The Chernobyl Accident

What happened?
What were the root causes?

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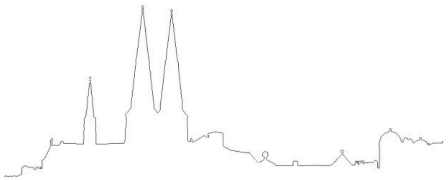
In Sweden, it started at the Forsmark NPP in the morning of April 28, 1986

The same morning at Oskarshamn NPP

The Steering Group for the Swedish Project on Release Mitigation in Case of Severe Acccidents had started one of its regular meetings…

- The meeting was broken up by a telephone call with information from Forsmark on radioactivity outside the plant
- The SSI experts in the group were recalled to Stockholm
- OKG radiophysicists cut some grass outside O3 and put it in a nuclear spectrometer



The same morning at Oskarshamn NPP

The Steering Group for the Swedish Project on Release Mitigation in Case of Severe Acccidents had started one of its regular meetings…

First shock:

- The nuclide spectrum observed must come from a power reactor core which had seen temperatures of at least 1500 -2000 C. (also detected at Studsvik as confirmed by telephone)

- In the evening, Moscow announced that an accident had occurred at the Chernobyl NPP but that the reactor was stable

The next morning on April 29:

Second shock:

- The Scientific Attaché at the USSR Embassy in Stockholm came to the SKI offices and asked if we had any advice to provide on extinguishing fires in graphite.
- We had not much actual advice to give – but we realized that the situation was not under control at Chernobyl.

- As a consequence, SKI decided to set up a small expert group to try to collect any information available on the state of the reactors at Chernobyl so as to be able to advise SSI on the likelihood of additional releases that might affect Sweden.
- The group subsequently moved to the SSI emergency center at Haga Tingshus, with daily contacts with colleagues in Germany and US .

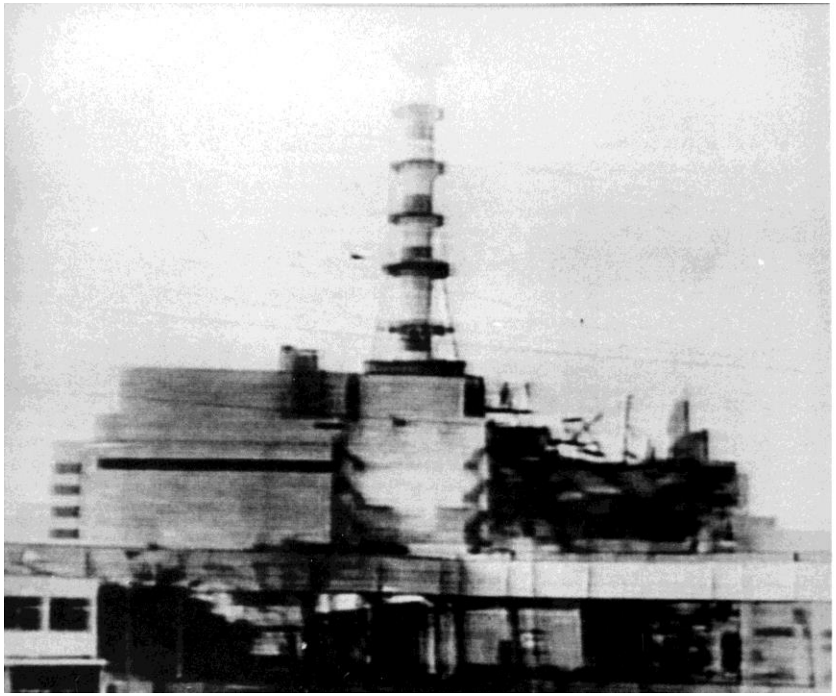
The next day, April 30

Third shock:

- Soviet television showed this picture of Chernobyl 3-4 (also shown on Swedish TV).
  - The Soviet commentator said that ”the damage, as shown in this picture, disproves Western reports of massive destruction or fire at the facility”

Obviously, the picture shows a totally destroyed reactor, with a severely damaged and probably burning core lying open to the sky among the rubble....

