Chernobyl

:

A Failure in Safe Operations

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Chernobyl: A Failure in safe Operations

A compilation of poor design and unsafe operations caused the most catastrophic power system disaster in human history.

Main Causes

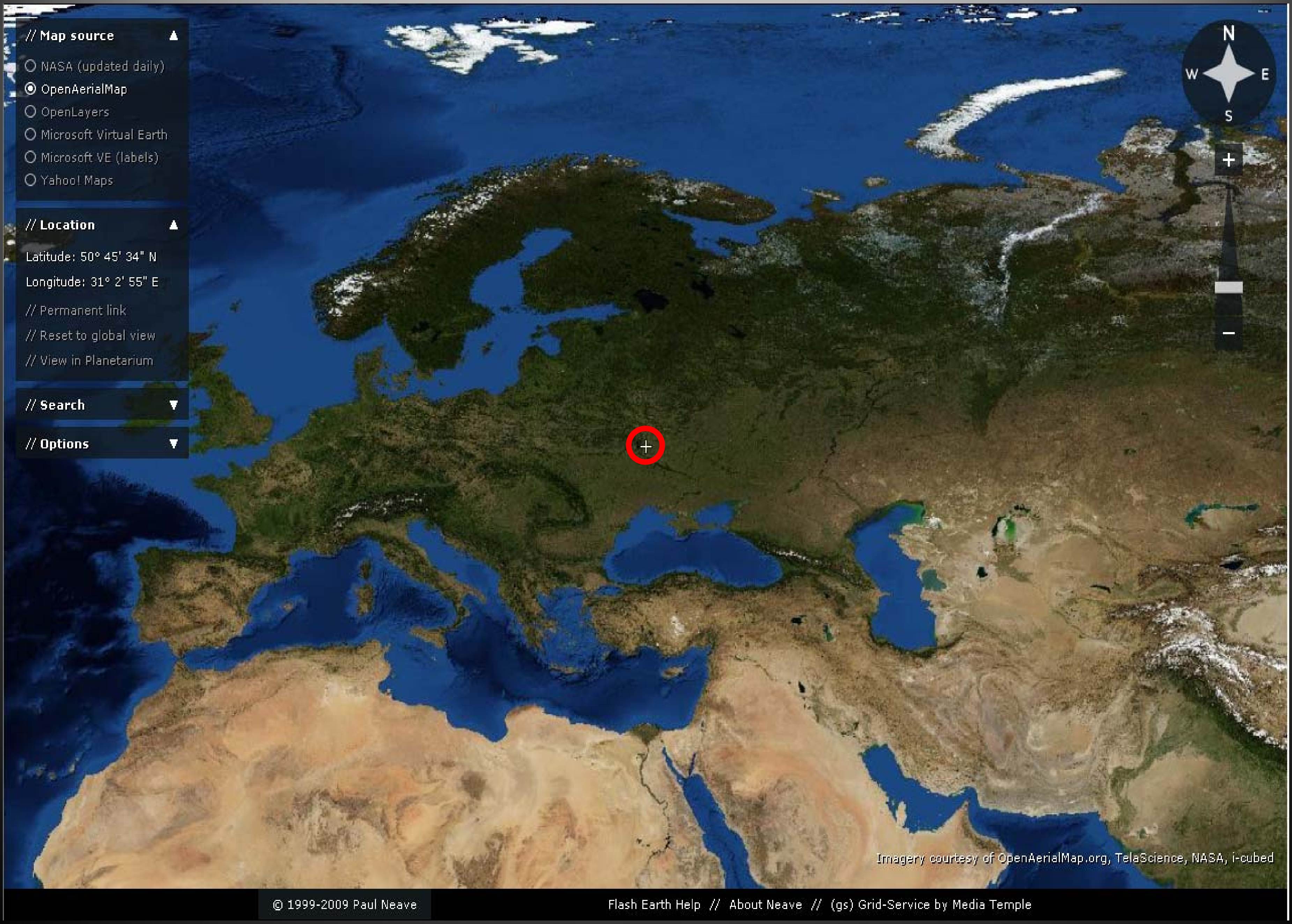
- Inherent flaws in the RBMK-type fission reactor (USSR design)
- Multiple automatic protection systems were disabled
- The equipment was operated outside of multiple prescribed operating limits

Training Concepts

- The Value of a “Safety Culture”
- The Operator’s decision making authority.
- The integrity of any piece of equipment is directly related to its operating limit.
- History, Causes, and Consequences of the Chernobyl disaster.

The incident

- April 26, 1986
- Chernobyl Nuclear Power Station, Ukraine
- Catastrophic failure of Unit #4 Reactor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NASA (updated daily)
OpenAerialMap
OpenLayers
Microsoft Virtual Earth
Microsoft VE (labels)
Yahoo! Maps
// Location
Latitude: 50° 45' 34" N
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Imagery courtesy of OpenAerialMap.org, TelaScience, NASA, i-cubed
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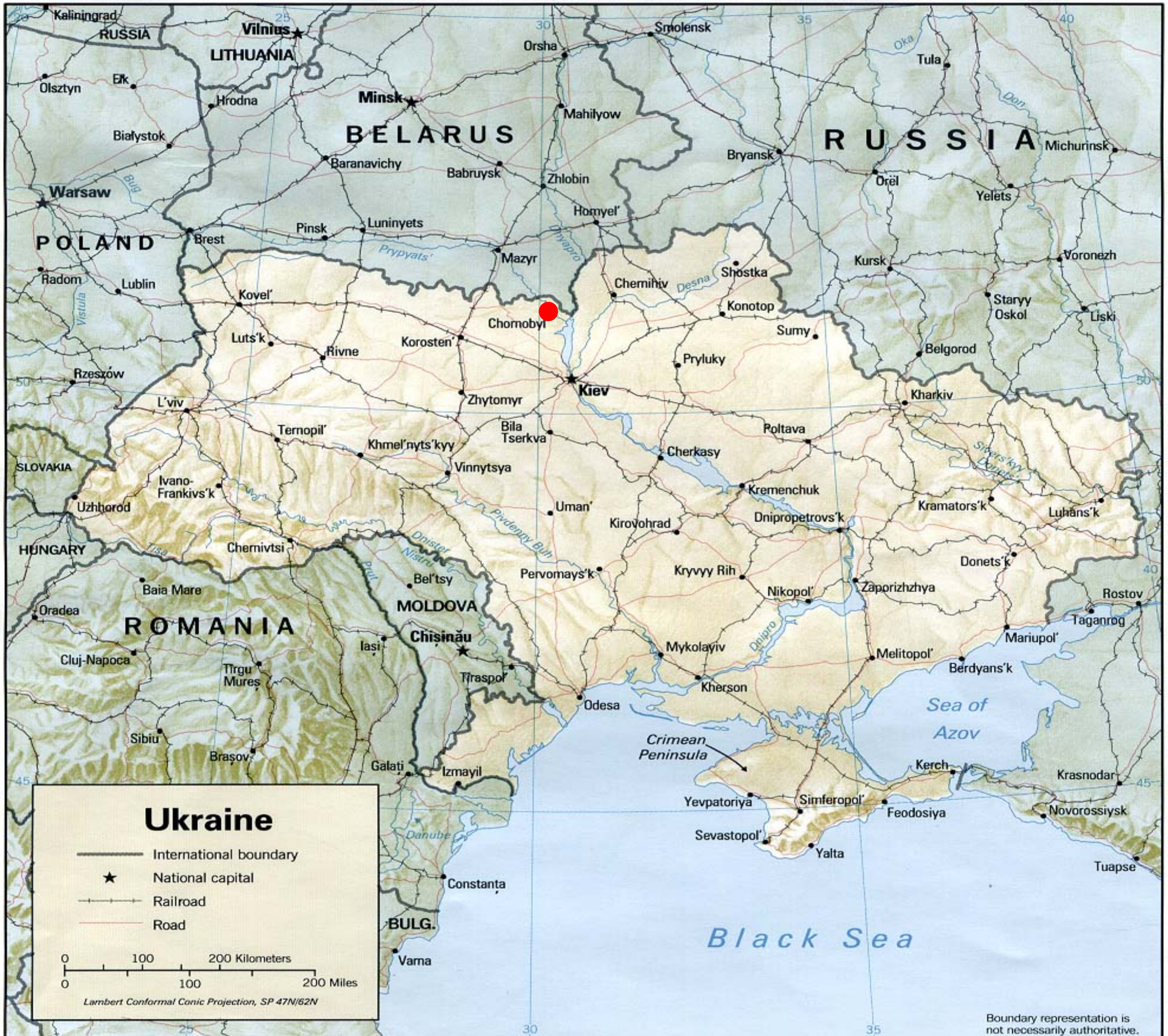

