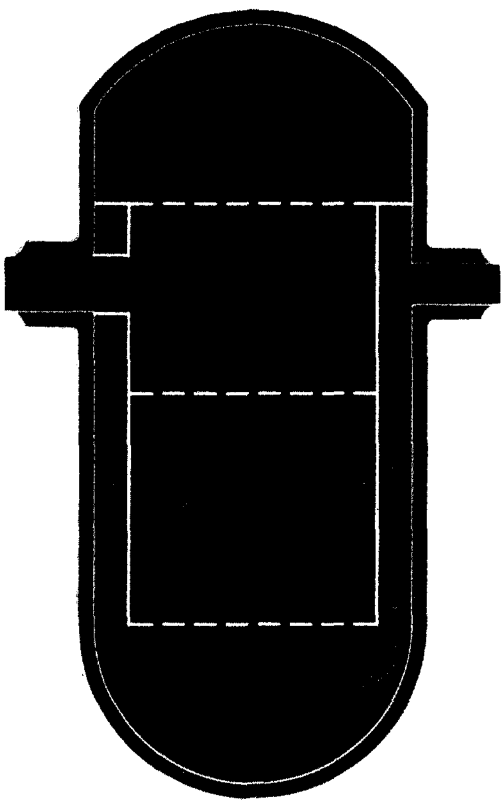
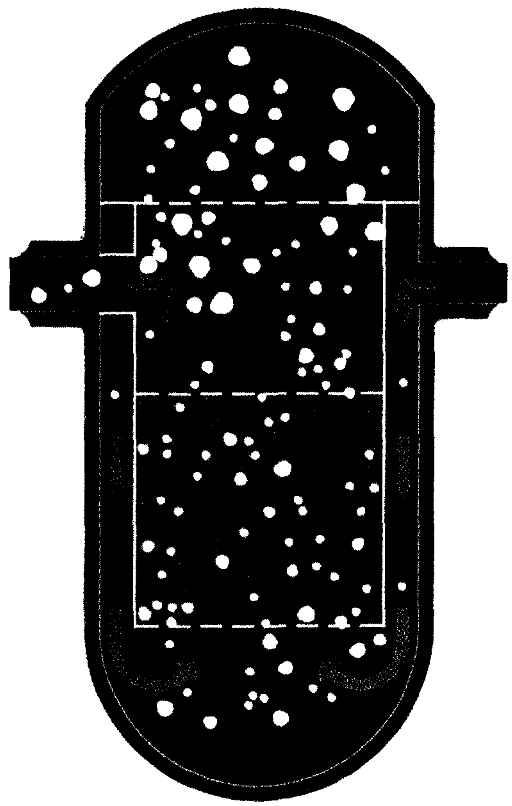
TRACANALYSIS OF THE THREE MILE ISLAND ACCIDENT

Sidebar 1:



t = 0
Normal operation

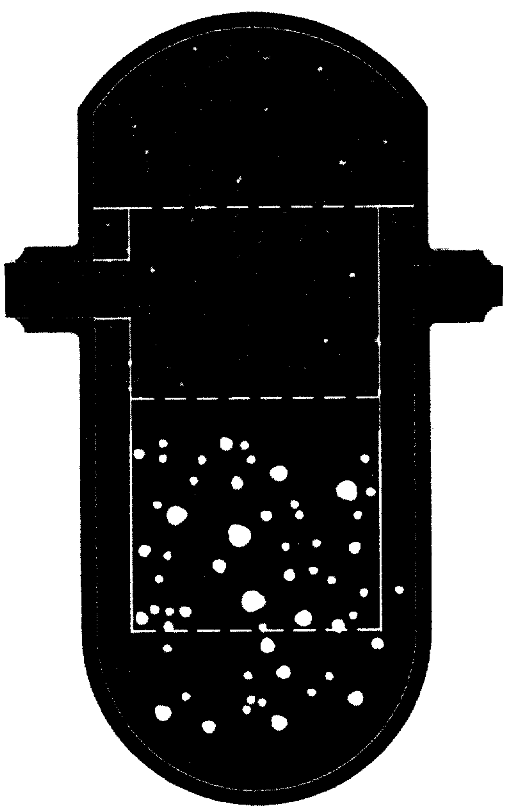


t = 70 **min**
Equilibrium conditions in core
Cooling by boiling and forced convection

