Radiation Biology, Protection and Applications
The Chornobyl Accident

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The Chornobyl disaster

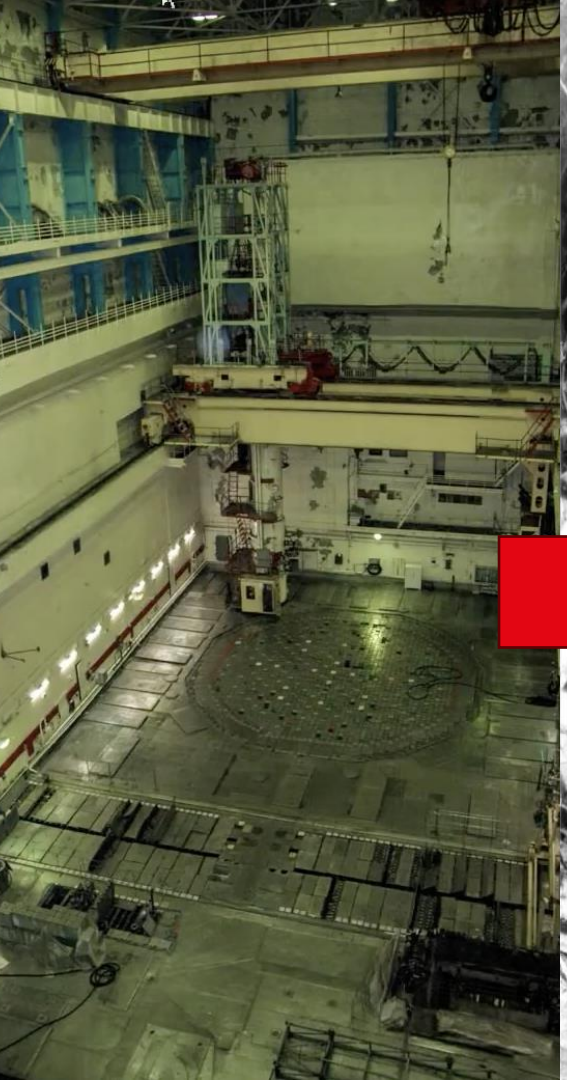
26 April 1986, 1:23AM: RBMK type Reactor No 4 of the Chernobyl Nuclear Power Station explodes

Steam explosion and reactor meltdown destroys the reactor building, releasing large quantities of radioactive material into the environment

Largest uncontrolled release of radionuclides into the environment (14 EBq) over the next 10 days

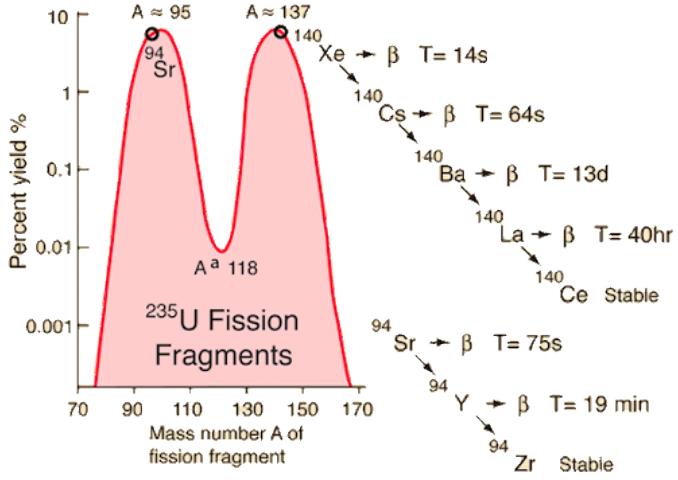
Overall response efforts required 500’000 people, 68 G-USD[2019]


euronews



What was released?