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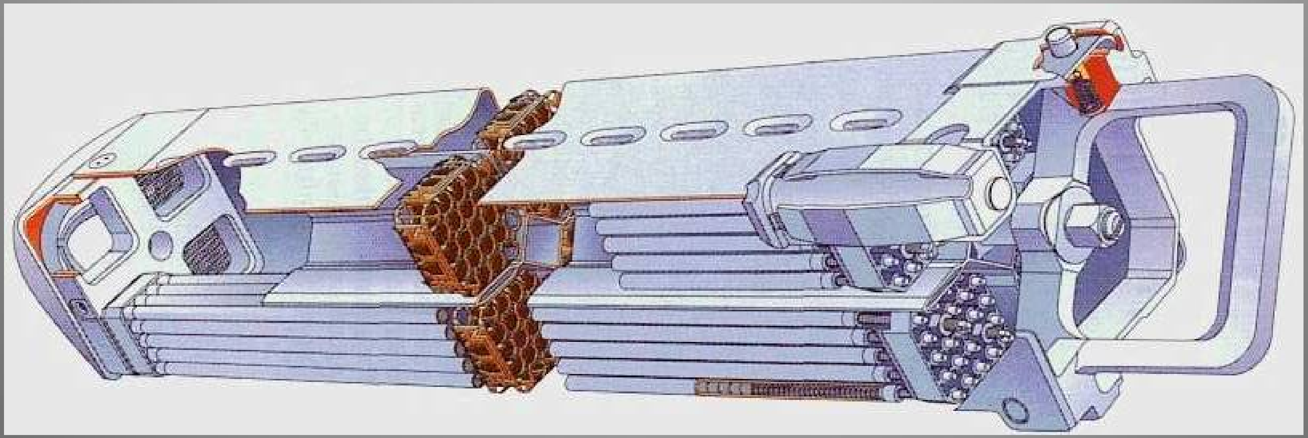
The incident

- Adverse unit conditions existed.
- Unit was operated outside of safe operating parameters.
- Reactor Core became unstable and led to an uncontrolled nuclear chain reaction.

Conditions Prior to Test

- “Safety Test” scheduled for Reactor #4 routine shut-down.
- Reactor #4 dropped in power output dramatically.
- Protection schemes disabled to prevent unit shut-down due to unstable conditions.



- Control rods are removed from the reactor beyond the minimum safety requirements.
- Reactor output rises to 200 MW from 30 MW.

- Auxiliary Systems are Unstable at low power outputs (below 600 MW).
- Cooling pumps began to malfunction (due to low reactor output levels).
- Water flow to core switched to manual control and emergency cooling systems disabled.
- Xenon gas build-up inside Reactor Core (due to low reactor output levels).

Breaches in Protocol:

1) Safety Systems disabled
2) Reactor operated at unstable output levels
3) Control Rods removed beyond minimum safety requirements.
4) Too much Cooling Water Pumped into the Core on Manual Control
5) “Safety Test” procedure conducted improperly, at unstable reactor output levels.

Factors and flawed design

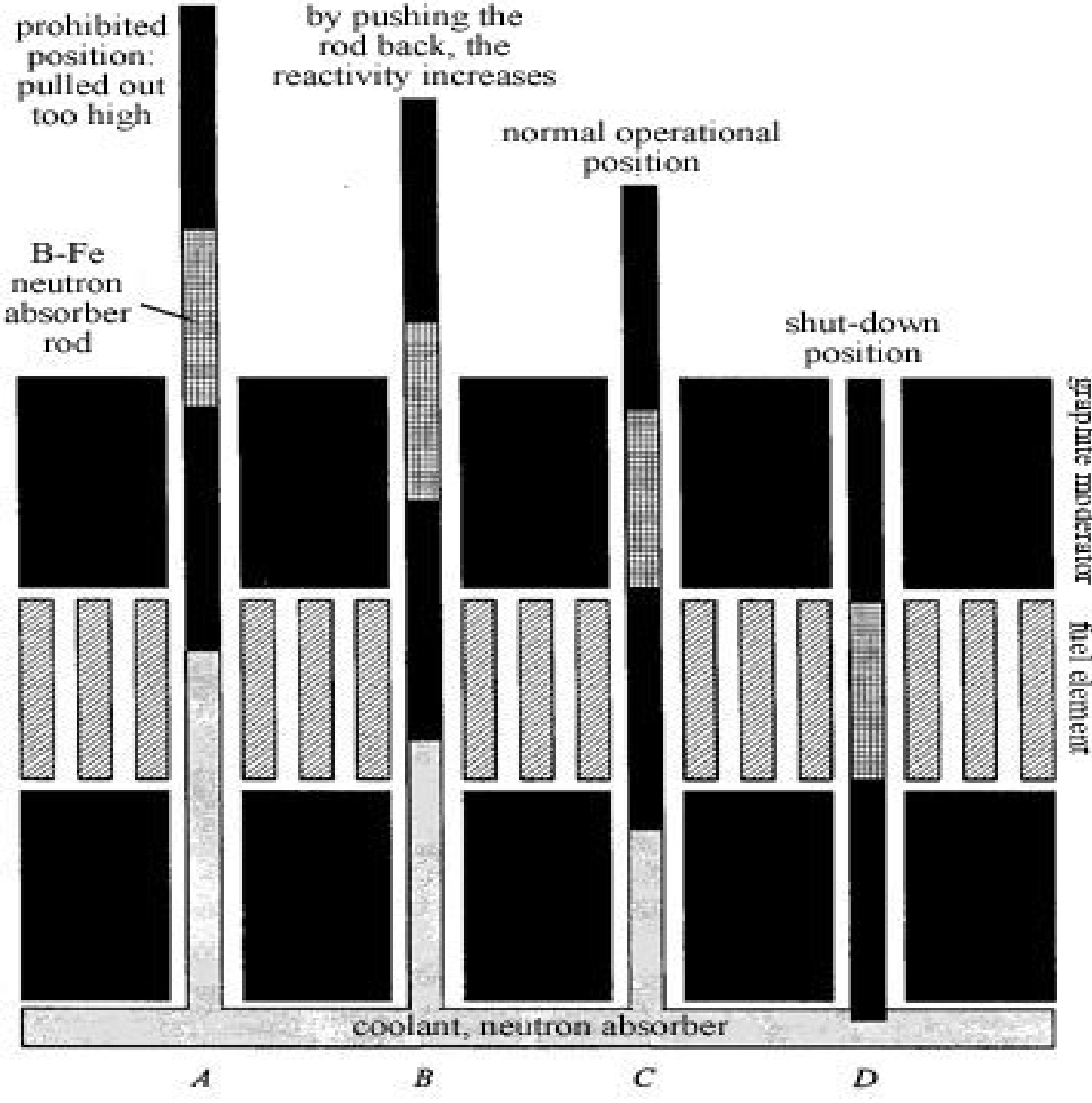
- *Positive Void Coefficient –*
  - Water acts as a neutron absorber.
  - Steam does not.
  - As the ratio of steam to water increases, the output of the reactor increases.
  - Increased reactor output increases the steam to water ratio.
  - <u>Can only occur when cooling system</u> is not operating properly.