It was not until Hans Blix, then IAEA DG, visited Chernobyl more than a week later that we had independent confirmation that the state of the reactor had been reasonably stabilised.



The Chernobyl 4 Nuclear Power Reactor

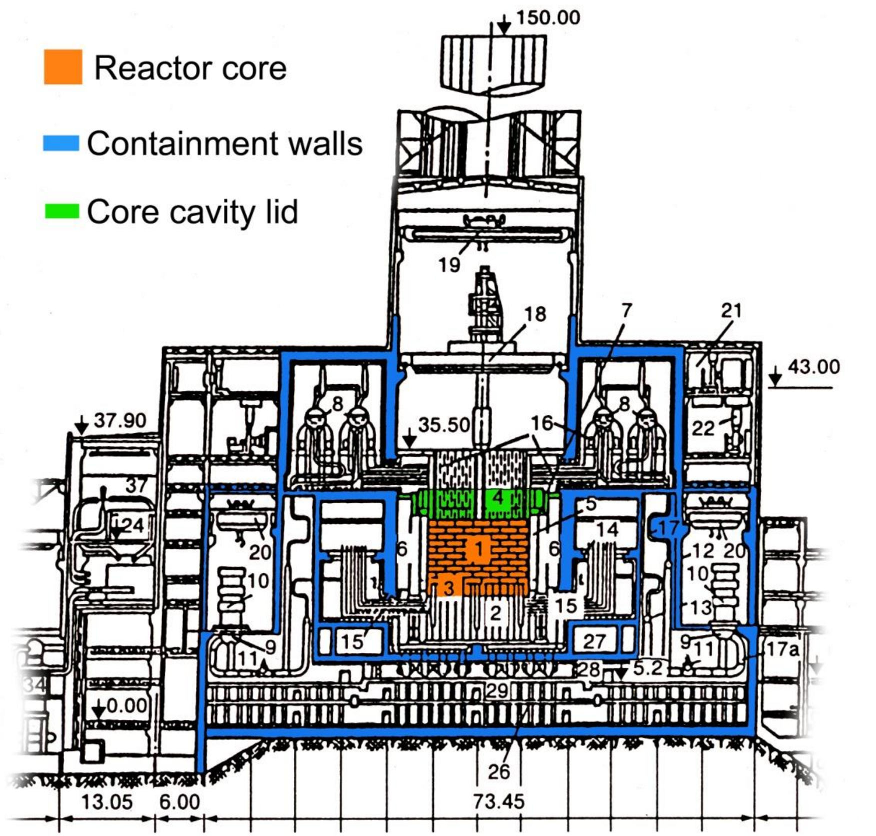
Soviet-built Light Water Cooled Graphite Moderated Reactor (RBMK)
3200 MWth, 1000 Mwe. First connection to the grid Dec 22, 1983

Pre-accident design features included:

- The reactor core consists of 1661 water-cooled fuel channels surrounded by graphite blocks acting as moderator.

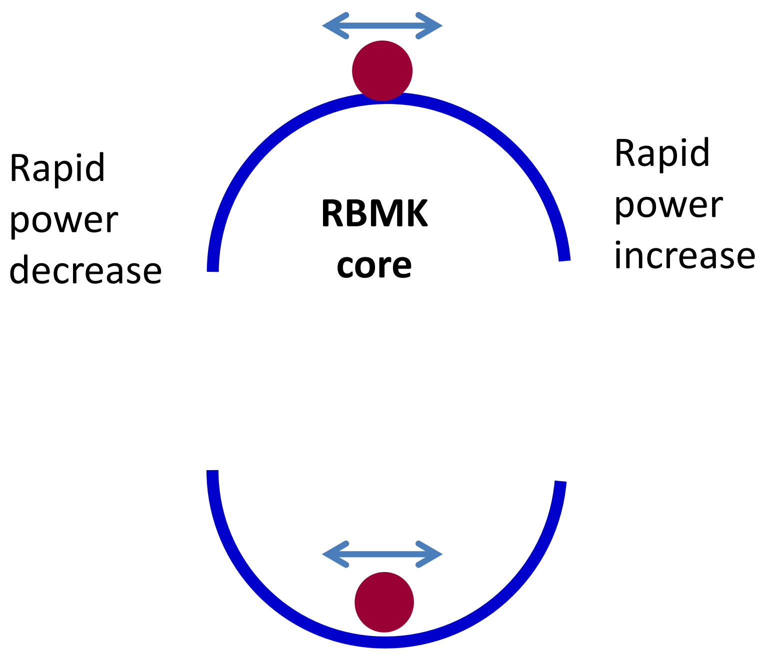
- Positive void coefficient (up to $+5b_{eff}$) in normal steady-state refueling operating regime. This means that increased boiling in a fuel channel would lead to a power increase.