- All of the Xenon gas
- Half of the Iodine and Caesium
- 5% of the reactor fuel



- Most material settled in the immediate surroundings
- Aerosol forming isotopes (Cs, Ru, Te, Sr) and gases (Xe, I) got swept across Ukraine, Belarus, Russia and to some extent Europe

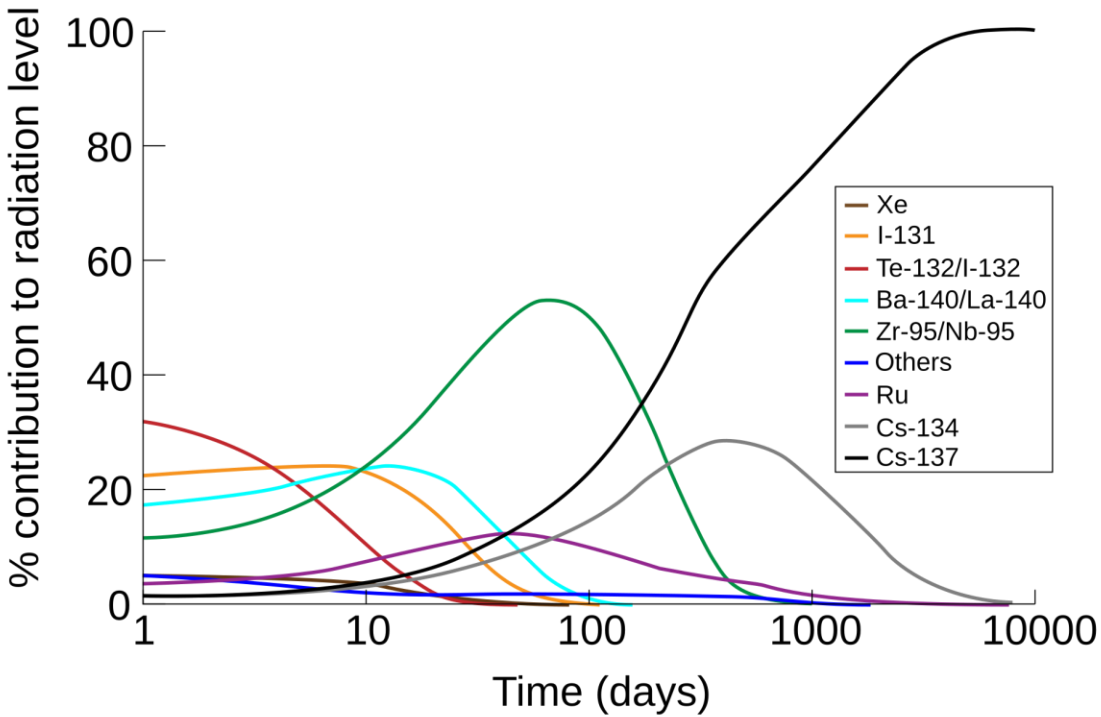
Nuclear Disaster **Radioactive Materials Derived from Nuclear Accidents**

	H-3 Tritium	Sr-90 Strontium-90	I-131 Iodine-131	Cs-134 Cesium-134	Cs-137 Cesium-137	Pu-239 Plutonium-239
Types of radiation	β	β	β, γ	β, γ	β, γ	α, γ
Biological half-life	10 days *1 *2	50 years *3	80 days *2	70-100 days *4	70-100 days *3	Liver: 20 years *5
Physical half-life	12.3 years	29 years	8 days	2.1 years	30 years	24,000 years
Effective half-life [calculated from biological half-life and physical half-life]	10 days	18 years	7 days	64-88 days	70-99 days	20 years
Organs and tissues where radioactive materials accumulate	Whole body	Bones	Thyroid	Whole body	Whole body	Liver and bones

Effective half-life: Related to p.27 of Vol. 1, "Internal Exposure and Radioactive Materials"
Effective half-lives are calculated based on values for organs and tissues where radioactive materials accumulate as indicated in the table of biological half-lives.
*1: Tritium water; *2: ICRP Publication 78; *3: JAEA Technical Manual (November 2011); *4: Assumed to be the same as Cesium-137; *5: ICRP Publication 48

Relative impact on radiation levels by isotope

- Noble gases and aerosols contribute most
- Short term impact mostly driven by Iodine (→iodine pills)
- Long term impact driven by Cs134 and Cs137
- Main sources of radiation dose to humans: External gamma/beta, internal beta



