EVENTS LEADING TO A RELEASE FROM THE CORE

MODULE I

I-1

WILL FOCUS ON LIGHT WATER REACTORS (LWR)

- Pressurized Water Reactors (e.g., WWERs)
- Boiling Water Reactors
- Concepts apply to all designs

I-2

MATH UNITS

$2000 = 2\ E3 = 2 \times 10^{3}$

$0.04 = 4\ E\text{-}2 = 4 \times 10^{-2}$

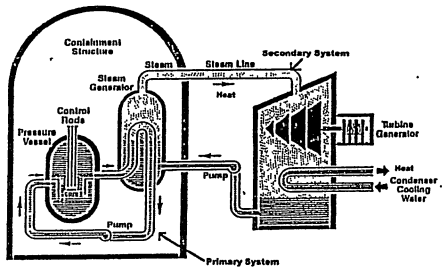
I-3

OBJECTIVES OF EMERGENCY RESPONSE

- Reduce the risk or mitigate an accident at its source
- Reduce the risk of serious deterministic health effects (deaths)
  - Keep acute dose below health effects threshold
- Reasonably reduce the risk of stochastic effects (cancers)
  - Do more good than harm
  - Avert dose according to international guidance

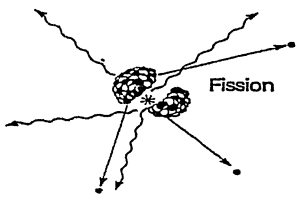
I-4

PRESSURIZED WATER REACTOR (PWR)



I-5

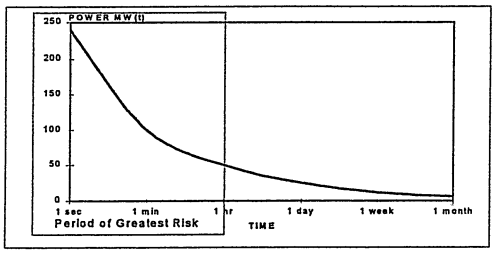
SOURCE OF RISK



I-6

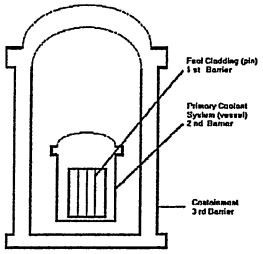
DECAY HEAT

- 80% Reduction 1st hour
- Failure to remove could result in release



I - 7

FISSION PRODUCT BARRIERS TO PREVENT A RELEASE



Deterministic Health Effects Require

- Core damage
- Early containment failure

I - 8

Reactor inventories (Bq) and the amount needed to be released to give off-site deaths at 1 km

TYPICAL

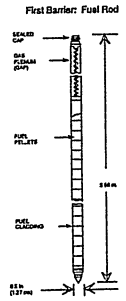
	Noble Gas (Xe, Kr)	Iodine (I)	Cesium (Cs)
Reactor Core	1.4E19*	2.7E19*	5.5E17
Spent Fuel Pool (3 years)	1E16	6E15	1E18*
Coolant	3.7E14	1.8E13	7E10
Release Required for Deaths at 1km	5E18	1E18	1E17

*Sufficient for Early Deaths

I - 9

FIRST BARRIER: FUEL ROD - FUEL PIN

- Once damaged - immediate release of "GAP"
  (3 - 5% I, Cs, Xe & Kr)
- No major release without damage to fuel pin or rod
- 20% failure = severe core damage



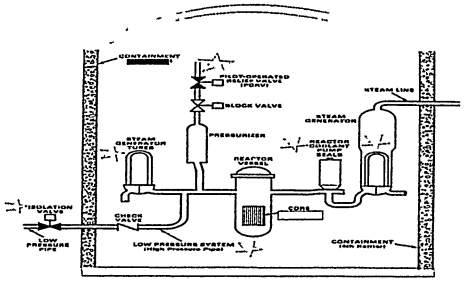
I - 10

SECOND BARRIER: PRIMARY SYSTEM

- Holds water that cools the core
- Must fail before core damage or major release
- Many possible failure points