Cross-section of an RBMK reactor (from IAEA INSAG-7)



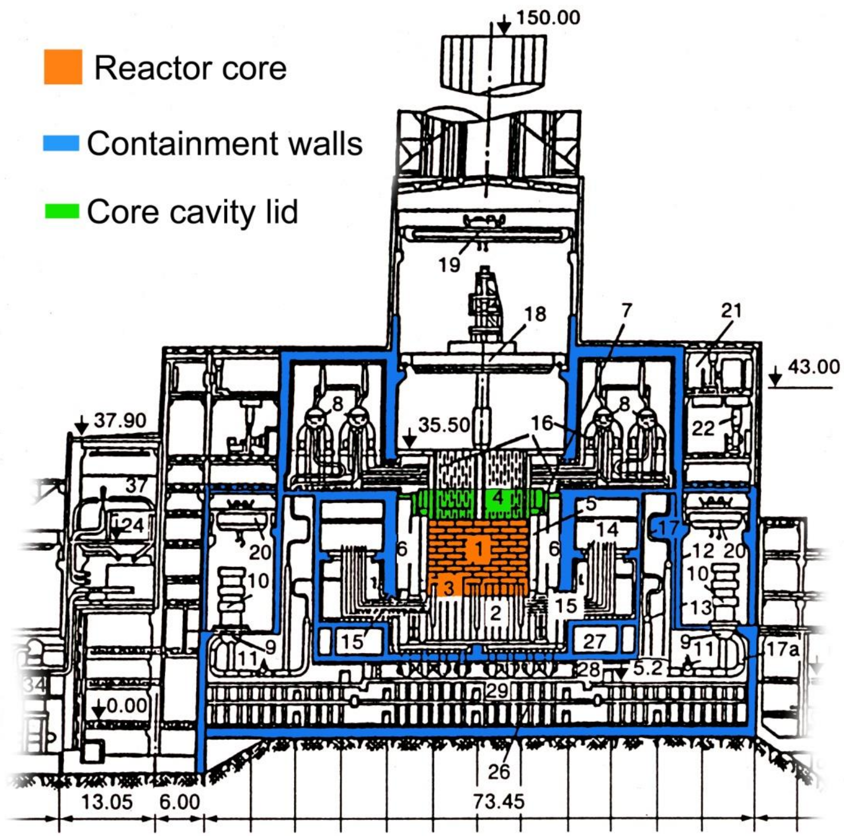
The Chernobyl 4 Nuclear Power Reactor

Core stability properties (vastly simplified)



BWR and PWR cores are inherently stable

Cross-section of an RBMK reactor (from IAEA INSAG-7)