Reactor building after the accident

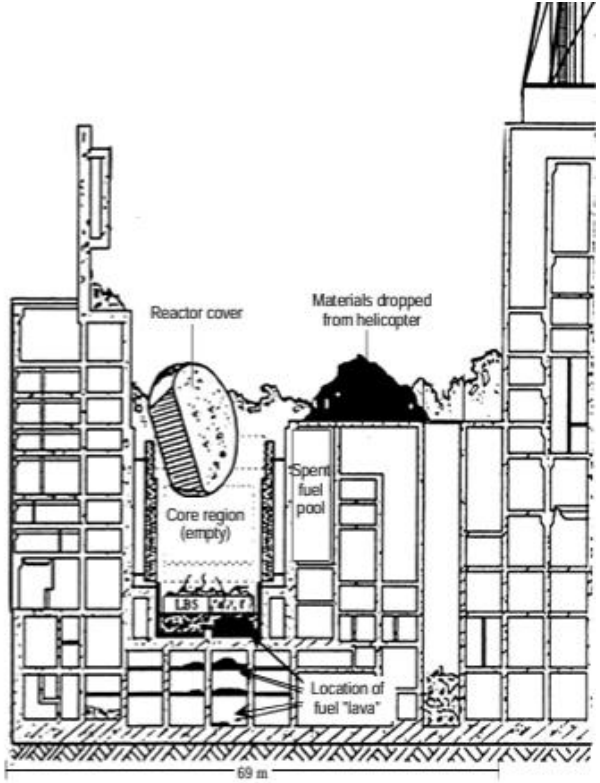
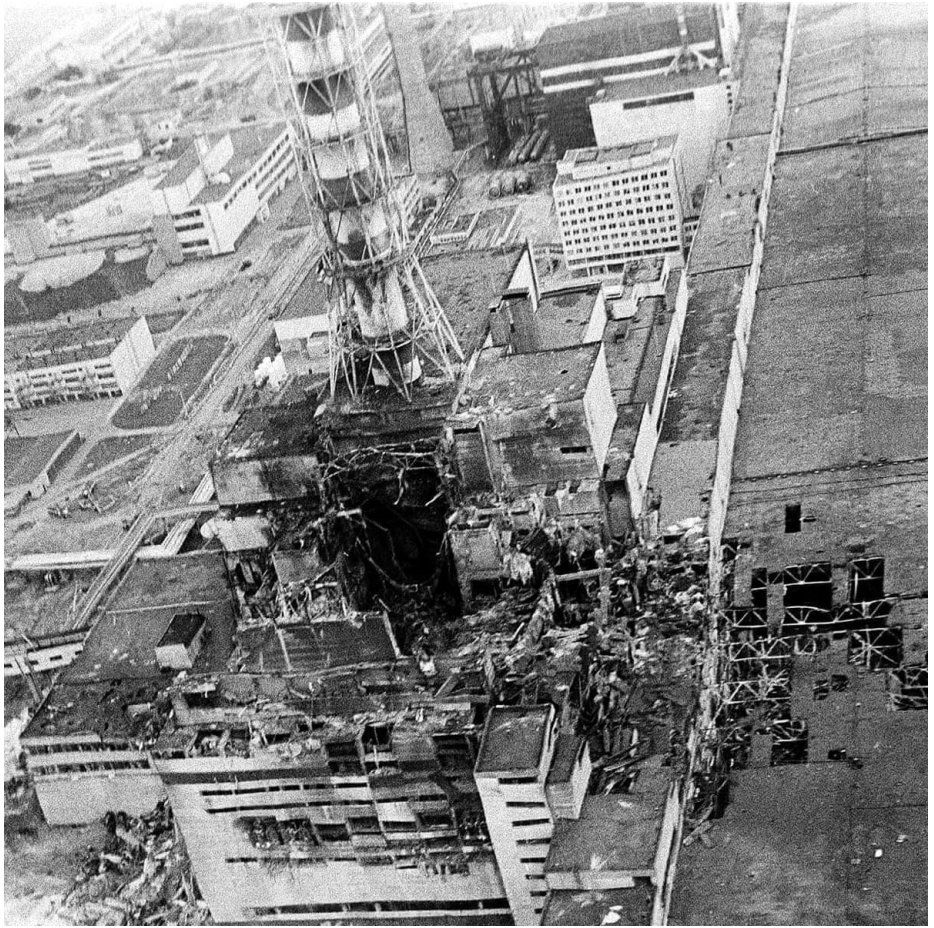


Figure I. Cross-section view of damaged Unit 4 Chernobyl reactor building.