I - 11

TYPICAL PRIMARY SYSTEM FAILURE LOCATIONS



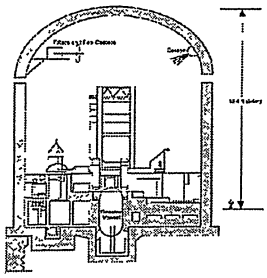
I - 12

THIRD BARRIER
The Containment, Accident Localization Volume, The Box

Designed to
- Withstand break in primary system
  - Ice
  - Suppression pool
  - Size/Strength
  - Relief valves & sprays
- Provide long term decay heat removal
  - Spray
  - Coolers
- Reduce fission products
  - Sprays
  - Filters
  - Pools

I - 13

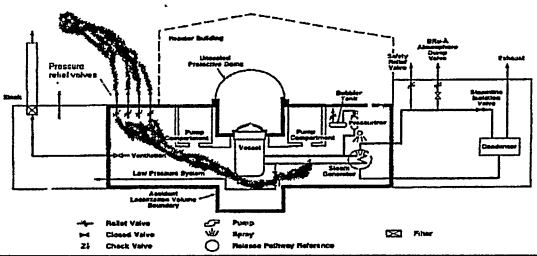
LARGE HIGH PRESSURE CONTAINMENT



Control :
- Blow down by size/strength
- Fission products by sprays
- Decay Heat by spray + recirculation

I - 14

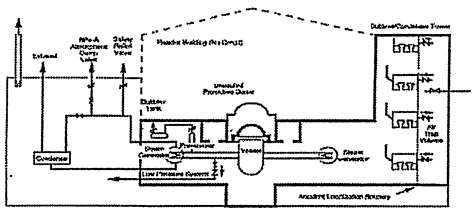
WWER 230 CONTAINMENT



Blow-down controlled by relief valves and sprays
Fission product reduction by sprays

I - 15

WWER-440 213 CONTAINMENT

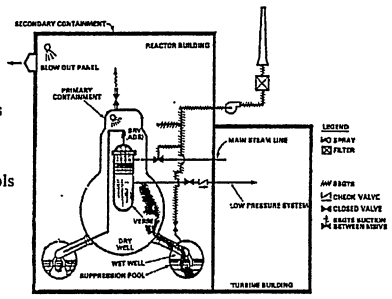


- Blow-down controlled by bubble tower (pools)
- Fission product reduction by sprays

I - 16

BWR REACTORS

- Blow-down controlled by suppression pools
- Fission Product Reduction by Pools + Sprays



I - 17

RELEASES NEEDED FOR OFF-SITE CONSEQUENCES

Consequences Off-Site	I/Cs Release Fraction	Core Status	Containment Status
Deaths	0.10	Melt	Early Failure
Vomiting	0.02	Gap Release	Large
Evacuation	1 E-4	Clad Failure	Large
Thyroid Block	1 E-5	Minor Damage	Small Leak
Restrict Milk	1 E-8	Minor Damage	Small Leak

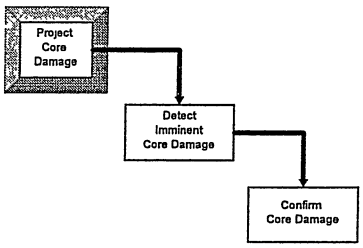
I - 18

THE TWO FUNDAMENTAL QUESTIONS CONCERNING THE PLANT

- Will the core be damaged?
- How will the containment perform?

