . . . . .  
 . . . . . (>3000K)  
 가 (Cold crucible) 가 가 가  
 150kW, 50kHz . 가  
 가 . . . . . , . . . . .  
 , 가 가 , . . . . . ,  
 가 가 , 60cm, 150cm,  
 2cm , 가 60cm, 120cm,  
 1cm 가 가 . TROI-32  
 1 . . . . . 가 2  
 (IRCON 1500~3500°C) . 가  
 (grey-body condition) 가 가  
 . 가  
 K-type 가  
 . (Piezoelectric pressure transducer, PCB Piezotronics Inc., Model 112A, maximum  
 range: 60MPa 20MPa)가 .

underwater pressure transducer(PCB model W138A26, maximum range : 160MPa) . . . . .

(Druck Co., Model PMP4060, maximum range: 3.5MPa, Rosemount model 1511: 2.0MPa)가

VXI system(Agilent  
 Technology) 가 CCD  
 Phantom V4.0 512×512 pixel 1000 frames/sec  
 CCD  
 가 ( zirconia)  
 가 가  
 Zr 가 Zr 가 ,  
 zirconia 가  
 가 가 가 가 가 가  
 , 가 plug  
 , puncher ,  
 triggering , ,

### 3. TROI

zirconia TROI-27 TROI-32 6  
 . TROI-27 UO<sub>2</sub> ZrO<sub>2</sub> 80 : 20 9.5kg 38K  
 67cm ( : 60cm) . TROI-28  
 UO<sub>2</sub> : ZrO<sub>2</sub> = 80 : 20 12.1kg 가 60cm 가  
 67cm . TROI-29  
 11.5kg 50 : 50 TROI-28 가  
 . TROI-30 zirconia (0 : 100) 3.0kg TROI-28 TROI-29  
 가 . TROI-31 70 : 30 12.0kg  
 가 67cm ( : 60cm) . TROI-32  
 14.6kg 87 : 13 TROI-31  
 . TROI-27 TROI-32 2 3 .

#### 3.1. TROI-27

TROI-27 17.0kg UO<sub>2</sub> ZrO<sub>2</sub> (80:20 - UO<sub>2</sub> : ZrO<sub>2</sub>)  
 . 9.5kg , 38K 67cm  
 2 IRCON 2 ,  
 3300K 가 . 3 ,  
 가 가  
 . 4 0.15MPa  
 . 5 , 55kN  
 . [16, 17]  
 steam spike 가 . steam spike ,

가

### 3.2. TROI-28

TROI-28 가 17.0kg  
 80 : 20 12.1kg  
 67cm 6  
 3500K 가 7  
 up 가 break-  
 8 가  
 가 185K 9  
 0.04MPa 가 가

### 3.3. TROI-29

TROI-29 TROI-28  
 50 : 50 (UO<sub>2</sub> : ZrO<sub>2</sub>) 14.3kg 11.5kg  
 67cm 가  
 10 3450K  
 11  
 가 12  
 21K 가 13 80K  
 가 가 가

### 3.4. TROI-30

TROI-30 zirconia 12.2kg  
 zirconia 3.0kg 67cm  
 가 14 가  
 15 가  
 가 가 가 가  
 100K 가 가  
 16 가 40K  
 가 가 가  
 17 5.5MPa  
 가 가

### 3.5. TROI-31

TROI-31 70 : 30 (UO<sub>2</sub> : ZrO<sub>2</sub>)  
 17.0kg 70 : 30 12.0kg 67cm  
 18  
 가 3450K  
 가 가 19  
 가  
 [15] steam spike 가 20 21  
 0.25MPa  
 80kN

### 3.6. TROI-32

TROI-32 87 : 13 (UO<sub>2</sub> : ZrO<sub>2</sub>)  
 가 (cold crucible) UO<sub>2</sub>  
 19.95kg 87 : 13 14.56kg  
 67cm 22  
 3530K 23  
 가  
 24 27K  
 25 210K 가

