Table 2.1-1 Chronology of Major TMI-2 Accident Events

Elapsed Time h:min:s	Event or Condition
-0:00:01	Condensate pump 1A and condensate booster pumps trip.
0:00:00	Feedwater pumps trip, turbine trips.
0:00:03	PORV opens at 2255 psig.
0:00:08	Reactor trip (control rods dropped) at 2355 psig.
0:00:13	PORV failed to reclose at 2205 psig.
0:00:15	Indicated pressurizer level peaked at 256 inches and began a rapid decrease.
0:00:14	Auxiliary feedwater pumps achieved normal discharge pressure.
0:00:15	Steam generator levels indicate 74 inches (startup range).
0:00:30	PORV and pressurizer safety valve outlet temperatures alarmed high.
0:00:38	Steam generator A water level at 23.8 inches. Auxiliary feedwater valves open as level decreases below 30 inches and give dual indication on panel.
0:00:40	Steam generator B water level at 23.7 inches and decreasing.
0:00:41	Operator manually started one of the three makeup pumps (pump 1B).
0:00:54	Pressurizer level reached lowest level (158 inches) and started to rise.
≥0:01:00	NRC estimate of onset of steam void formation.
≥0:01:45	Steam generators A and B boiled dry.
0:02:01	High pressure injection initiated (1000 gpm) when reactor coolant pressure fell below 1600 psig setpoint.
0:03:12	Reactor coolant drain tank relief valve began opening intermittently.
0:03:13	Operators bypassed the high pressure injection system.
0:03:28	Pressurizer high level alarm.
0:04:38	Operator throttled high pressure injection isolation valves and stopped makeup pump 1C.
0:04:52	Second let-down cooler put in service to allow increased letdown.
0:05:00	Pressurizer level reached 377 inches and continued to rise.
0:05:15	An operator restarted condensate pump 1A.

Table 2.1-1 Chronology of Major TMI-2 Accident Events (continued)

Elapsed Time h:min:s	Event or Condition
>0:05:15	Operators tried to restart condensate booster pump 2B but it tripped.
0:05:30	Saturated conditions indicated. Indicated reactor coolant temperature (T_h=582°F) and pressure (1340 psig) reached saturation.
0:06:00	Pressurizer steam bubble lost.
0:07:29	Reactor building sump pump 2A started (140 gpm).
0:08:00	*Figure 2.4-5. Expansion/Saturation Due to LOFW/LOCA.*
0:08:18	Operator opened auxiliary feedwater block valves.
0:10:19	Second reactor building sump pump (2A) started.
0:10:48	High (5.65 ft) reactor building sump level alarm. Sump soon overflowed (6 ft).
0:11:43	Pressurizer level indication came back on scale and dropped rapidly (20 inches in 1 min..) as reactor coolant loop temperatures continued to decrease from the heat being removed by the steam generators.
0:14:48	Reactor coolant drain tank rupture disk blows.
≥0:14:50	Reactor coolant pump alarms sound.
0:18:00 ●	Waste exhaust monitors showed a small increases in radioactive iodine. Reactor building exhaust showed a tenfold increase in reading of radioactive emissions.
0:22:00	Abnormal out-of-core source-range neutron flux behavior.
0:24:58	PORV outlet temperature was 285.4°F. Safety valve outlet temperature was 270°F.
0:28:00	Operators have been dispatched to the auxiliary building to confirm pressurizer level indication and/or determine source of water that has filled pressurizer.
>0:30:00 ●	Emergency diesel generators shut off.
~0:36:00	Auxiliary feedwater pump 2B turned off.
0:38:10	Reactor building sump pumps turned off.
~0:40:00	Increasing count rate continued on the source range neutron detector.

Table 2.1-1 Chronology of Major TMI-2 Accident Events (continued)