Factors and flawed design

- The cooling system is know to be unstable at levels of low reactor output, according to:
  - The operating procedures
  - The safety regulations, and
  - The unit design specifications.

Factors and flawed design

- Flawed Control rod design that displaces coolant (water) upon insertion into the reactor core.
- Chernobyl Reactor #4 did not have a reactor containment system.


prohibited position: pulled out too high
by pushing the rod back, the reactivity increases
normal operational position
B-Fe neutron absorber rod
shut-down position
graphite moderator
fuel element
coolant, neutron absorber
A
B
C
D

Against the Law

The three reasons a RBMK reactor could not be licensed in the USA:

1) Positive Void Coefficient
2) Flawed control rod mechanisms
3) No reactor containment system

The “Safety” Test

The Test:

If primary power is lost, can the turbine inertia run the cooling pumps until the diesel units take over station service?

The “Safety” Test

- The test began at 1:23:04 AM
- The unit reactor was at 200 MW output. The procedure calls for 700-1000 MW output.
- The flow of coolant water decreases gradually as the inertia from the turbines is spent.

The “Safety” Test

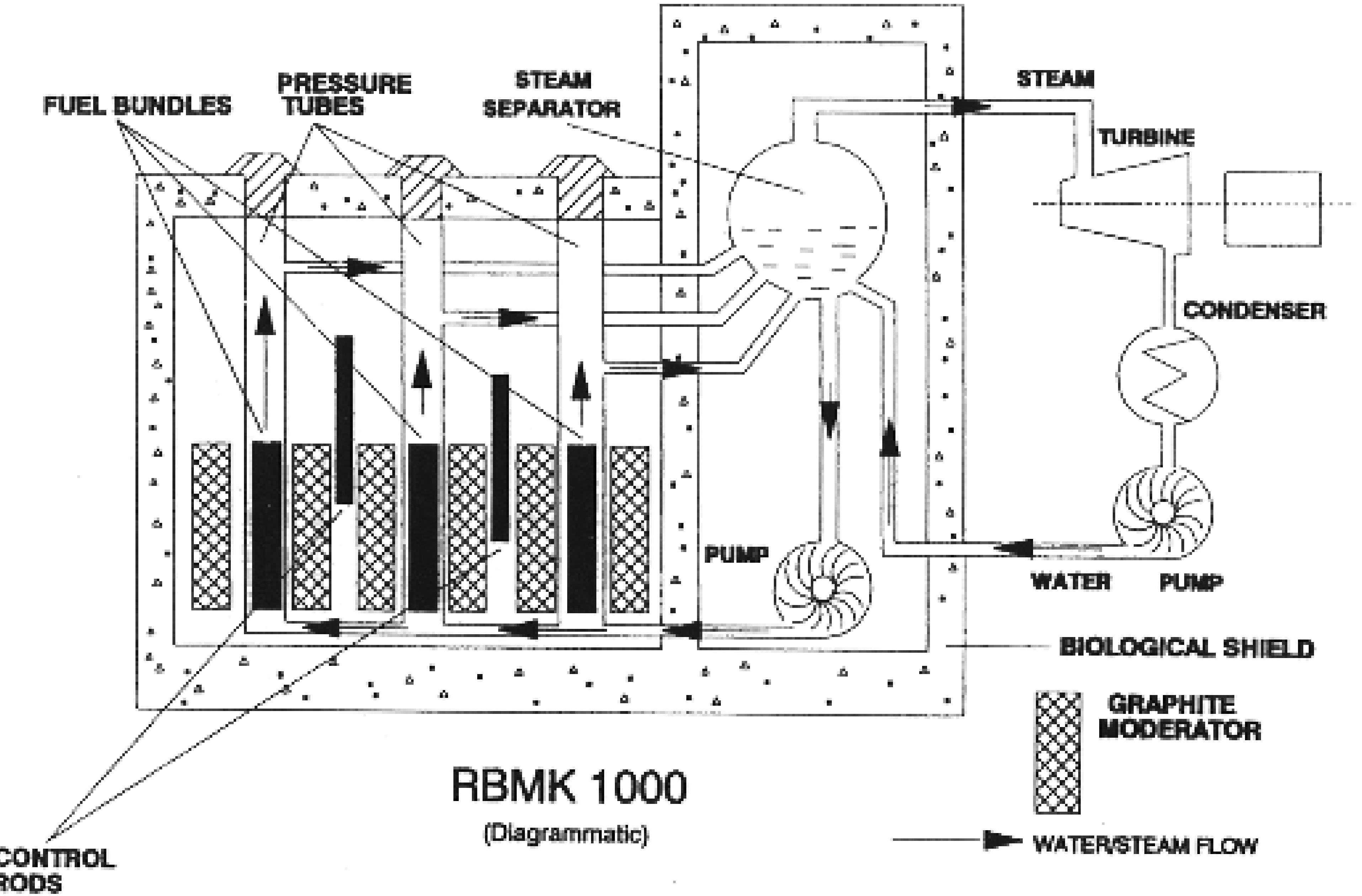
- A Positive Void Situation begins to take place, as Steam in the Reactor increases.
- Xenon and Water are the primary controlling agents for the fission reaction inside the core.
- Both begin to diminish as thermal energy rises.

The “Safety” Test

- Reduced coolant flows were not adequate to cool the reactor.
- The Reactor is unstable, with little control element remaining to inhibit the nuclear reaction.
- At 1:23:40 AM, (36 seconds later) the test was concluded.

The “Safety” Test

- The Rapid Emergency Defense operation (SCRAM) was initiated, dropping all control rods into the reactor at once.
- Due to the flaw in control rod design, coolant is displaced as the rods begin to enter the reactor.
- This displacement creates a full-scale Positive Void Reaction.