Clip from HBO series *Chernobyl*

Speaker

Fact check on the clip

- Realistic display of the firemen deployment, uncertainty of danger
- Unrealistic depiction of radiation burns (in the show it develops in seconds/minutes, it actually takes hours or days)

- Grigorii Khmel, driver of one of the fire engines: “We didn't know much about radiation. Even those who worked there had no idea. There was no water left in the trucks. Then those boys who died went up to the roof—Vashchik, Kolya and others, and Volodya Pravik ... They went up the ladder ... and I never saw them again.”
- Anatoli Zakharov, fireman: "I remember joking to the others, 'There must be an incredible amount of radiation here. We'll be lucky if we're all still alive in the morning.'
- “Of course we knew! If we'd followed regulations, we would never have gone near the reactor. But it was a moral obligation—our duty. We were like kamikaze!”

Immediate situation

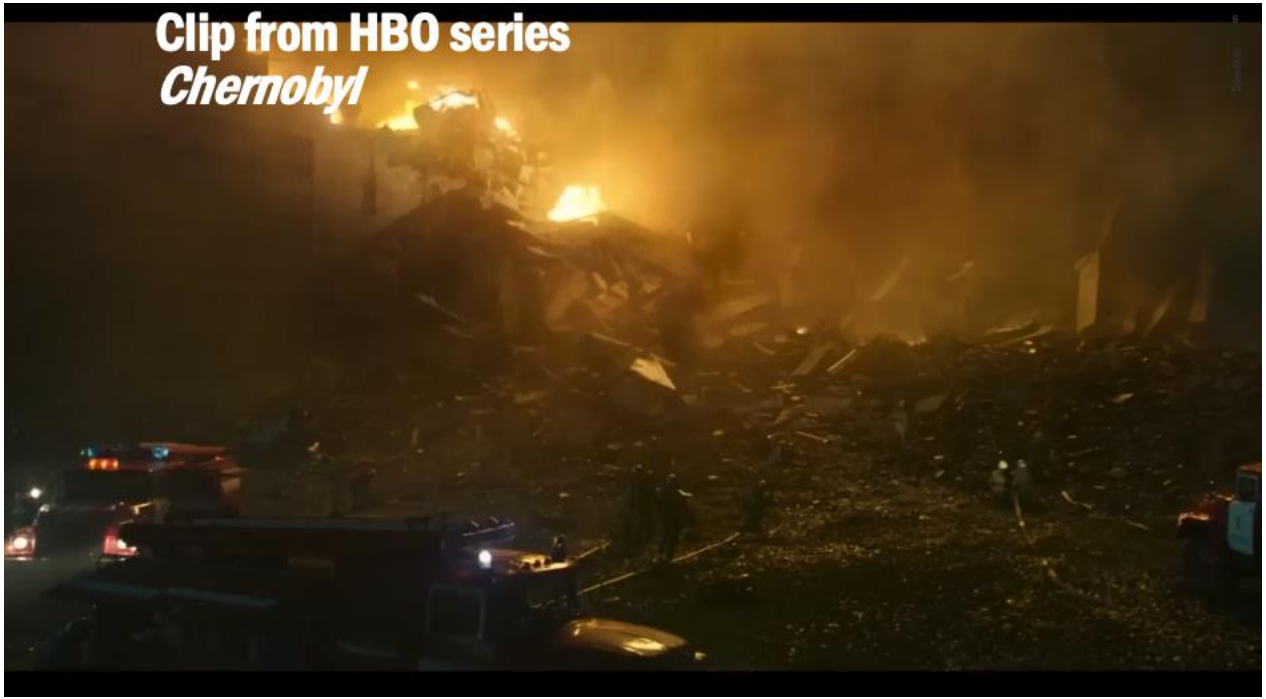
Reactor building is on fire, Chernobyl power plant firemen get deployed at 1:30AM to attempt to extinguish the flames

Reactor materials are scattered on the ground (firemen reported touching ‘hot’ graphite)

Fires extinguished by 5AM, 250 firemen deployed in total

5 of the firemen died of acute radiation sickness by July 1986

Radiological situation



- Radioactive materials on the ground: U, activated C, Zr
- Radioactive gases and steam in the air
- Worst areas immediately next to the reactor up to 180 Gy/hr or 50mGy/s (LD50 dose of 5 Gy within minutes)
- Dosimetry was difficult: Power plant personnel had detectors that could only measure up to 3.6 Roentgen/hr (roughly 36mSv/hr)!