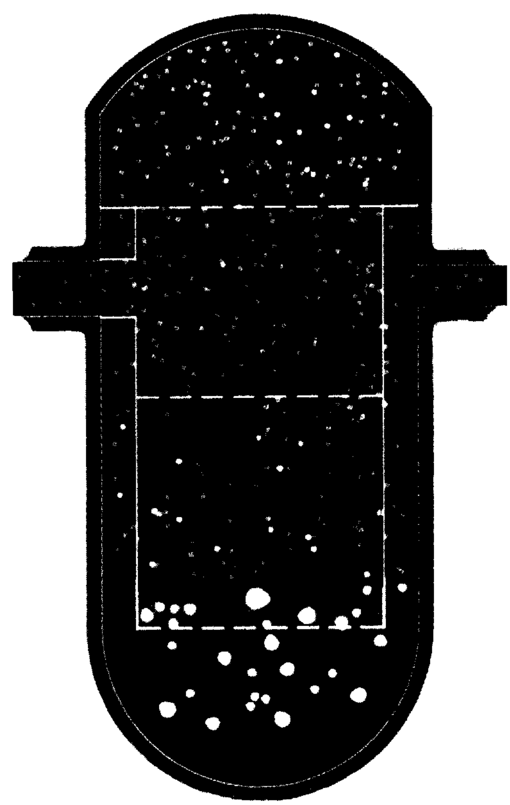
Them were no eyewitnesses to the scene within the Unit 2 reactor—and the instrument readings gave only an incomplete and misleading picture. However, from the TRAC analysis we have been able to reconstruct an accurate account of the conditions inside the primary system during the first three hours of the accident.

After steady-state initial conditions for the system were established, the transient calculation was initiated by stopping the flow of feedwater to the steam generators. The primary system pressure then rises above the normal operating range and the pilot-operated relief valve opens. The pressure continues to rise until about 10 seconds when automatic scramming of the reactor causes the pressure to drop. Because the valve fails to close, the system pressure continues to decrease until the steam generators dry out at about 2 minutes. With no heat removal through the steam generators, the pressure begins to rise again until about 8 minutes when auxiliary feedwater is supplied to the steam generators. With the valve still open, the enhanced heat transfer in the steam generators causes the system pressure to decrease further. Finally, an equilibrium state is attained in which decay heat produced in the core is balanced by the energy removal in the steam generators and through the open valve.

During the equilibrium period, which lasts from about 15 to 75 minutes, the primary system loses coolant continuously through



t = 102 min
Primary pumps off
Steam and water separate
Cooling by natural convection
Core temperature rises



t = 180 min
Vessel head filled with hydrogen from cladding oxidation
Upper 75% of core uncovered

the open valve and the letdown system, and the flow through the valve is stable at about 20 kilograms per second.* The low system pressure permits boiling in the core, which provides enough cooling to offset the coolant losses and maintain a stable system pressure and low core temperatures.

This stability ends after all of the primary pumps are tripped (the B-loop pumps were tripped at 73 minutes and the A-loop pumps at 100 minutes). From this point on, the system operates in a natural circulation mode, and energy removal through the steam generators is less efficient than in the forced convection mode (pumps on). Without forced circulation, steam and water in the primary system separate. The core becomes partially uncovered and the fuel rods begin a temperature "excursion."