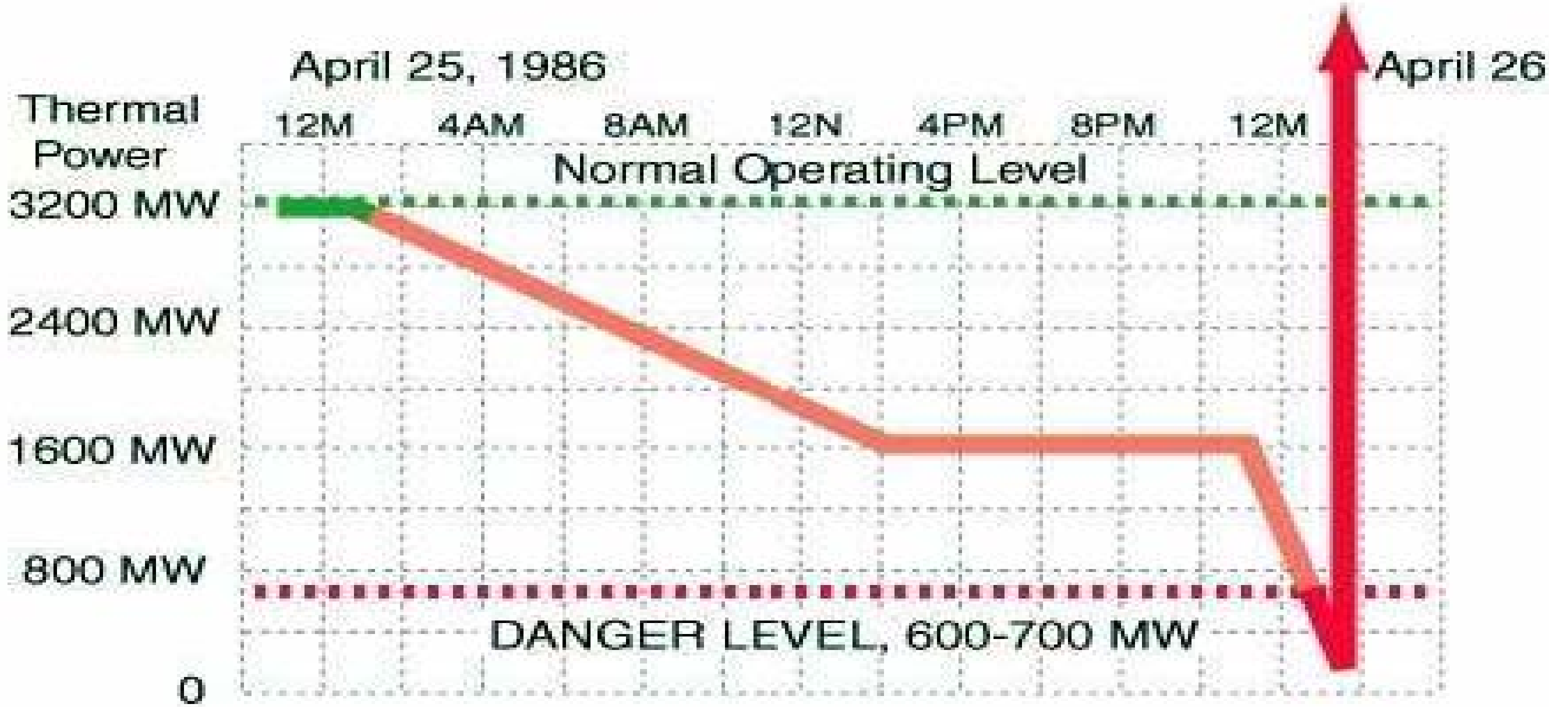
RBMK 1000

(Diagrammatic)

The “Safety” Test

- This reaction increased the reactor output to 10,000 MW almost instantaneously.
- Nuclear energy “Spike” warped the control rod channels, halting the insertion of the control rods.
- The fission reaction was no longer controllable.

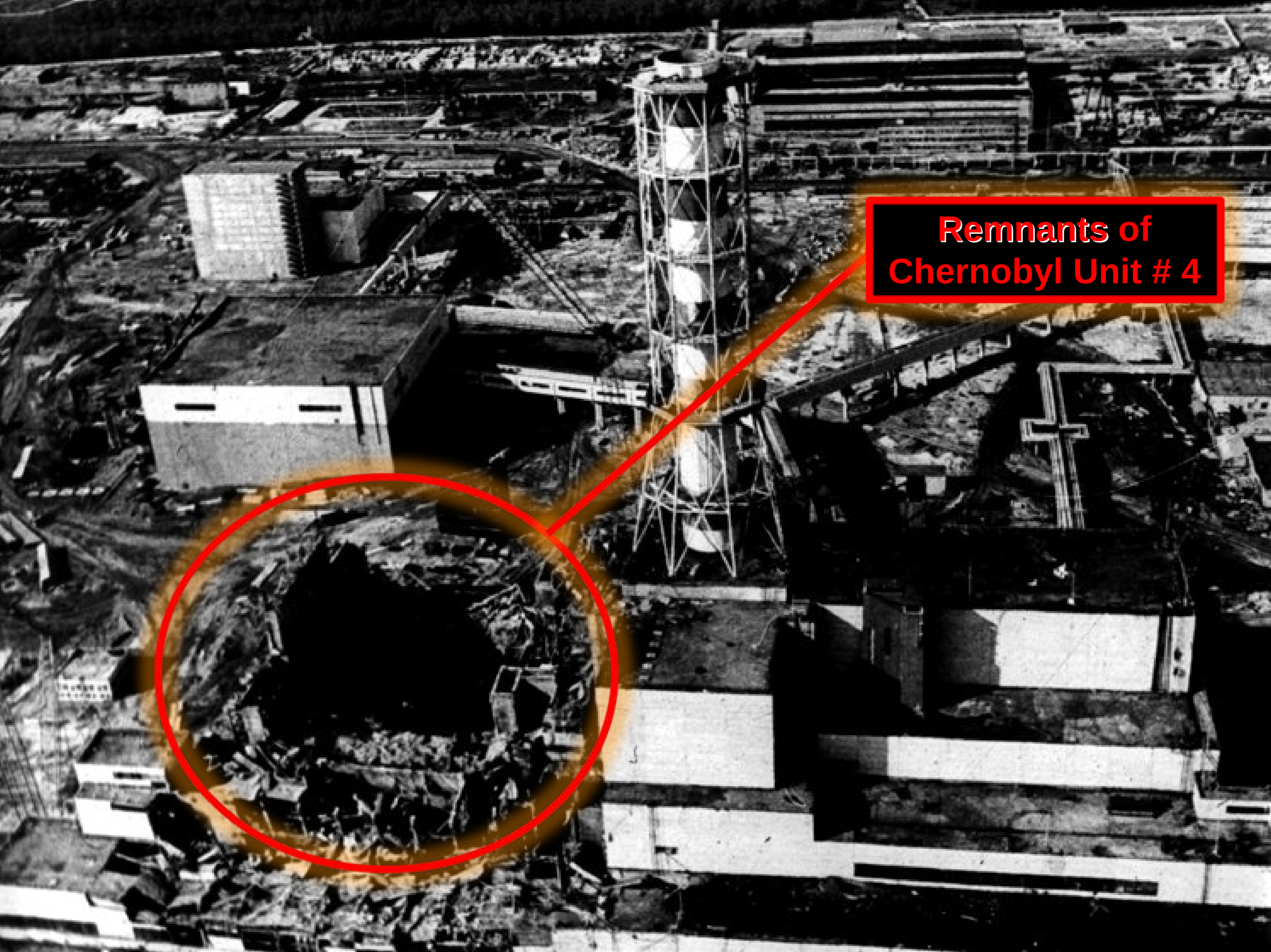
A Chronology of Disaster, Chernobyl



"It was like airplane pilots experimenting with the engines in flight!" Soviet scientist Legasov.