### 4.

TROI-27 TROI-32

- zirconia(UO<sub>2</sub> : ZrO<sub>2</sub> = 0 : 100)
- 25 70 : 30  
 (UO<sub>2</sub> : ZrO<sub>2</sub>) steam spike 가  
 [15] 가
- 80 : 20 (UO<sub>2</sub> : ZrO<sub>2</sub>) steam spike 가  
 TROI [16, 17] 가  
 80 : 20 가 38K  
 steam spike 가  
 steam spike
- mush zone 50 : 50 87 : 13 (UO<sub>2</sub> : ZrO<sub>2</sub>)  
 mush zone 가  
 zirconia 70 : 30  
 가 가

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10. K. H. BANG and G. D. Jeun, "Minimum Film Boiling Temperatures for Spheres in Dilute Aqueous Polymer Solutions and Implications for the Suppression of Vapor Explosions," *Journal of Korean Nuclear Society*, **27**, No.4, 544-554 (1995).
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1. Sensor descriptions in the TROI-32 test

<b>Parameter</b>	<b>Sensing location</b>	<b>Sensor description</b>
Melt temperature	Top window	IRCON pyrometer (1500 ~ 3500°C)
Coolant temperature	IVT101 ~ IVT103	0.5mm, Thermocouple
Dynamic pressure in the coolant	IVDP101 ~ IVDP103	PCB model 112A <60MPa
Under-water dynamic pressure	UWDP101 ~ UWDP102	PCB model W138A26 <160MPa
Dynamic load at the test section bottom	IVDL101	PCB model W217B <500kN
Ambient temperature in the pressure vessel	PVT001 ~ PVT005	1.0mm, Thermocouple
Static pressure in the furnace vessel	FVSP001	Rosemount model 1511 <2.0MPa
Static pressure in the pressure vessel	PVSP004, PVSP005	Druck model PMP4060 <3.5MPa
Dynamic pressure in the pressure vessel	PVDP004, PVDP005	PCB model 112A <20MPa
Melt velocity	IVT201 ~ IVT208	0.5mm, Thermocouple
Gas Sampling for Hydrogen detection	GAS005	Gas sampling bottle
FCI phenomena visualization	13 windows available	30pps videos and 1000pps video

2. Initial condition & results for the TROI tests (TROI-27 ~ TROI-29)

	TROI test number	Unit	27	28	29
Melt	Initial Charge Composition	[w/o]	79/20/1	79/20/1	49.5/49.5/1
	Temperature	[K]	3300	3500	3450
	Charged mass	[kg]	17.0	17.0	14.3
	Initiator mass	[kg]	0.1	0.15	0.15
	Released mass	[kg]	9.510	12.105	11.510
	Plug/puncher diameter	[cm]	8.0/6.5	8.0/6.5	8.0/6.5
	Initial jet diameter	[cm]	8.0	4.5	5.0
	Free fall in gas	[m]	3.8	3.8	3.8
	Test Section	Water mass	[kg]	189	241
Initial height		[cm]	67	67	67
Final height		[cm]	29	64	63
Cross section		[m <sup>2</sup> ]	0.283	0.36	0.36
Initial temperature		[K]	335	284	287
	Sub-cooling	[K]	38	89	86
Pressure Vessel	Initial pressure(air)	[MPa]	0.110	0.105	0.110
	Initial temperature	[K]	296	289	289
	Free volume	[m <sup>3</sup> ]	8.023	8.023	8.023
Results	Maximum PV pressurization	[MPa]	0.035	0.040	0.030
	Time to reach peak	[sec]	5	5	4
	Maximum PV heat-up	[K]	60	185	80
	Time to stabilize	[sec]	10	15	15
	Maximum water heat-up	[K]	23	-	21
	Time to stabilize	[sec]	10	-	25
	Steam explosion		SS	NO	NO
	Dynamic pressure peak	[MPa]	0.15	-	-
	Duration	msec	12.0	-	-
	Impulse	kN	55	-	-
	Duration	msec	40.0	-	-
Debris	Total	[kg]	9.510	12.105	11.510
	>6.35mm	[kg]	0.860	1.355	0.910
	4.75mm ~ 6.35mm	[kg]	1.000	1.260	1.190
	2.0mm ~ 4.75mm	[kg]	3.210	4.620	4.375
	1.0mm ~ 2.0mm	[kg]	1.875	2.355	2.245
	0.71mm ~ 1.0mm	[kg]	0.675	0.790	0.770
	0.425mm ~ 0.71mm	[kg]	0.975	0.960	1.020
	<0.425mm	[kg]	0.915	0.765	1.000
H2 gas	Before/After the interaction	[ppm]	229/2788	943/2450	<10/619
	Mass	[g]	1.831	1.609	0.407
Note			80:20 Warm water H2(KRIS S)	80:20 Visualize 2 Video H2(KAE RI)	50:50. Visualize. 2 Videos. 0.5mm TC(IVT) H2(KAE RI)