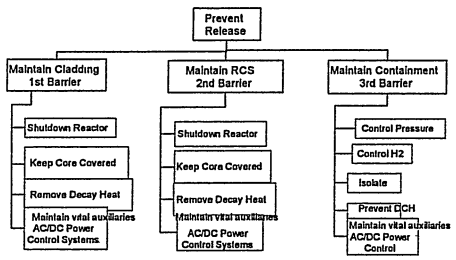
I - 19

CORE DAMAGE ASSESSMENT



I - 20

MAINTAIN CRITICAL SAFETY FUNCTIONS AND YOU PROTECT THE BARRIERS



I - 21

CRITICALITY CONTROL (Shutdown fission reaction)

- During accident reactor must be shutdown for safety system to function.
  (Safety systems designed only for decay heat not power)
- Rapid insertion of control rods (scram or trip reactor)
- Failure to shutdown very serious-results in cladding failure in minutes

I - 22

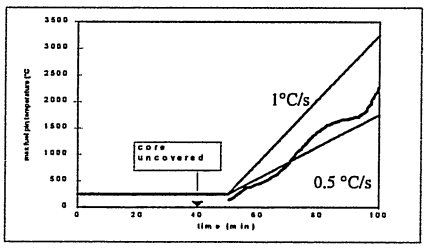
COOL FUEL CLADDING (CORE) & REMOVE DECAY HEAT TO ENVIRONMENT

- Failure to cool
  - fuel cladding could result in failure within minutes
  - containment could result in failure within hours to days

I - 23

KEEP CORE COVERED AND COOL

- Fuel cladding heat-up once uncovered with no injection
- Note increased heat-up rate due to Zr-water reaction at 20 min after core uncovery



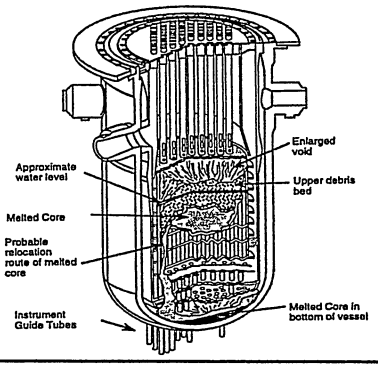
I - 24

FUEL DAMAGE PROGRESSION VS. AVERAGE FUEL PIN TEMPERATURE

Time after uncovery	Temperature	
45 - 90 min	3000 °C	Melting of fuel pellets (UO_2) Possible melt through of vessel
	2500 °C	Release of all volatile fission products
30 - 60 min	2300 °C	Possible formation of uncoolable core
	2000 °C	Formation of „liquified fuel": fuel dissolves in melted components
20 - 40 min	1700 °C	Very rapid release of iodine, cesium and noble gases
	1400 °C	Very rapid steam - zircalloy reaction- release of H_2 and failure of fuel cladding
10 - 20 min	1000 °C	Possible cladding burst - release of fission products in fuel gap
	315°C	Normal operating temperature

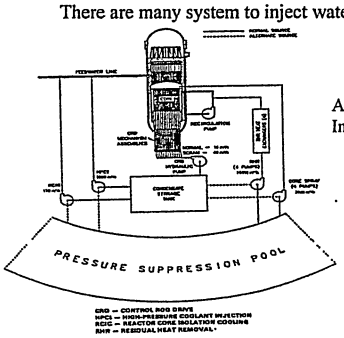
I - 25

TMI CORE - ONCE RECOVERED WITH WATER



I - 26

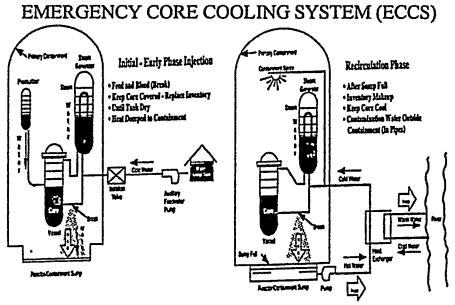
There are many system to inject water into core



At 1 hour 60 m^3/h needed
In BWR > 10000 m^3/h available

I - 27

EMERGENCY CORE COOLING SYSTEM (ECCS)