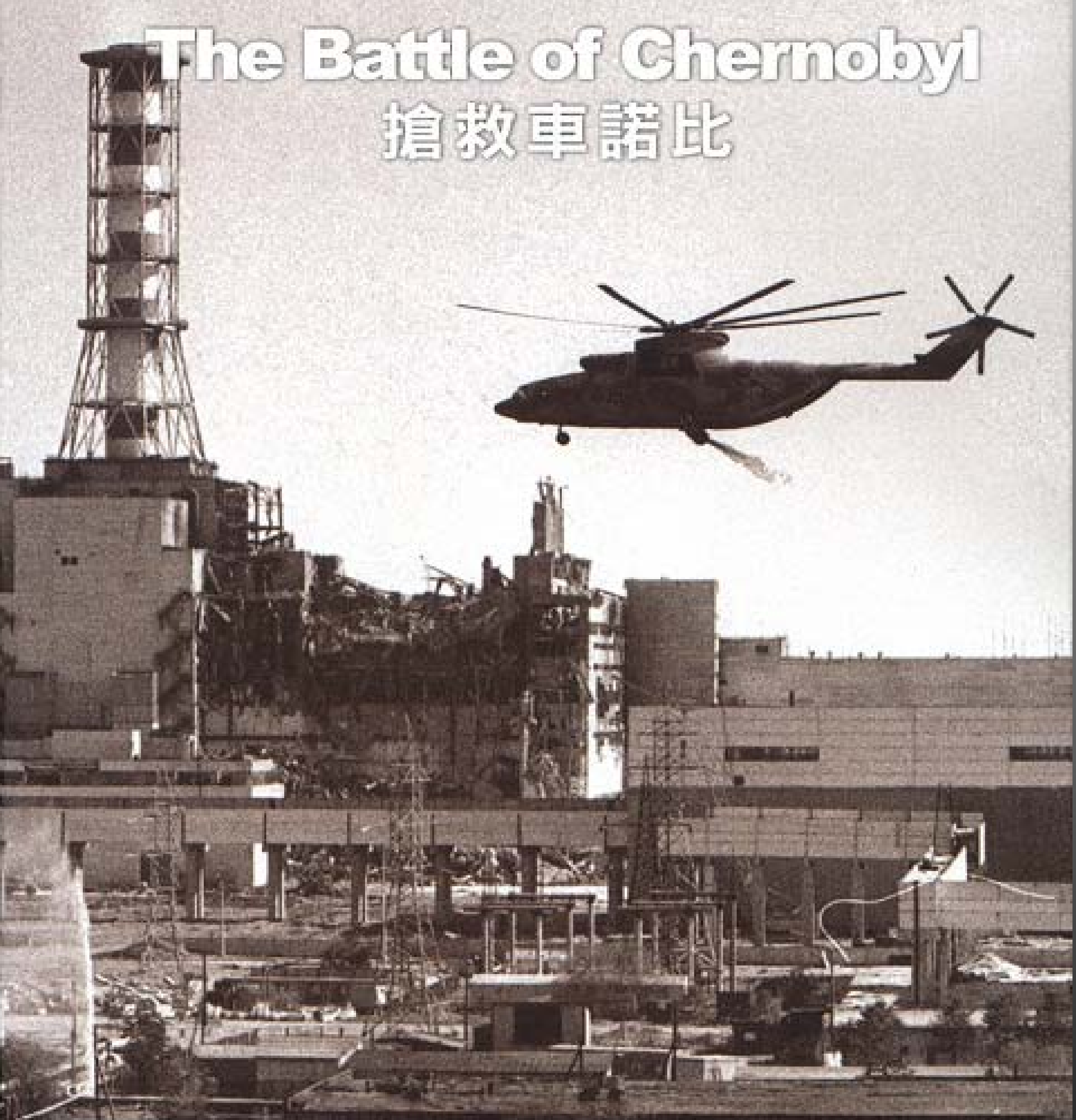
The Explosions

- The first explosion blew containment lid off the reactor core.
- Inrush of Oxygen led to Combustion of Core materials.
- This second explosion, and resulting fire, spread massive amounts of radioactive materials.


Remnants of
Chernobyl Unit # 4

Emergency response and control

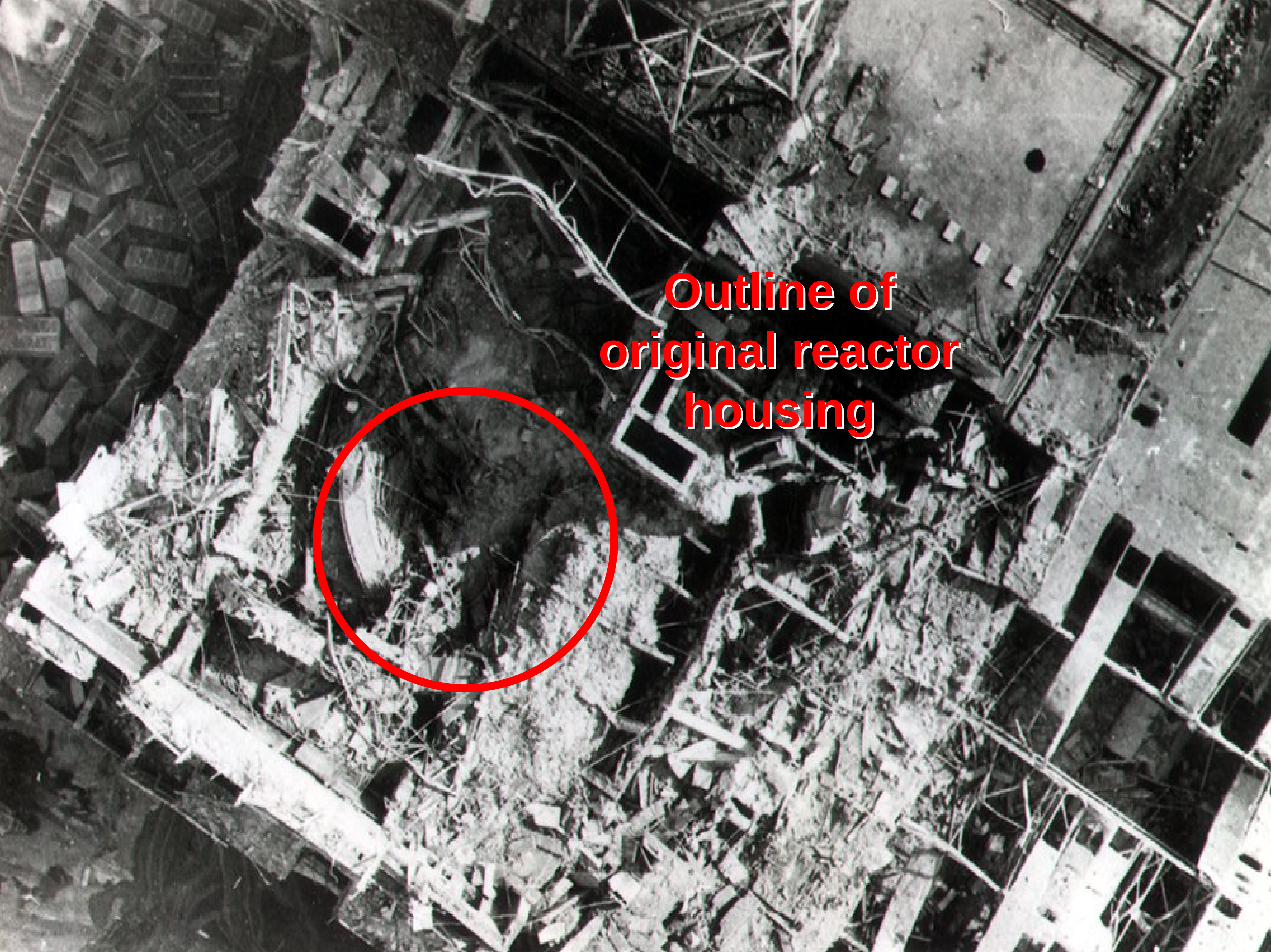
- The reactor fire burned for 10 days.
- The first attempt to extinguish the fire was to pump water into it.
- Water was pumped into the core for 10 hours before they realized that it would not be adequate.