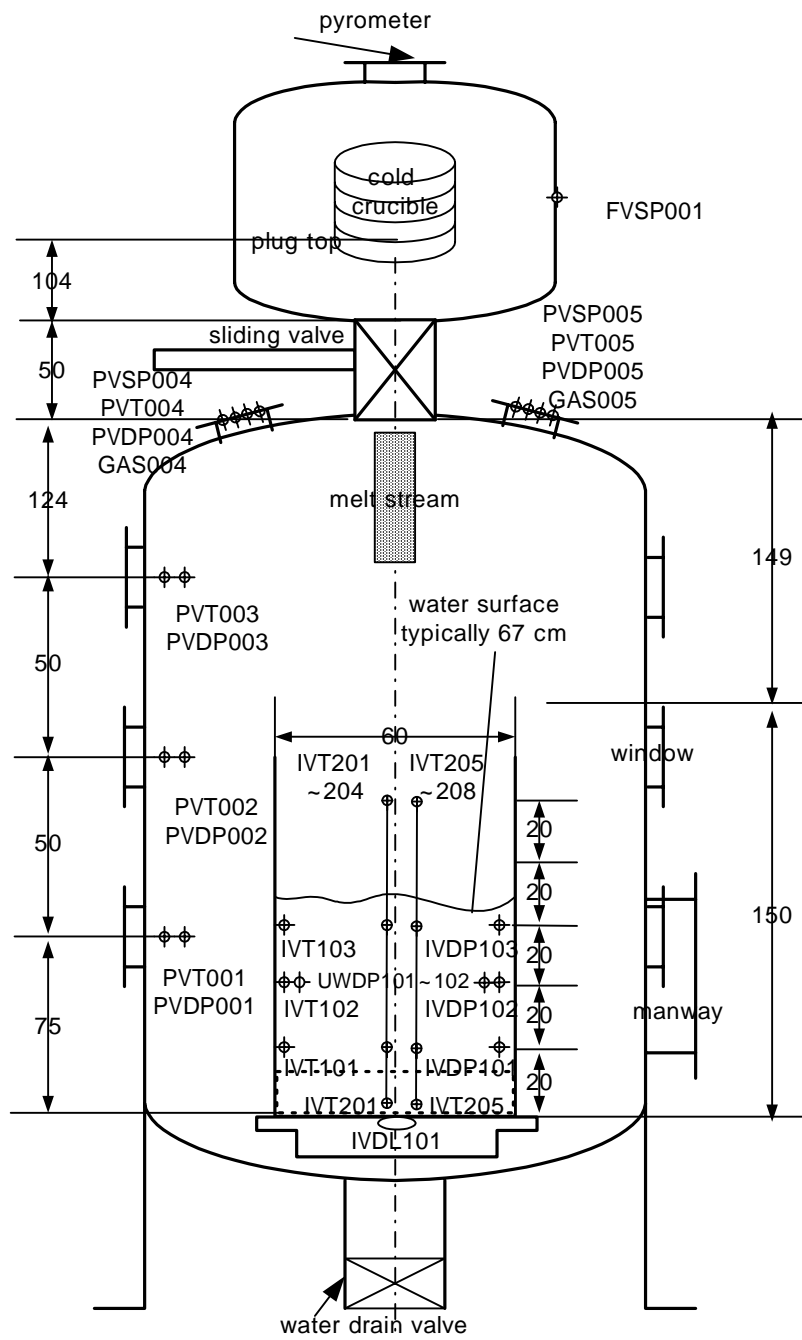
\* NO : No steam explosion, SS : Steam spike