I - 28

MAINTAIN VITAL AUXILIARIES

- Their loss could lead to failure of several critical functions
- Loss of AC Power
  - Loss of injection pumps
  - Loss of containment cooling
- Loss of DC Power
  - Loss of control
  - Loss of instrument
- Loss of control (e.g., personnel must evacuate control room)

I - 29

FAILURE TO SHUTDOWN (ATWS)

Problem (real or imagined)

Normal heat removal system shutdown

Safety systems starts to protect core and containment isolation

Primary system failure (safety valves open)

Safety systems cannot replace total water loss

Core uncovers <15 - 30 minutes>

Fuel failure <30 - 60 minutes>

Release of fission products from core

I - 30

MAINTAIN THE CONTAINMENT AFTER CORE DAMAGE

- Control Pressure
- Control H_2
- Isolate (Close)
- Prevent/Control By-Pass Accident
- Prevent DCH

I-31

CONTROL CONTAINMENT PRESSURE

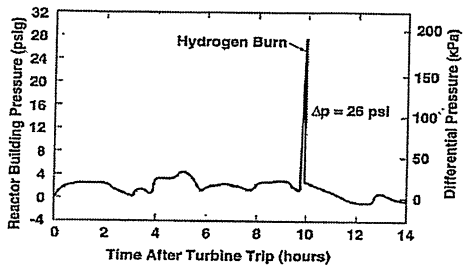
- Must remove decay heat for days - weeks
- Loss of active systems results in containment failure in many hours
- Most containments fail at 2 - 3x design pressure

	Design Leak Rate % /day	Design Pressure kPa
US	0.1 - 0.25	100 -500
VVER 230	100	100
VVER 213	15	150
VVER 1000	NA	400

I-32

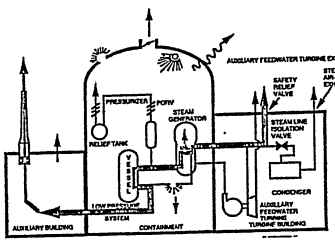
H_2 Generated During Core Damage Can Burn In The Containment

TMI Containment Pressure vs. Time



I-33

BY-PASS ACCIDENT

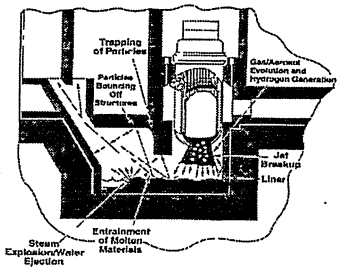


- Route from core to atmosphere
- LOCA outside containment
- Steam generator tube rupture (SGTR)

I-34

DIRECT CONTAINMENT HEATING - DCH

- At melt through of vessel
- Many ways to fail containment
- Possible for hours after core damage



I-35

CONTAINMENT VENTING

- Used by operators to reduce pressure and hydrogen
- Predictable
- May release large amounts of fission products
- Part of Emergency Operating Procedures

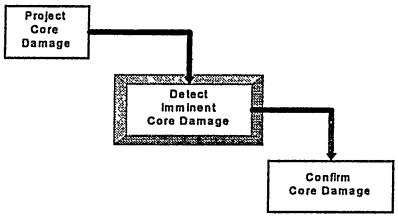
I-36

WHAT DO WE KNOW ABOUT THE WAYS A CONTAINMENT CAN FAIL?

WHEN	CHALLENGE (Failure means)	PREDICTABLE ?
Start of Accident	Existing Leak	No
	Isolation Failure	No
	By-Pass	No
Before Vessel Melt-Through	Overpressurization	No
	Hydrogen Combustion	No
	Late By-Pass	No
	Late SGTR	No
	Venting	Yes
At or Soon After Vessel Melt-Through	Steam Explosion	No
	Hydrogen Combustion	No
	Direct Containment Heating (DCH)	No
	Melt - Contact with Containment	No
	Venting	Yes
> 2 hrs after Vessel Melt - Through	Overpressurization	No
	Hydrogen Combustion	No
	Basement Melt Through	No