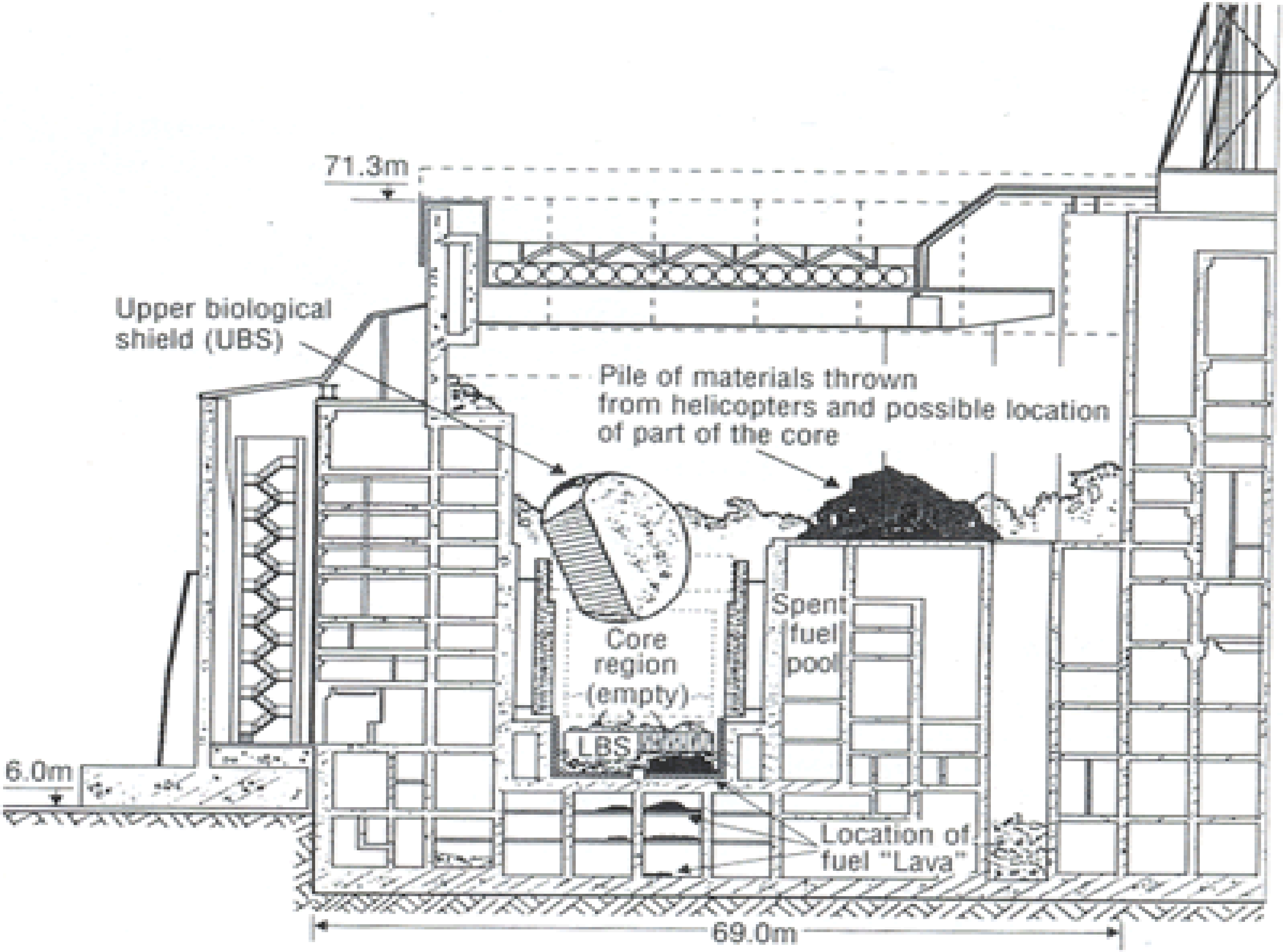


Russian Military Helicopters made passes over the reactor for 9 days following the initial explosions, dumping dry materials into the reactor, trying to extinguish the blaze.

Emergency response and control

- The dry materials used:
  - Boron – neutron absorber for fission control.
  - Sand – smother.
  - Lead – melt and seal from oxygen.
- The blaze was eventually extinguished by injecting liquid nitrogen into the core of the reactor on the 10^{th} day.


Outline of original reactor housing



71.3m
Upper biological
shield (UBS)
Pile of materials thrown
from helicopters and possible location
of part of the core
Spent
fuel
pool
Core
region
(empty)
LBS
6.0m
Location of
fuel "Lava"
69.0m