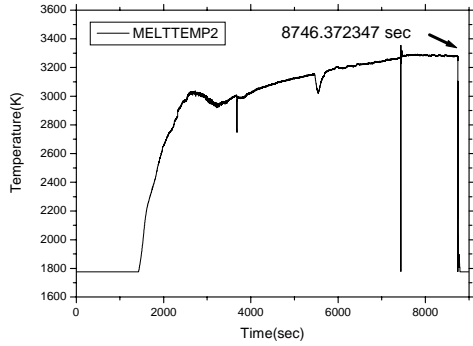
3. Initial condition & results for the TROI tests (TROI-30 ~ TROI-32)

	TROI test number	Unit	30	31	32
Melt	Initial Charge Composition	[w/o]	0/99/1	69/30/1	86/13/1
	UO <sub>2</sub> / ZrO <sub>2</sub> / Zr				
	Temperature	[K]	3600	3450	3530
	Charged mass	[kg]	12.165	17.0	19.950
	Initiator mass	[kg]	0.15	0.15	0.15
	Released mass	[kg]	2.980	12.000	14.560
	Plug/puncher diameter	[cm]	8.0/6.5	8.0/6.5	8.0/6.5
	Initial jet diameter	[cm]	3.0	8.0	8.0
	Free fall in gas	[m]	3.8	3.8	3.8
Test Section	Water mass	[kg]	241	189	189
	Initial height	[cm]	67	67	67
	Final height	[cm]	-	46	66
	Cross section	[m <sup>2</sup> ]	0.36	0.283	0.283
	Initial temperature	[K]	284	287	290
	Sub-cooling	[K]	89	86	83
Pressure Vessel	Initial pressure(air)	[MPa]	0.114	0.111	0.113
	Initial temperature	[K]	286	287	293
	Free volume	[m <sup>3</sup> ]	8.023	8.023	8.023
Results	Maximum PV pressurization	[MPa]	0.026	0.026	0.038
	Time to reach peak	[sec]	5	4	6
	Maximum PV heat-up	[K]	40	100	210
	Time to stabilize	[sec]	13	17	12
	Maximum water heat-up	[K]	40	35	27
	Time to stabilize	[sec]	10	20	25
	Steam explosion		SE	SS	NO
	Dynamic pressure peak	[MPa]	5.5	0.25	-
	Duration	msec	5	10	-
	Impulse	kN	-	80	-
Duration	msec	-	15.0	-	
Debris	Total	[kg]	2.980	12.000	14.560
	>6.35mm	[kg]	0.345	1.875	1.890
	4.75mm ~ 6.35mm	[kg]	0.270	1.365	1.670
	2.0mm ~ 4.75mm	[kg]	0.875	3.680	6.590
	1.0mm ~ 2.0mm	[kg]	0.620	2.395	1.955
	0.71mm ~ 1.0mm	[kg]	0.210	0.780	0.745
	0.425mm ~ 0.71mm	[kg]	0.260	0.940	0.935
	<0.425mm	[kg]	0.400	0.965	0.775
H <sub>2</sub> gas	Before/After the interaction	[ppm]	<10/<10	186/71	89/1010
	Mass	[g]	<0.007	0.047	0.663
Note			Pure ZrO <sub>2</sub> Visualize. Broken wall.	UWDP Rigid IV	87:13 2 UWDP →thermal transient. Rigid IV

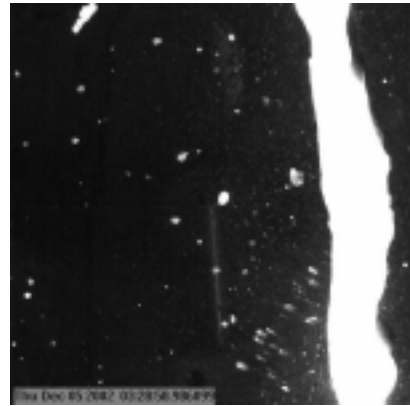
\* NO : No steam explosion, SE : Steam explosion, SS : Steam spike