Clip from HBO series *Chernobyl*

Doses to power plant personnel and first responders

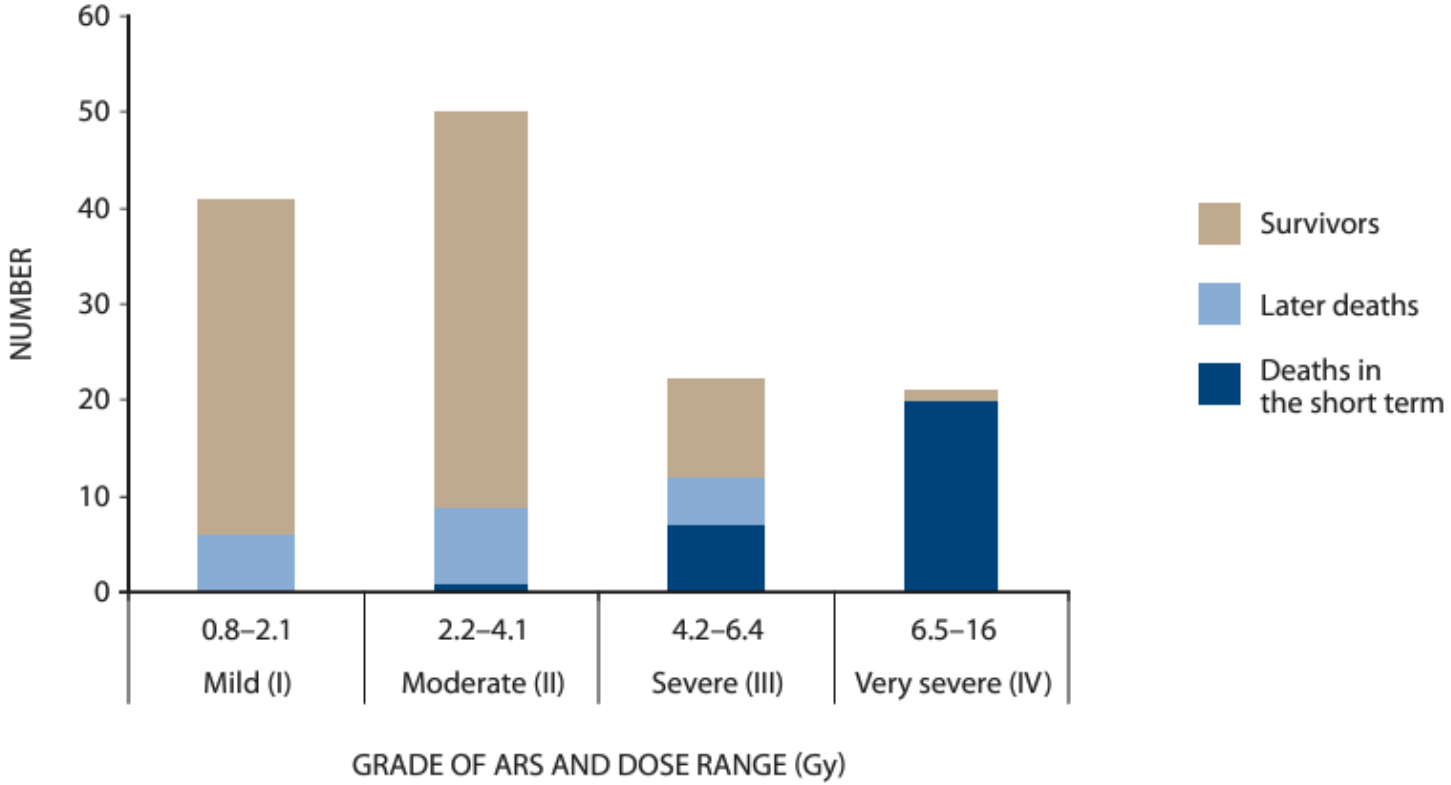
- 134 patients diagnosed in total with acute radiation syndrome
- 28 died within for four months, mostly due to bone marrow failure
- Dominant source of exposure: β irradiation of the skin due to contamination of clothes
- Neutron irradiation insignificant
- Internal contamination minor importance