The Liquidators

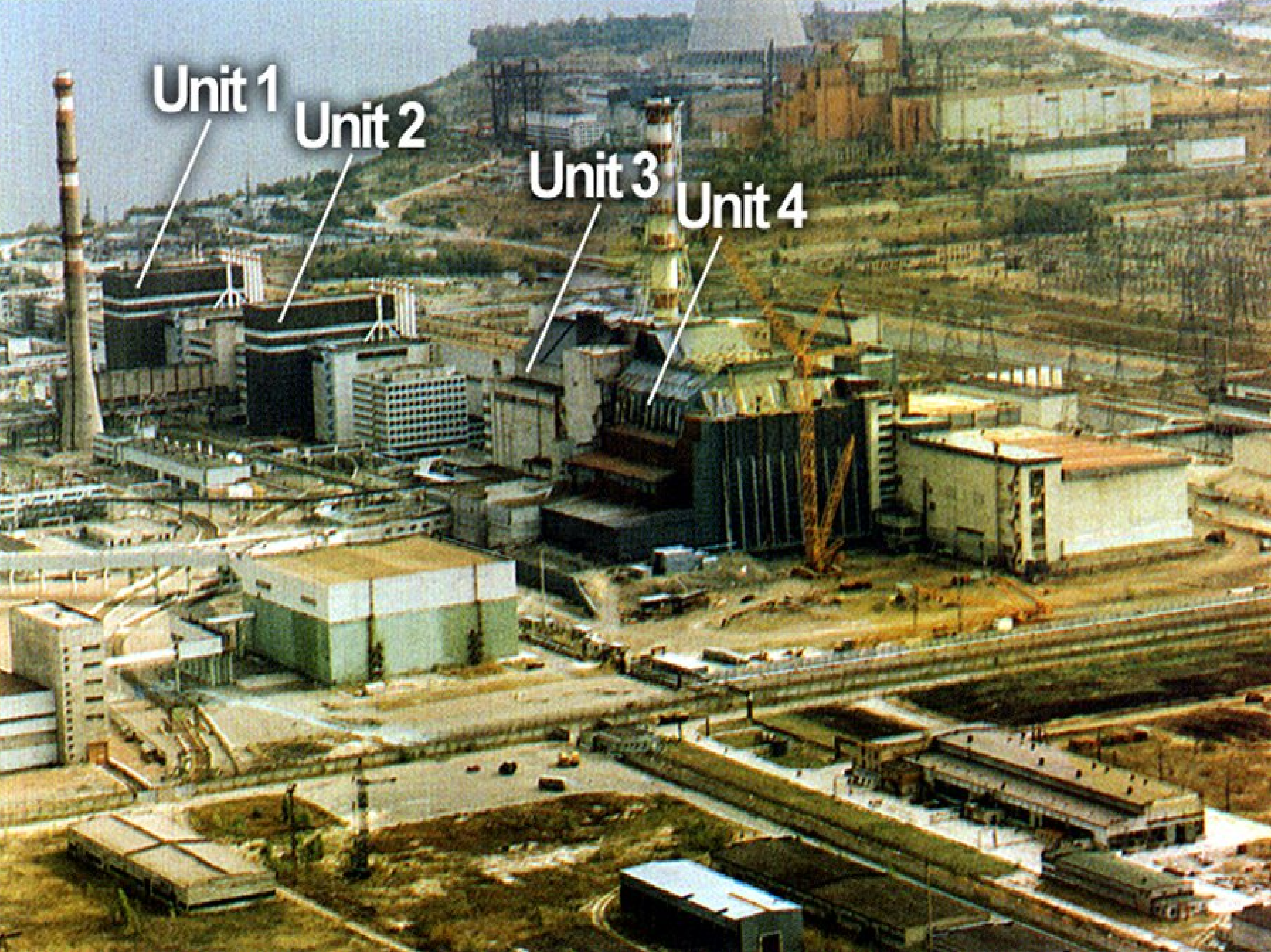
- The people responding to this emergency and the following containment efforts were know as “The Liquidators.”
- Over 600,000 people were involved in the emergency response, clean-up, and containment efforts.

The Liquidators

Workers and Soldiers were gathered from all over Russia, Ukraine, and Belarus to respond to the disaster at Chernobyl. Many of them died, and more still suffer from the effects of Radiation Poisoning.

The Sarcophagus

- Made of steel and concrete.
- Took approximately 7 months to construct.
- Keeps the radioactive Materials contained from the environment (weather).
- Is not completely sealed
- Temporary Structure, built to last for 20 – 30 years.
- Built 22 years ago and is currently in a state of decay.
- Repairs are made as needed.


Unit 1
Unit 2
Unit 3
Unit 4

The NEW SAFE Confinement (NSC)

- The “New Safe Confinement” (NSC) is the new structure being erected to more adequately contain the remains of the Chernobyl Unit #4 Reactor.

- This project is a collaborative effort from the international community to prevent further radioactive contamination from this site.

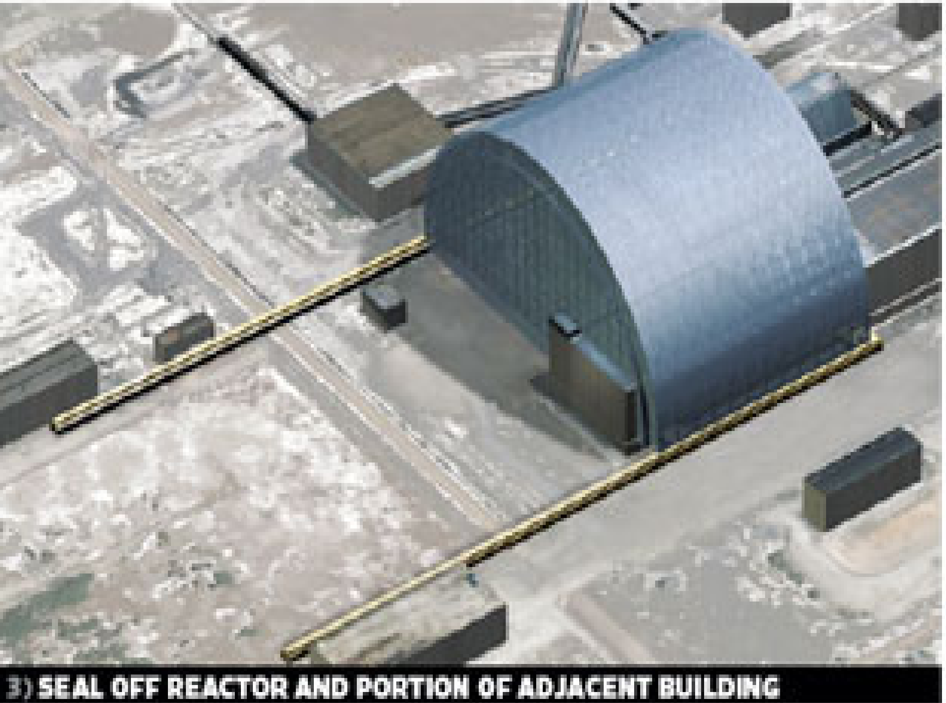
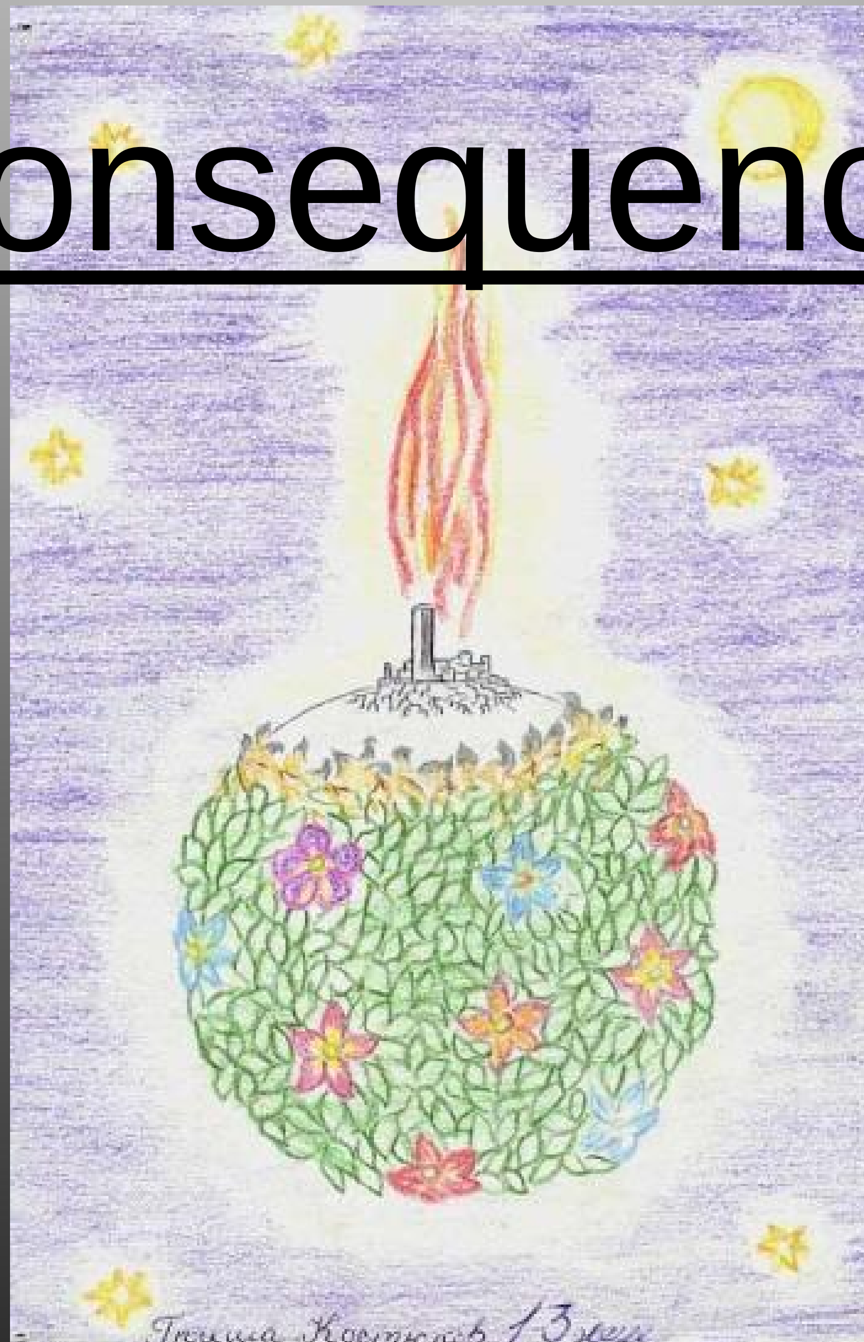