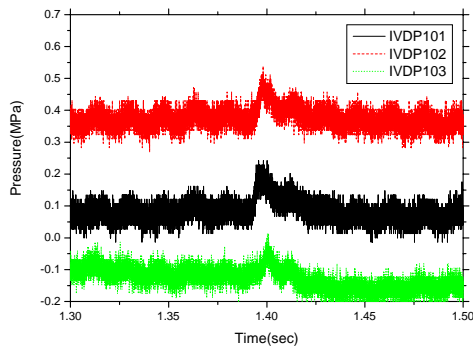
1. Schematic diagram of the TROI facility



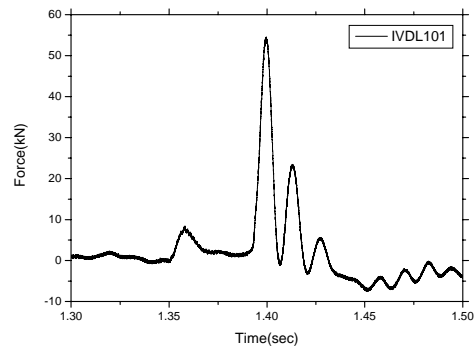
2. Melt temperature in the TROI-27 test



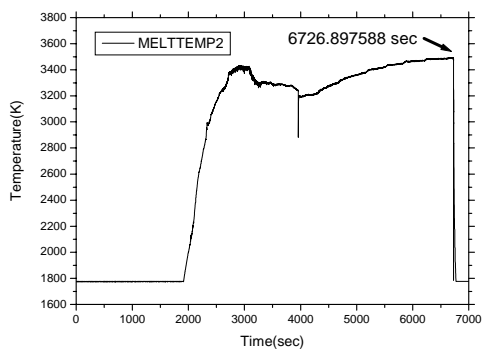
3. Photograph of melt injection in the TROI-27 test



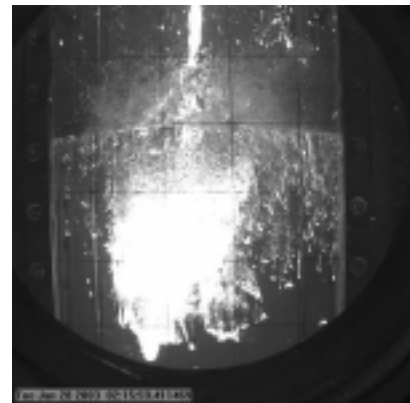
4. Dynamic pressures in the TROI-27 test



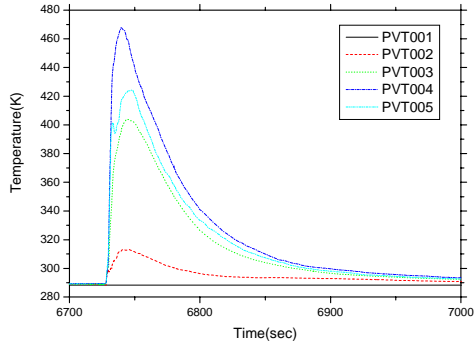
5. Dynamic load in the TROI-27 test



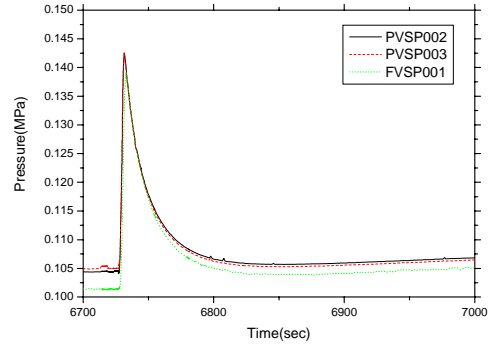
6. Melt temperature in the TROI-28 test



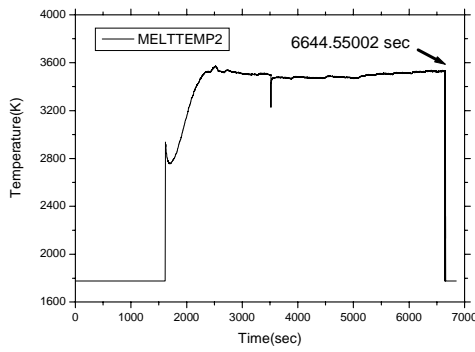
7. Photograph of melt entry into water in the TROI-28 test