From about 120 to 140 minutes boiling continues, the core water level drops, and the rods heat at roughly 0.25 kelvin per second. With coolant still flowing out the open valve and the letdown line and with steam moving through the core at the rate of 0.5 meter per second, the heat-transfer coefficients between the fuel rods and the steam are slightly higher than those for natural convection. By 140 minutes, the loops are essentially void (steam-filled) and water remains only in the pump suction legs (loop seals). The water

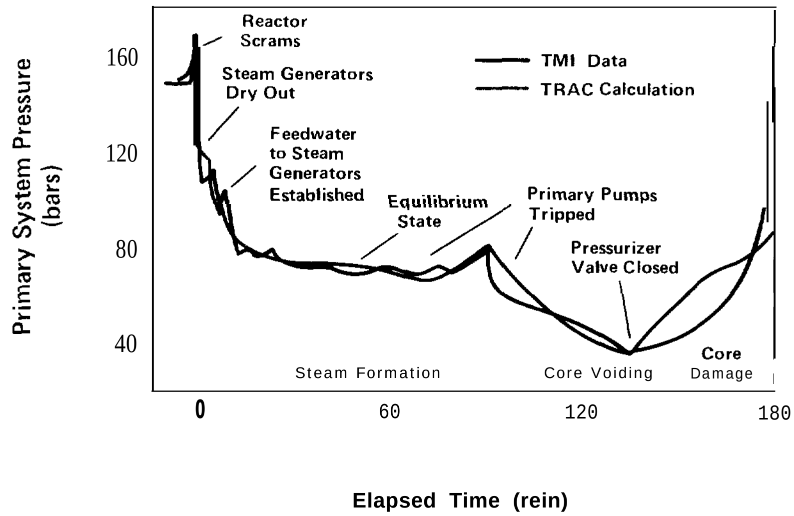
The transient calculation includes the assumption that the letdown flow was greater than the high-pressure injection flow by about 2.7 kilograms per second between 10 and 140 minutes.