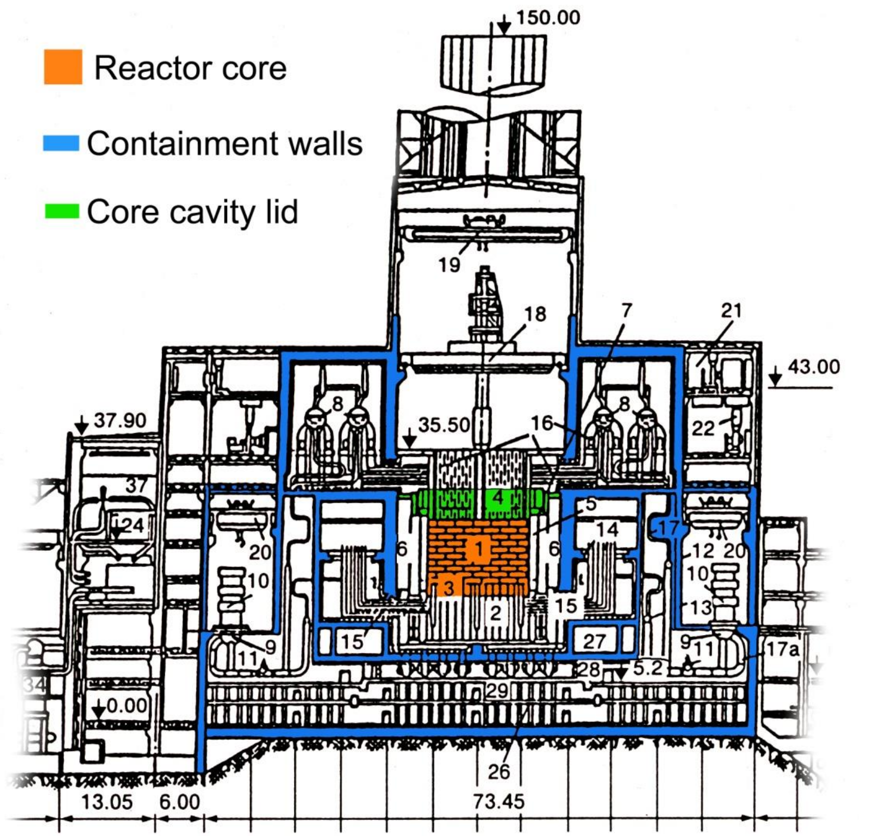
The Chernobyl 4 Nuclear Power Reactor

Pre-accident design features included:

•211 control rod channels. Control rods so designed that fully withdrawn control rods could initially introduce some positive reactivity in lower core region on re-insertion.

•"Compartementalized" containment with pressure suppression pools below the reactor. Each compartment in principle designed to handle break of largest pipe in that compartment. Core cavity designed to handle break of two fuel channels.

Cross-section of an RBMK reactor (from IAEA INSAG-7)



What happened at Chernobyl 4?
(condensed version)

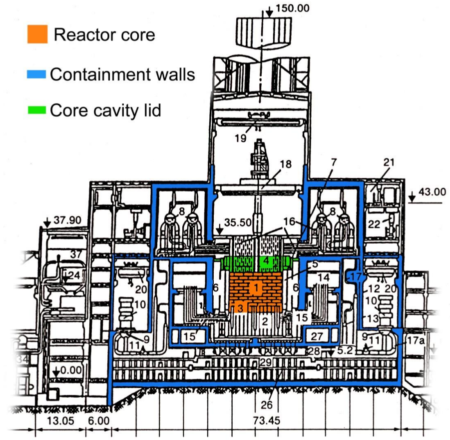
Fri 25 April 1986 01:00:00

•Power reduction starts in preparation for a planned maintenance outage. In the process, a safety test is planned. The test is planned to take place at about 25% of full power (~750 MWt).

04:00 – 23:10

•Power reduced to about 1500 MWt

• At 14:00 the electricity grid controller asks for a delay in the testing program for grid stability reasons. This prolongs operation at reduced power, which in fact increases core instability. There are, however, no formal restrictions in procedures on operating time at reduced power.