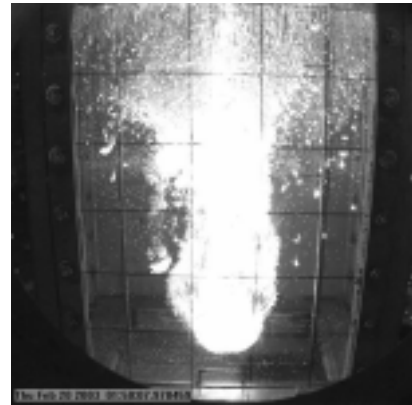
8. Temperatures in the pressure vessel in the TROI-28 test



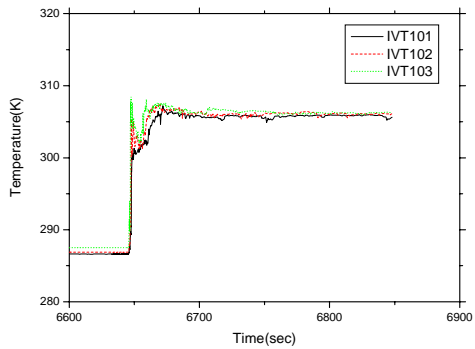
9. Static pressures in the TROI-28 test



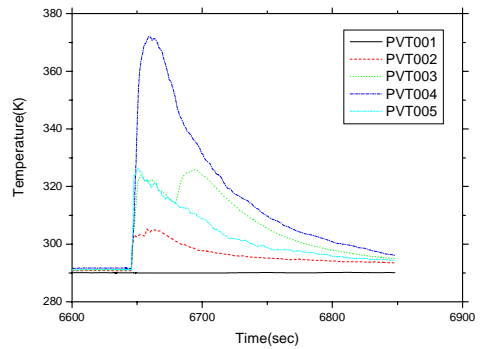
10. Melt temperature in the TROI-29 test



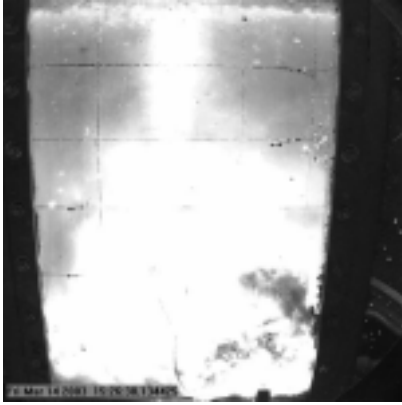
11. Photograph of melt propagation in the water in the TROI-29 test



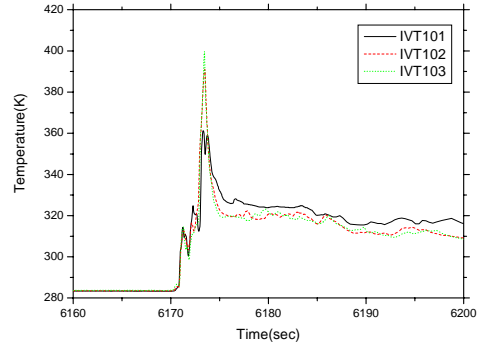
12. Water temperatures in the interaction vessel in the TROI-29 test



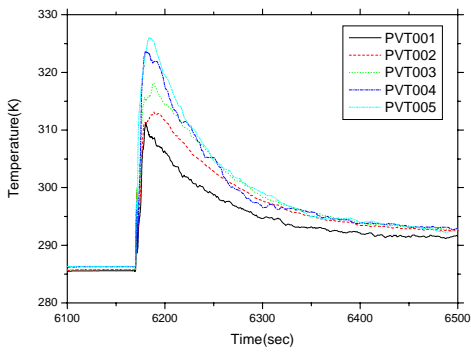
13. Temperatures in the pressure vessel in the TROI-29 test