I - 37

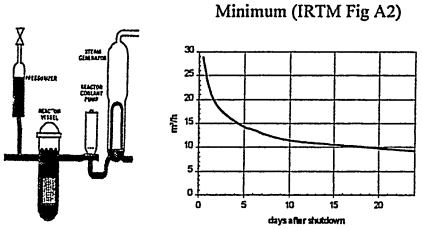
CORE DAMAGE ASSESSMENT



I - 38

IMMINENT CORE DAMAGE INDICATED BY SYSTEMS TO INJECT WATER

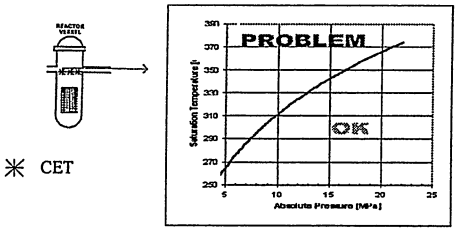
Minimum (IRTM Fig A2)



I - 39

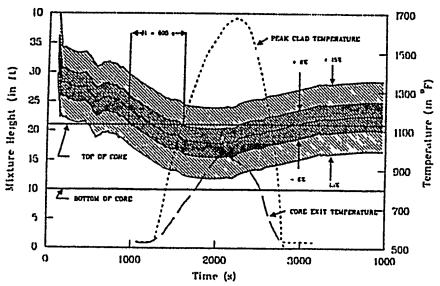
IMMINENT CORE DAMAGE INDICATED BY PWR TEMPERATURE / PRESSURE

IRTM Fig. A1



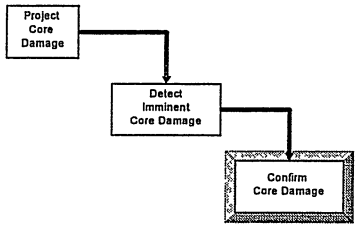
I - 40

PREDICTED RESPONSE OF CET and WATER LEVEL INSTRUMENTS TO SMALL BREAK



I - 41

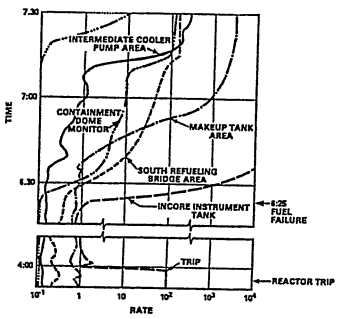
CORE DAMAGE ASSESSMENT



I - 42

TMI AREA MONITORS

RADIATION LEVELS WILL INCREASE IN PLANT AFTER CORE DAMAGE



I - 43

PRIMARY COOLANT OR CONTAINMENT AIR SAMPLES

- SLOW - can not be taken until after damage, and it takes time to assess
- UNDER SOME CONDITIONS NOT RELIABLE
  - no coolant
  - containment by-passes

I - 44

SOME KEY INDICATORS OF CORE DAMAGE

Safety Function Status	Predict fuel (core) damage
?	?
Water Level	Indicates imminent core damage
Core Temperature	Indicates imminent core damage
Radiation Levels	Confirm core damage

I - 45

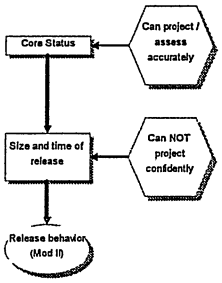
INSTRUMENTS CAN BE CONFUSING DURING ACCIDENTS

- Never use a single instrument as a basis for assessment
- During TMI radiation monitors:
  - Failed, and showed high, low, or middle levels
  - Were influenced by nearby sources
  - Were not representative
  - Were incorrectly read
  - Were not correctly calibrated
  - Were source of "more puzzlement than enlightenment"

BUT: most increased after core damage

I - 46

EARLY ACCIDENT ASSESSMENT



I - 47