An RBMK control room (Ignalina 1990)

What happened at Chernobyl 4?
(condensed version)

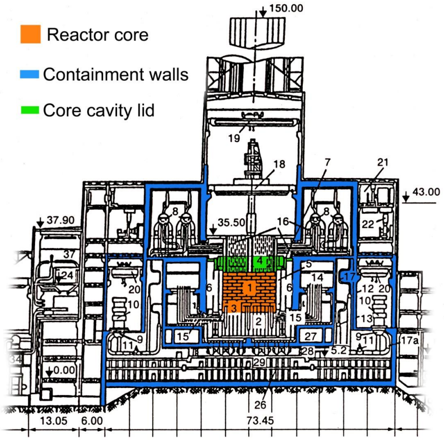
23:10 – 01:23 Sat 26 April

- Power reduction resumed.
- At 00:28, at a power of 500 MW, when switching between power control modes, the power drops to 30 MW but is restored to 200 MW and stabilized at 01:03.

Some plant computer systems malfunctioned, delaying operator access to up-to-date information on core parameters ***.***

01:23:04 Sat 26 April

- The reactor is now far outside the allowed operational region with respect to operational reactivity margins. Operators unaware of/ignored this situation.
- Test to supply emergency power to four main circulations pumps is initiated.



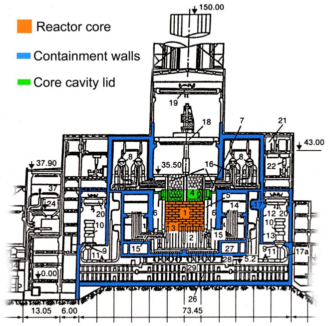
An RBMK control room (Ignalina 1990)

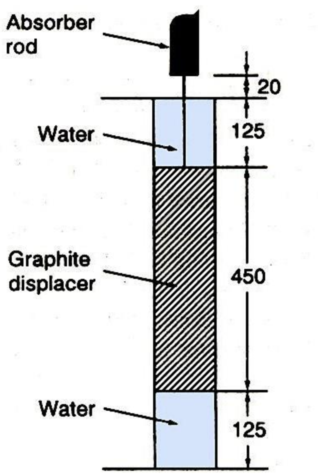
What happened at Chernobyl 4?
(condensed version)

01:23:40 Sat 26 April

- Operator pushes the reactor trip button. Control rods start to move down into the core, introducing some positive reactivity in lower parts of the core.
- As a result, power starts to increase rapidly, amplified by the positive void coefficient. Power may have reached up to 100 times full power within seconds

- At 1:23:49: alarm for increased pressure in the reactor cavity, indicating rupture of fuel channels due to overheating.
- At 1:24 severe shocks are recorded in operating log.





Fully withdrawn position of a control rod of the RBMK emergency protection system relative to the reactor core (pre-accident). Dimensions in cm.

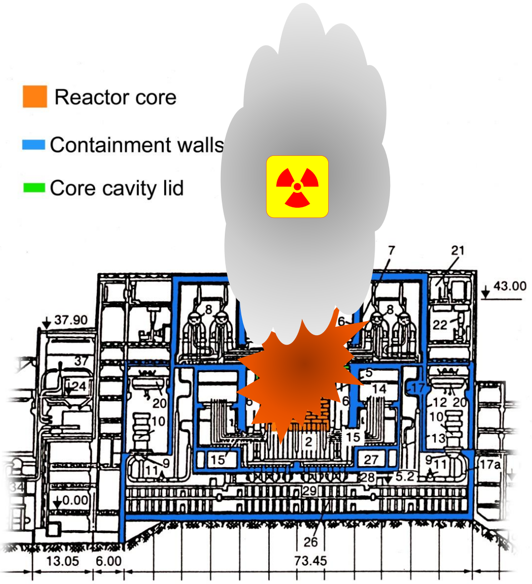
What happened at Chernobyl 4?
(condensed version)

01:24 Sat 25 April - Tue 5 May

•Escaping steam and gases from ruptured fuel channels overpressurizes the core cavity, lifting and overturning its 1000 ton lid, rupturing all fuel channels, also lifting the control rods out of the core.

•A second explosion occurred, probably the combined effect of control rods (but not fuel and moderator) disappearing and hydrogen. Evaporated fuel and fuel fragments were spewed high up in the air.

•A graphite burn started in the rubble that remained of the core.