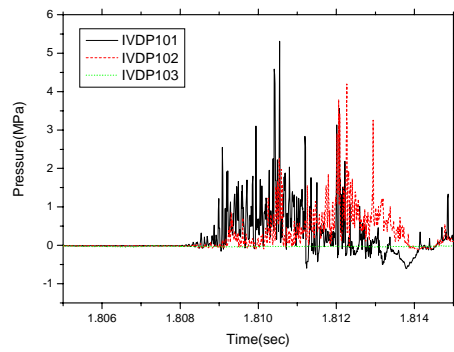
14. . Photograph of triggering in the TROI-30 test



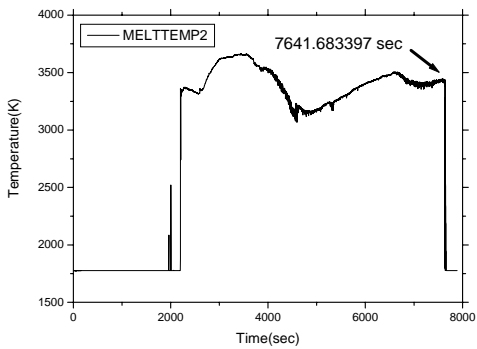
15. Water temperatures in the TROI-30 test



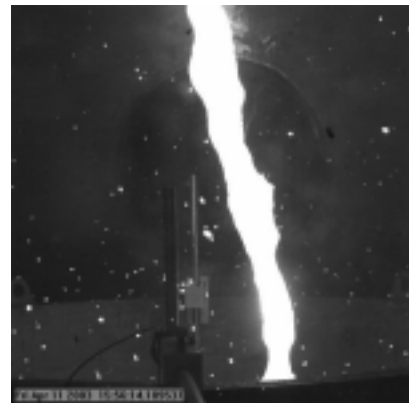
16. Temperatures in the pressure vessel in the TROI-30 test



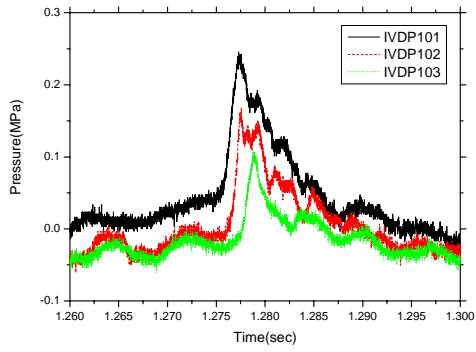
17. Dynamic pressures in the TROI-30 test



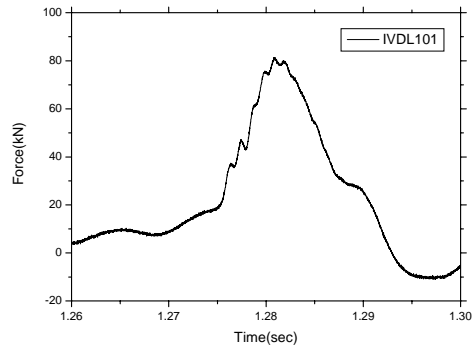
18. Melt temperature in the TROI-31 test



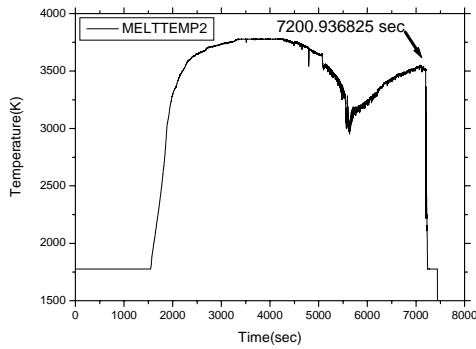
19. Photograph of melt injection in the TROI-31 test



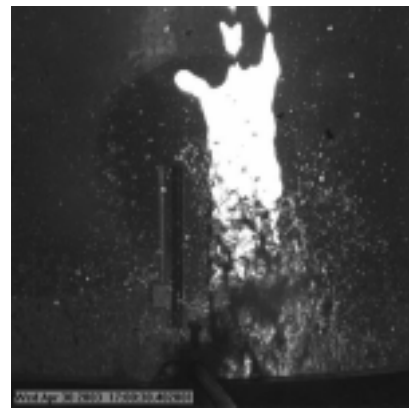
20. Dynamic pressures in the TROI-31 test