Firefighter treated at Moscow ‘Hospital 6’

Firefighter clothes in the Pripyat basement

Figure VII. Outcome for patients with ARS

While the figure indicates the numbers of later deaths for each category of ARS, most of the cases are not attributable to radiation exposure



Speaker

Containment efforts

- Evacuation of Prypyat and surrounding villages
- Creation of ‘exclusion zone’ of 30 km radius
- Extinction of burning graphite in the remaining core (took 10 days, mostly via helicopter)
- Removal of reactor debris on surrounding buildings to reduce radiation levels (Reactors 1-3 were intact and operating!) to enable ‘sarcophagus’ construction

Radioactive plume spread until 9th of May 1986

Speaker

Liquidation efforts

- Debris on roofs needed to be cleaned up
- Robots often failed due to high dose rate
- Civil and military personnel called to the effort called ‘liquidators’
- Construction of sarcophagus completed by November 1986

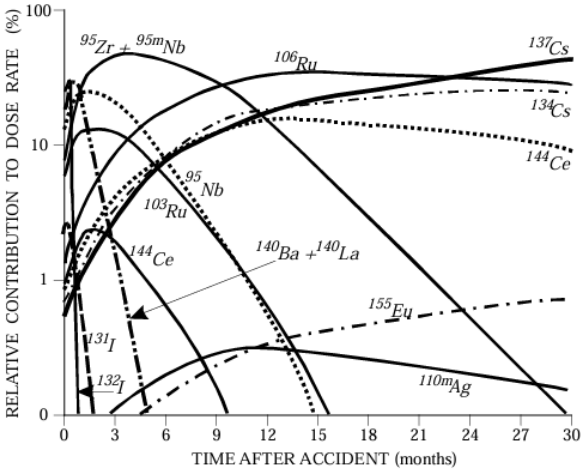


Figure XIV. Contributions of radionuclides to the absorbed dose rate in air in areas close to the Chernobyl reactor site [M3].

Clip from HBO series *Chernobyl* *‘90 seconds’*

Speaker

Doses to liquidators

A. Doses to workers involved in response and recovery

30. The average effective dose received by the recovery operation workers between 1986 and 1990, mainly due to external irradiation, is now estimated to have been about 120 mSv. The recorded worker doses varied from less than 10 mSv to more than 1,000 mSv, although about 85% of the recorded doses were in the range 20–500 mSv. Uncertainties in the individual dose estimates vary from less than 50% to up to a factor of 5, and the estimates for the military personnel are suspected to be biased towards high values.

31. The collective effective dose to the 530,000 recovery operation workers is estimated to have been about 60,000 man Sv. This may, however, be an overestimate, as conservative assumptions appear to have been used in calculating some of the recorded doses.

32. There is not enough information to estimate reliably the average thyroid dose to the recovery operation workers.

SOURCES AND EFFECTS OF IONIZING RADIATION

United Nations Scientific Committee on the Effects of Atomic Radiation

UNSCEAR 2008
Report to the General Assembly
with Scientific Annexes

VOLUME II
Scientific Annexes C, D and E

Monument to Those Who Saved the World

Uncertainties in the individual dose estimates vary from less than 50% to up to a factor of 5, and the estimates for the military personnel are suspected to be biased towards high values.

“Of course we knew! If we'd followed regulations, we would never have gone near the reactor. But it was a moral obligation—our duty. We were like kamikaze!”

Doses to general population

33. The high thyroid doses among the general population were due almost entirely to drinking fresh milk containing ^{131}I in the first few weeks following the accident.

The average thyroid dose to the evacuees is estimated to have been about 500 mGy (with individual values ranging from less than 50 mGy to more than 5,000 mGy).

35. As far as whole body doses are concerned, the six million residents of the areas of the former Soviet Union deemed contaminated received average effective doses for the period 1986–2005 of about 9 mSv, whereas for the 98 million people considered in the three republics, the average effective dose was 1.3 mSv, a third of which was received in 1986. This represents an insignificant increase over the dose due to background radiation over the same period (~50 mSv). About three-quarters of the dose was due to external exposure, the rest being due to internal exposure.