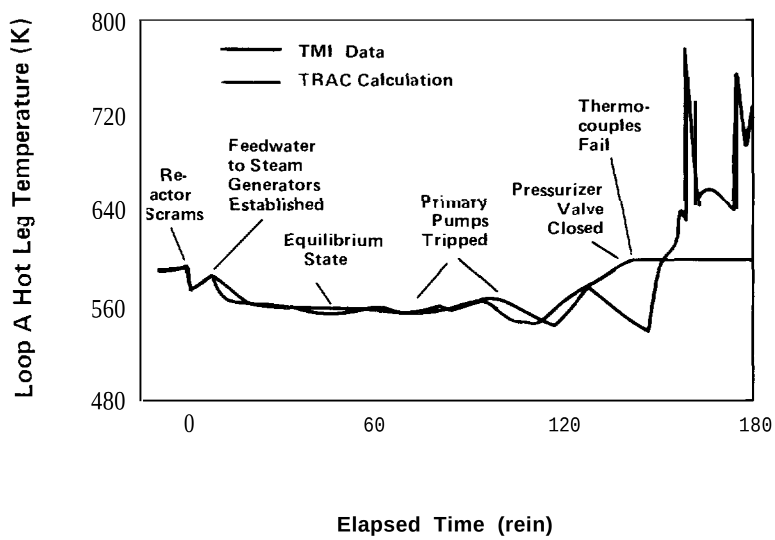
Sidebar 1: Continued

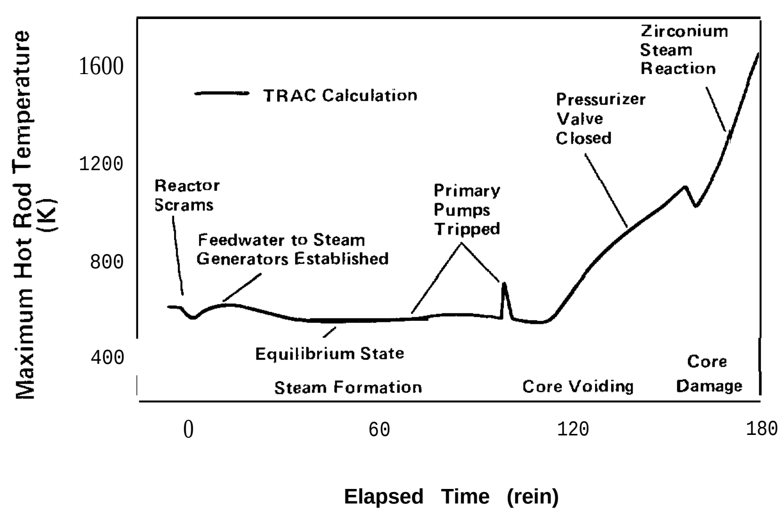
level in the pressurizer drops because of increases in letdown flow rates and decreases in system pressure that cause the water in the pressurizer to flash to steam.

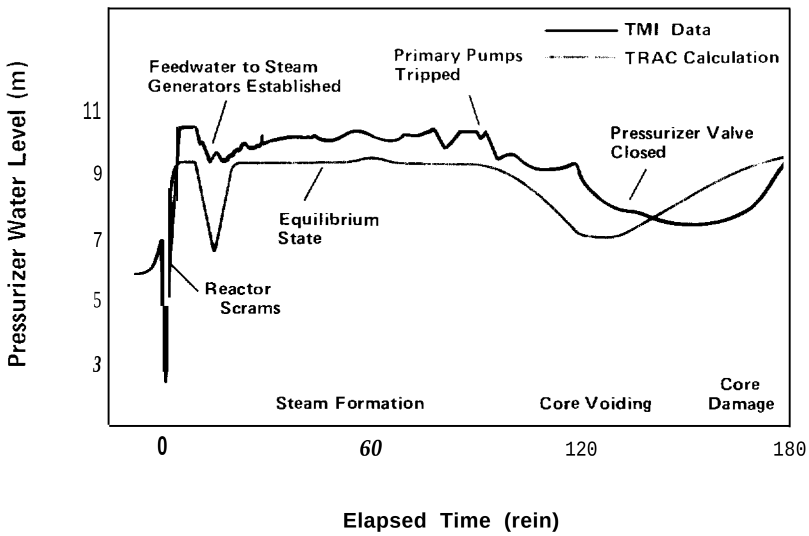
Closing the block valve in series with the pilot-operated relief valve at 140 minutes causes the steam flow in the core to stagnate. Steam can no longer escape through the valve and water in the loop seals prevents any flow through the loops. Without natural circulation, the system begins to pressurize and continues to pressurize for the remainder of the calculation. Vapor velocities through the core are generally less than 0.1 meter per second and the heat-transfer coefficients are very low (on the order of 50 watts per square meter per second, representative of natural convection to superheated steam). The steam begins to superheat and the rod temperatures continue to increase, except for a brief temperature drop at 160 minutes. This temperature decrease is caused by boiling in the lower core cells, which enhances the vapor velocities for a brief period. When these cells become void, the vapor velocities decrease and the rods again heat. The rods continue to heat at a slightly higher rate than before until the temperature reaches about 1300 kelvin and the zirconium-steam reaction be gins to provide a significant additional heat source. Then the core temperatures increase at about 1 kelvin per second. The calculation was stopped when the rod temperatures exceeded 1650 kelvin because at that point the core modeling was no longer realistic.