What happened at Chernobyl 4?
(condensed version)

01:24 Sat 25 April - Tue 5 May

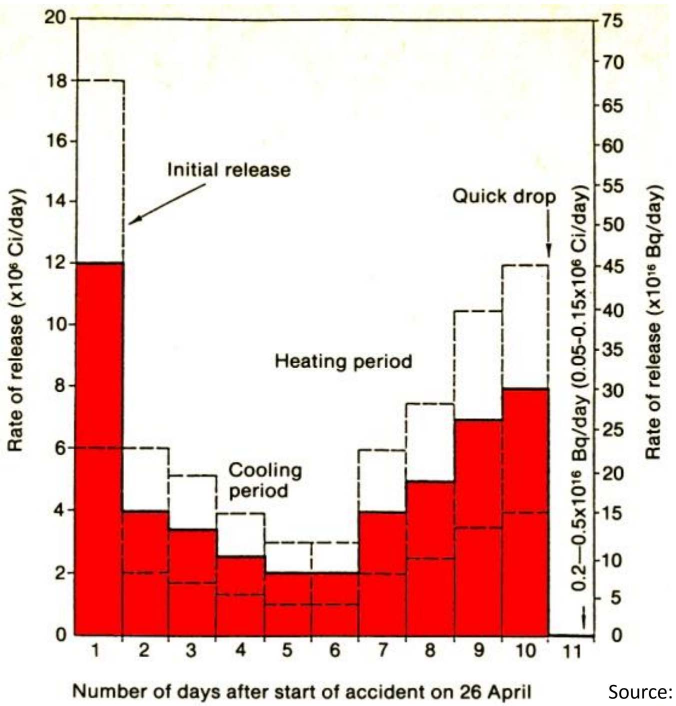
• Hot fuel and graphite fragments initiated fires on the roof of the turbine building and elsewhere.

• The fires were rapidly extinguished by the local fire brigade, but many firemen exposed themselves to lethal radiation doses for lack of protection.

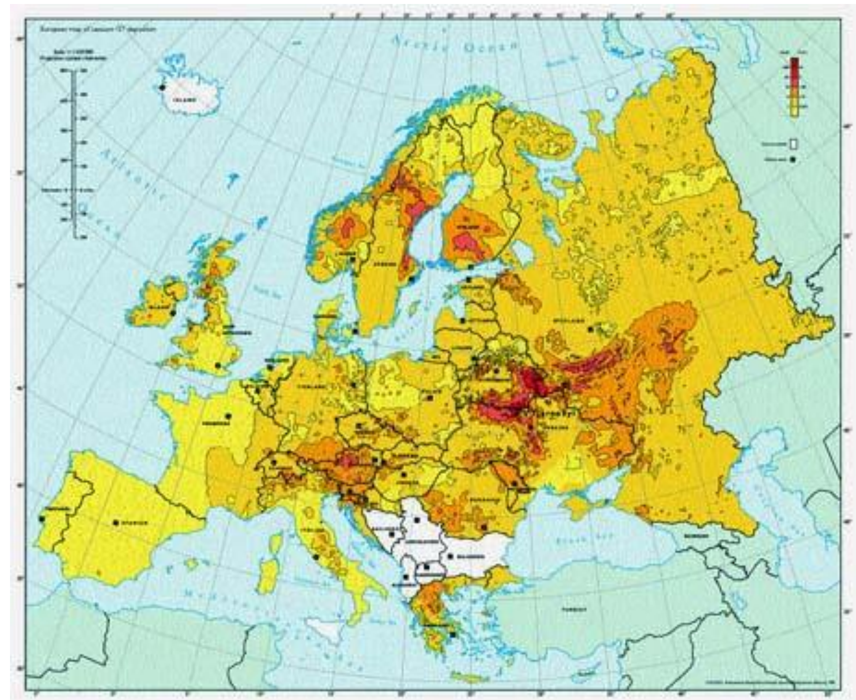
• Attempts were initially made to cool down the damaged core by bombarding it from helicopters with sand and lead but this approach had to be abandoned for fear of overloading remaining building structures.