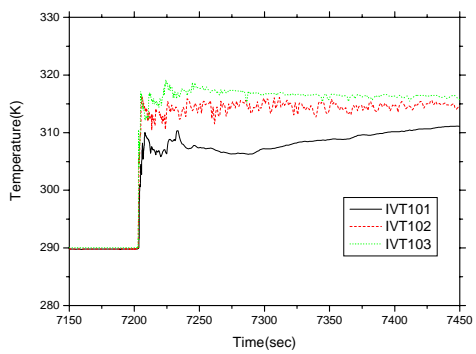
21. Dynamic load in the TROI-31 test



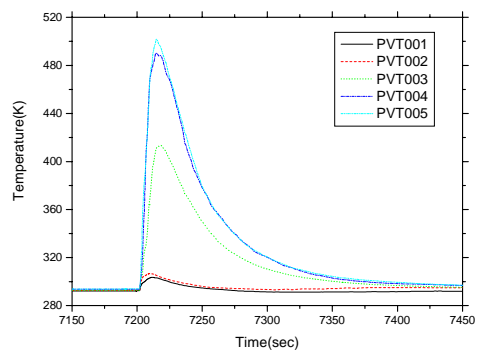
22. Melt temperature in the TROI-32 test



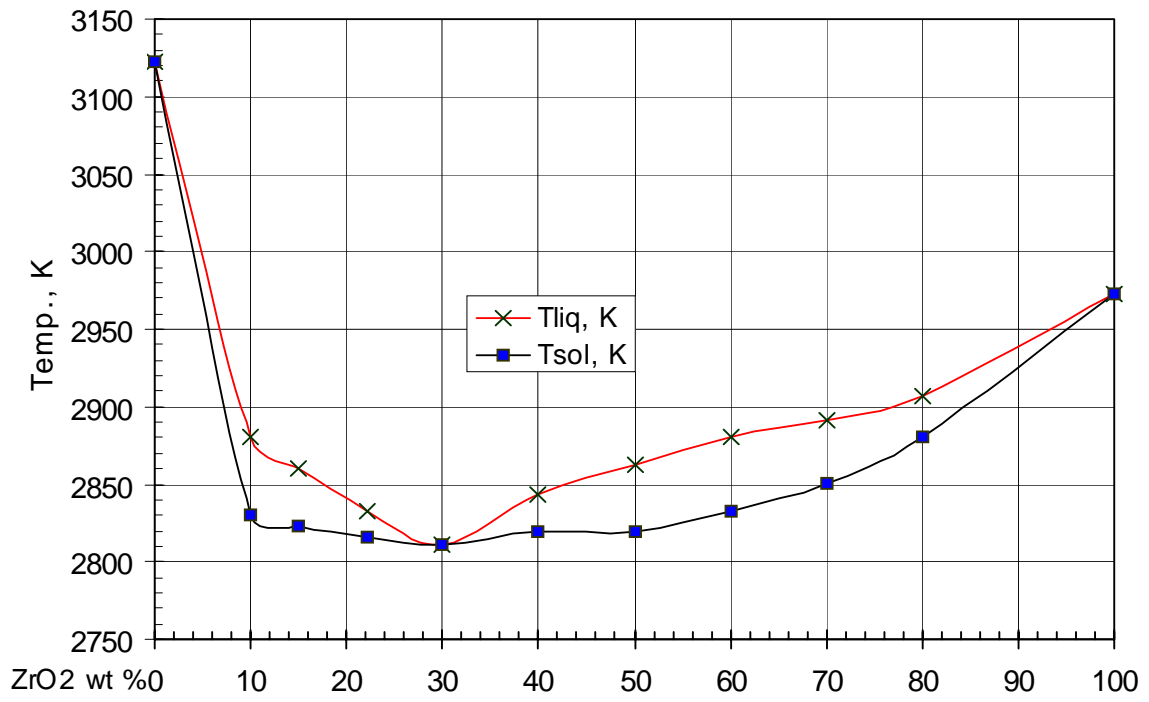
23. Photograph of melt injection in the TROI-32 test



24. Water temperatures in the TROI-32 test



25. Temperatures in the pressure vessel in the TROI-32 test



26. Phase diagram of corium