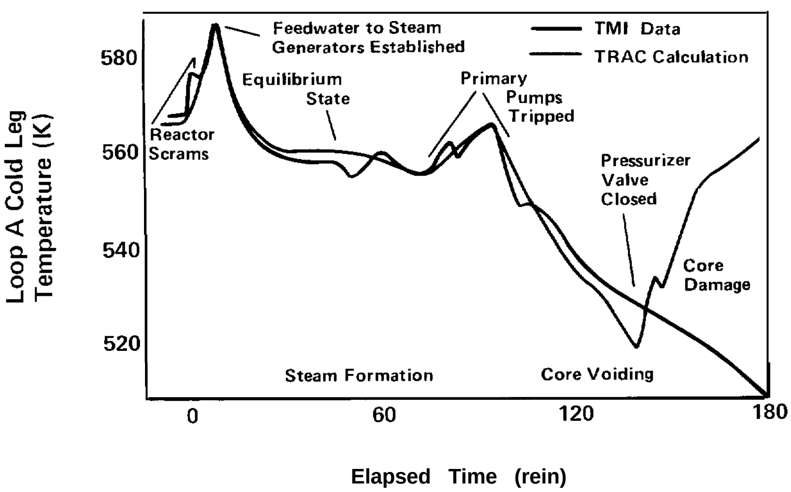
At approximately 3 hours, the top 75 per cent of the core is uncovered. The fuel-rod temperatures remain relatively low in the lower core region because some water is still available for cooling, The pressurizer water level is increasing both in the TRAC calculation and in the plant data. The pressurizer never empties because steam produced in the core condenses in the bottom of the pressurizer and countercurrent flow limiting at the pressurizer inlet prevents the downward flow of water against the upward flow of steam. ■

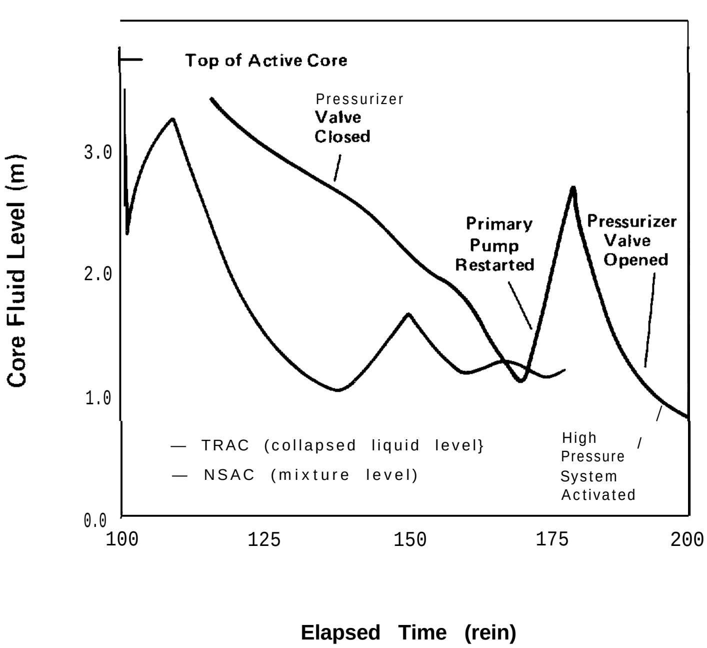







TMI Data
TRAC Calculation
Feedwater to Steam Generators Established
Primary Pumps Tripped
Pressurizer Valve Closed
Equilibrium State
Reactor Scrams
Steam Formation
Core Voiding
Core Damage
Pressurizer Water Level (m)
11
9
7
5
3
0
60
120
180
Elapsed Time (rein)


Feedwater to Steam Generators Established
TMI Data
TRAC Calculation
Equilibrium State
Primary Pumps Tripped
Reactor Scrams
Pressurizer Valve Closed
Core Damage
Steam Formation
Core Voiding
Loop A Cold Leg Temperature (K)
580
560
540
520
0
60
120
180
Elapsed Time (rein)


Top of Active Core
Pressurizer Valve Closed
Primary Pump Restarted
Pressurizer Valve Opened
High Pressure System Activated
— TRAC (collapsed liquid level}
— NSAC (mixture level)
Core Fluid Level (m)
3.0
2.0
1.0
0.0
100
125
150
175
200
Elapsed Time (rein)