• After ten days, cooling of the damaged core was achieved by streaming nitrogen from below through tunnels excavated under the reactor building.

Recalling Chernobyl 4 releases – the fallout over Europe



Source:
IAEA INSAG-1

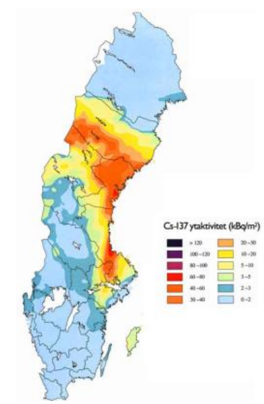


Source:
European
Commission
1998

Total releases (mainly in the first ten days)

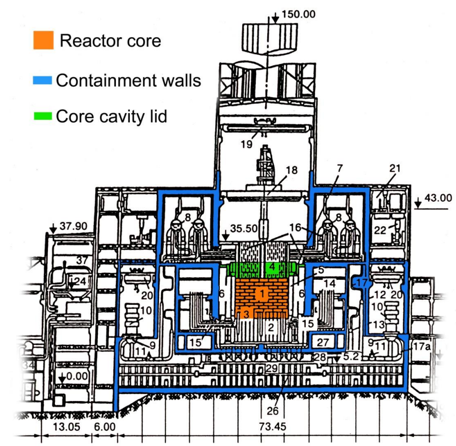
Radionuclide	Release (PBq)	% of core inventory
Iodine 131	1 800	~60
Caesium 137	85	~30

Total amount of Cs-137 deposited over Sweden:
~4 Pbq

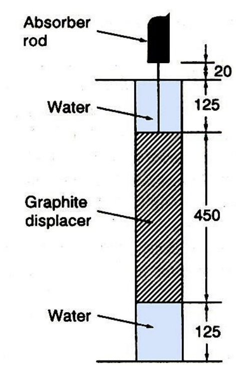


Root causes to the Chernobyl accident:
Crucial deficiencies in safety management

- ***Design approval, notably***
  - ***Reactor stability properties and associated requirements as to fuel properties and operating limits and conditions (OLC)***
  - ***Design of the control rods***
  - ***Design basis for core cavity integrity (e.g. rupture of single fuel channels vs. blockage or rupture in a lower group distribution header below the core cavity, which could damage several fuel channels)***
- ***Delays in implementing identified safety improvements based on operating experience***
- ***Approval of the test procedure without proper attention to potential hazards***
- ***Decisions taken in the control room:***
  - ***Continuation of the test although the reactor was operating far outside both the planned test program and the "recommended" (but not strictly required) operating limits and conditions and with the reactor in a state poorly understood by operators.***



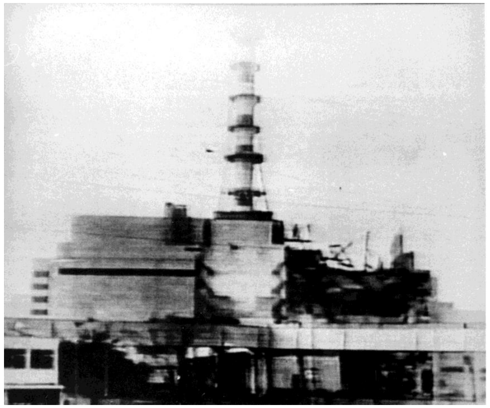
Source:IAEA INSAG-7



Root causes to the Chernobyl accident:
Crucial system deficiencies in the USSR

- A political and organisational system which was not able to eliminate or compensate for design deficiencies although these deficiencies were known for a long time prior to the accident (e.g. lessons learned from incidents),
- Weak regulatory oversight
- A testing programme which was insufficiently designed and assessed as to its safety aspects
- A form of management which placed excessive demand on plant staff with regard to their responsibility for safety.