Diagram of NSC construction process and placement.

Cause and Effect

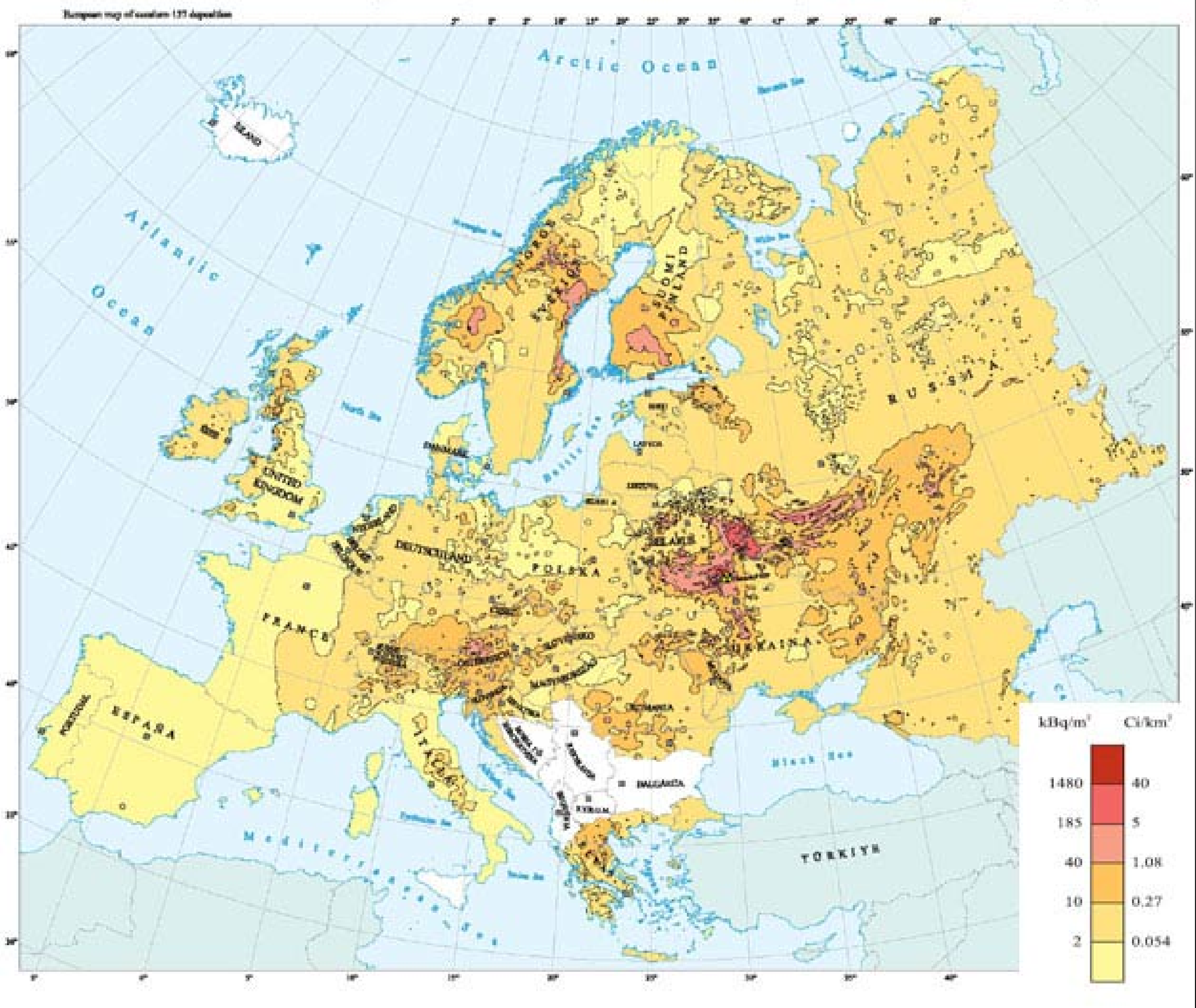
- The Chernobyl Reactor #4 catastrophic failure was caused by:
  - Neglect for prescribed operating limits and procedures,
  - The removal of automatic protection schemes, and
  - inherent design flaws in a nuclear device.
- This was the only catastrophic nuclear accident that has occurred.
- The consequences of this accident exceed those of any other single accident in human history biologically, socially, and economically.

Consequences



Consequences

- Radioactive Fallout, and the effects on human physiology and psychology.
- The cost of human life and severe detriment to the human standard of living in a large portion of Europe.
- Geographical inhabitability.
- Ecological devastation on a massive scale.
- Radioactive pollution from this incident will be evident for the next 125,000 years.



Arctic Ocean
Atlantic Ocean
UNITED KINGDOM
DEUTSCHLAND
POLSKA
FRANCE
ESPAÑA
ITALIA
RUSSIA
UKRAINA
BULGARIA
TÜRKIYE
SUOMI FINLAND
SVERIGE
NORGE
Black Sea
Mediterranean Sea
kBq/m²
Ci/km²
1480
40
185
5
40
1.08
10
0.27
2
0.054

Consequences

- Crippled the economies of the surrounding regions, which were primarily based on agriculture and livestock.
- The remaining 3 units were taken offline and construction halted on 2 other units. This amplified the energy crisis that already plagued the region.
- Negative social and political effects on the production of nuclear power.

Lessons

- The integrity of the power system and all associated equipment is defined by the associated operating limits.
- The Chernobyl disaster would have been prevented if the engineered protection schemes had not been disabled.
- Operating outside the bounds of prescribed operating limits and procedures is not safe.

Lessons

- The equipment operators did not have the authority to take reliable actions to ensure the safety and security of their equipment.

- Now, the operator has the decision making authority and responsibility to take whatever actions are necessary to ensure the reliability of the system they are responsible for.

Lessons

- The principles of our “Safety Culture,” in design and operation are what keep our systems reliable and safe.
- Safety and safe operations must always be priority # 1, regardless of any opposition.


The End
20
STOP
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