Elapsed Time h:min:s	Event or Condition
0:46:23	Letdown cooler monitor count rate began increasing. It would increase by a factor of 10 within the next 40 minutes.
~0:50:00	Operators called on-call operating engineer to the site.
1:00:00	*Figure 2.1-7. Reactor Coolant Voids Increasing.*
1:11:00	Operators initiate reactor building cooling.
1:13:40	Loop B reactor coolant pumps turned off. Loop A pumps kept on to retain pressurizer spray capability.
>1:14:00	Sample of reactor coolant indicates low boron concentration (700 ppm).
1:20:00	An operator had the computer print out the PORV (283°F) and pressurizer safety valve (211°F and 219°F) outlet temperatures.
1:27:00	Operators isolate steam generator B.
1:30:00	*Figure 2.1-8. Loop-B Stagnates After Pumps Shut Off.*
~1:30:00	Reactor coolant sample indicated 400-500 ppm boron and 4 µCi/ml.
1:40:40	Loop A reactor coolant pumps turned off.
1:42:30	Excore source-range detectors indicated increasing neutron flux levels. Emergency boration initiated.
1:51:00	Loop A and B hotleg (T_h) temperatures were increasing (eventually went off-scale high - 620°F). Cold leg temperatures were decreasing.
2:00:00	*Figure 2.1-9. Further Voiding After Loop-A Pumps Shut Off.*
2:00:00	Conference call.
2:14:23	Reactor building air sample particulate radiation monitor went off scale.
2:18:00	Fifteen to twenty people in control room at this time.
2:19:00	PORV block valve closed, loss of coolant halted.
2:20:00	Vessel water level had dropped to about midcore.
2:29:00	Hotleg temperature indications passed the high end of the instrument scale, 620°F.
2:30:00	1 R/h reported in makeup tank area of auxiliary building.

Table 2.1-1 Chronology of Major TMI-2 Accident Events (continued)

Elapsed Time h:min:s	Event or Condition
2:38:23	Letdown cooler A radiation monitor went offscale high.
2:39:23	Two samples indicated the boron concentration in the reactor coolant was 400 ppm. Emergency boration was started to avoid a reactor restart.
2:47:00	Alarm typewriter indication showed self-powered neutron detectors responding to high temperature down to 4 foot level of the core. 90% of the core exit thermocouples >700°F.
2:48:00	*Figure 2.1-10. Hydrogen Generation.*
2:50:00 ●	Start of melting, downward relocation, and crust formation.
2:54:00	Reactor coolant pump 2B was restarted and operated for 17 min.
2:56:00 ●	Site emergency declared.
2:57:00	Fifty to sixty people are in control room; attempting to resolve the crisis.
3:00:00	*Figure 2.1-11. Effects of Loop-B Pump Restart.*
3:12:00	PORV block valve opened to control reactor coolant pressure.
3:20:00	Engineered safeguards actuated, makeup pump 1C started, HPI flow increased.
3:21:00	Excore neutron instrumentation indicated a sharp decrease (reflood). Reactor building dome radiation monitor read 8 R/h.
3:23:23 ●	General emergency declared.
3:29:00	PORV block valve reclosed.
3:30:00	*Figure 2.1-12 Vessel Refilled.*
3:32:00	The makeup tank radiation level was at about 3 R/h, and the auxiliary building basement was reported flooded with airborne radioactivity. Spent-fuel demineralizer monitor read 250-900 mr/h. Source range monitor count rate shows increase by a factor of three.
3:37:00	Operators tripped makeup pump 1C.
3:42:00	PORV block valve again opened.
3:44:00 ●	Molten pour.

Table 2.1-1 Chronology of Major TMI-2 Accident Events (continued)

Elapsed Time h:min:s	Event or Condition
3:55:39	Reactor building automatically isolated on high (>4 psig) pressure. Makeup pump 1C started automatically.
>4:00:00	Over the next 90 minutes, core exit thermocouple readings were manually obtained ranging from 217 to 2580°F.
4:18:00	Makeup pumps 1A and 1C tripped. Operator attempted to restart pump 1A. Switch was then placed in "Pull to Lock."
4:20:00	Reactor building dome radiation monitor records 600 R/h.
4:22:00	Makeup pump 1B was started.
4:26:00	Sustained high pressure injection after this time.
~4:30:00	Condensate system completely shut down. Problems with the condensate system were continuing. The condenser had been steadily losing vacuum. It was necessary to maintain steam to the main turbine seals in order to operate the condenser at a vacuum. When main steam is not available, seal steam is provided by the oil-fired auxiliary boiler. The auxiliary boiler broke down, so that seal steam could not be maintained. It was, therefore, necessary to shut down the condensate system completely.
4:40:00 ●	Reactor building dome radiation monitor records 1000 R/h.
4:42:00	Auxiliary feedwater was turned off. Only a small amount of heat could be removed by the steam generator because the upper part of the primary system was filled by a mixture of steam and hydrogen gas. The water level on the secondary side was rising because more auxiliary feedwater was coming than was leaving as steam. At 4 hours 42 minutes, auxiliary feedwater was shut off.
~5:00:00 ●	Reactor building dome radiation monitor reaches 6000 R/h.
5:15:00	Initial repressurization began, PORV block valve shut.
5:29:00 ●	Emergency diesel fuel racks reset.
5:35:00	NRC Region 1 inspector reports no consideration of offsite evacuation, since utility reports no significant leakage, and there has been no significant off-site radioactivity yet.