In summary: deficient safety culture, all the way from control room to USSR government



Chernobyl 4
Impact on safety work

- Technical improvements on RBMK-type reactors such as core stability, control rods
- World-wide focus on safety culture and safety management
  - World Association of Nuclear Operators formed for industry-internal peer reviews
- Further strengthening of radiological emergency management, not least in Europe
- International nuclear safety regime considerably strengthened
  - Conventions on early notification and mutual assistance in case of nuclear accidents
  - **Convention on Nuclear Safety with mutual peer reviews of national safety work, not least nuclear regulatory regimes**
  - IAEA Safety Standards extended and strengthened (going from ”least common denominator” towards ”best international practices”)
  - IAEA peer review services expanded, for example to cover also regulatory regimes
  - International cooperation between regulators strengthened, not least within EU

Chernobyl (and later Fukushima) confirmed the soundness of Swedish severe accident management measures implemented after TMI

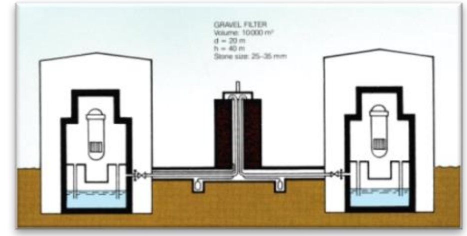
Key overall objectives in case of a severe accident:

- reach a stable state with damaged core covered by water and preserved containment integrity;
- keep releases of radionuclides that cause long-term land contamination below the equivalent of ~150 TBq Cs-137 (note: ~4000 TBq deposited over Sweden from Chernobyl).

Functional requirements include

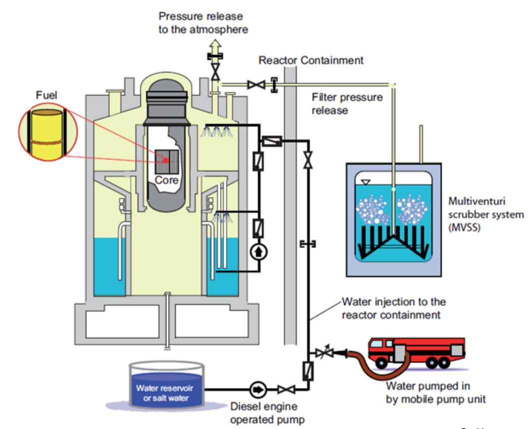
- 24h total station blackout;
- Pressure relief shall not need operator action (rupture disc).

Government decisions in 1981 and February 1986 on measures to be implemented



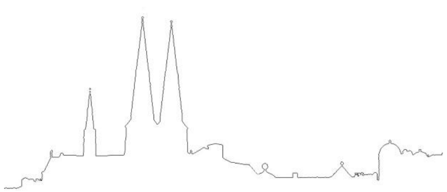
Source: Sydkraft/E.ON

Barsebäck
(pebble bed filter,
operational by the end of 1985)



Source: Vattenfall AB

Remaining ten reactors
(multi-venturi scrubbers,
operational in 1988)



Swedish safety objectives after the TMI accident still valid: Robust protection against socio-economic impacts intolerable to both society and industry

ACCIDENT	RELEASE OF Cs-137 (TBq)	EARLY FATALITIES	LATE FATALITIES	AFFECTED/ EVACUATED	COST ESTIMATE
Three Mile Island 1979 (core melt)	<< 1	0	No excess fatalities expected or observed	Short-term evacuation of nearby communities	~6.5 billion USD
Chernobyl 1986 (reactivity accident)	85 000	~40 (plant & rescue staff)	Maybe up to several thousands among those most exposed	>300 000 evacuated (many with stress-related symptoms)	250-500 billion USD
Fukushima Daiichi 2011 (3 core melts)	12 000	~60 (not by radiation)	Statistically significant increases not to be expected,	~150 000 evacuated (many with stress-related symptoms)	100-500 billion USD
EUR Design Extension Conditions (core melt)	< 100	0	Statistically significant increases not to be expected,	Precautionary short term evacuation in the vicinity of the plant?	< 20 billion USD? (loss of the reactor)

THANK YOU

FOR LISTENING!