Table 2.1-1 Chronology of Major TMI-2 Accident Events (continued)

Elapsed Time h:min:s	Event or Condition
5:43:00	By cycling the PORV block valve, reactor coolant pressure was maintained in the 1865-2150 psig range during the next 2 hours.
6:00:00	*Figure 2.1-13. Repressurized, Attempting to Collapse Vapor Bubble.*
6:04:00	Commenced filling steam generator A (to 97%) using condensate pumps.
6:10:00 ●	Airborne radiation levels in Unit 2 control room require evacuation of all but essential personnel.
6:17:00 ●	Unit 2 personnel put on masks to protect against possible radiation.
6:27:00	Everyone, except essential personnel, started moving to Unit 1 control room.
6:52:00 ●	People leaving the Unit 2 control room fail to close the door properly, possibly compromising the recirculation ventilation system.
7:00:00 ●	Communications in the Unit 2 control room were hampered by respirators. Communications problems led some personnel to remove respirators for short periods.
7:00:00	A tour of the auxiliary building found 10 R/h at the radiation waste panel, water standing on the floor in areas with floor drains, and the auxiliary building sumps full.
7:08:00	Auxiliary feedwater pump 2A was started. Level in steam generator A reached 100% (operating range).
7:38:54	Depressurization initiated to actuate core flood system.
7:40:00	Region 1 inspector reports that utility believes there will be no radioactive release to the surrounding area.
8:00:00	*Figure 2.1-14. Depressurizing, Releasing H_2.*
8:30:00	The power-operated emergency main steam dump valve was closed at the request of corporate management.
8:41:00 ●	Core flood tanks initiate, little flow.
9:04:00	Makeup pump 1C was shut off (concerned with borated water storage tank inventory).
9:10:00	Initial depressurization halted.

Table 2.1-1 Chronology of Major TMI-2 Accident Events (continued)

Elapsed Time h:min:s	Event or Condition
9:50:00 ●	*Figure 2.1-15. Second Depressurization Initiated, Hydrogen Burn.* High pressure injection actuated. Reactor building sprays actuated.
9:50:30	Makeup pump 1C was stopped.
9:57:00	Reactor building spray pumps were stopped.
10:26:15	Loop A T_h<620°F. Stays on scale 10 minutes.
10:30:00	*Figure 2.1-16 Reactor Coolant Pressure Near Minimum (400 psig).*
11:06:00	Pressurizer level decreased to 180 inches in the next 18 minutes. Loop A temperature was increasing.
11:08:00	Second depressurization attempt ends.
13:00:00	*Figure 2.1-17. Steam Generators Blocked By Hydrogen.*
≥13:00:00	About 13 hours after turbine trip, the auxiliary boiler was brought back into operation. Steam for the turbine seals was now available and it was possible to hold a vacuum on the condenser. Two condenser vacuum pumps were started. It was the operator's belief that the main condenser would soon be available.
13:20:00	Repressurization began.
14:35:00	NRC Region 1 inspector reported that there still appeared to be a bubble in loop B.
15:00:00 ●	*Figure 2.1-18. Repressurized, Flow Blocked by Hydrogen.*
15:33:00	Operator started reactor coolant pump 1A started, ran it for 10 seconds, then tripped it.
15:45:00	The station superintendent directed operators to start a reactor coolant pump.
15:50:00	Operator started reactor coolant pump 1A and let it run continuously.
16:00:00	*Figure 2.1-19. Forced Circulation Reestablished.*

TMI-2: A Textbook in Severe Accident Management R. E. Henry
NISD Professional Development Workshop 2007 ANS/ENS International Meeting
November 11, 2007 - Washington DC

Most Important Insight : *"An operator must never be placed in a situation which an engineer has not previously analyzed."*
Quote from "Design, Training, Operation – The Critical Links: An Operator's Perspective" by Ed Frederick control room operator for TMI-2.

Montage : "Stop EPR ni à Penly ni ailleurs" - mars 2021
Texte intégral (247 pages) : http://www.nanodata.com/sdn76/epr3/doc/ThreeMileIsland-severe-accident-management-2007.pdf