Figure V. The estimated average thyroid doses to children and adolescents living at the time of the accident in the most affected regions of Belarus, the Russian Federation and Ukraine [I14, K22, K25, L4, Z4]

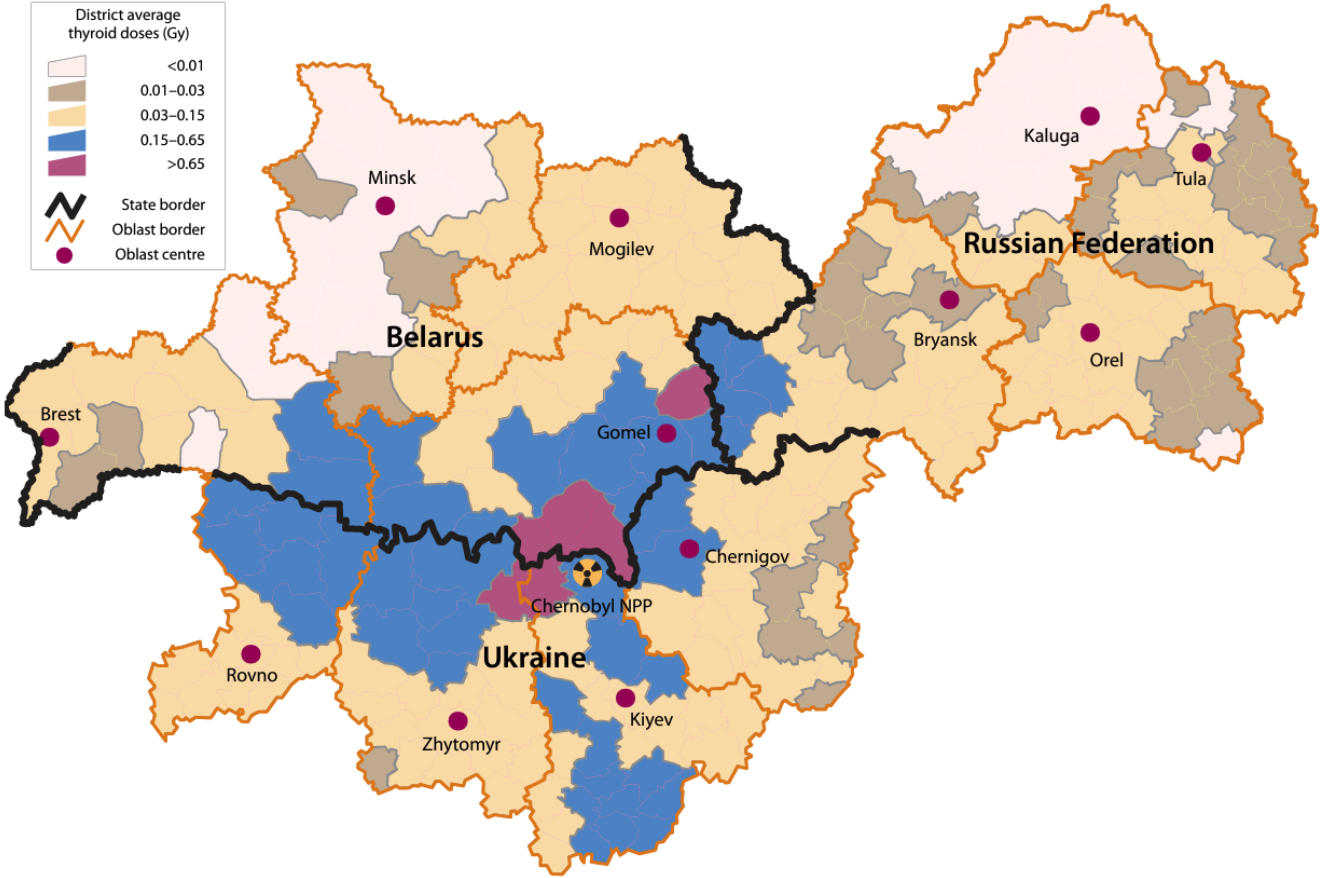
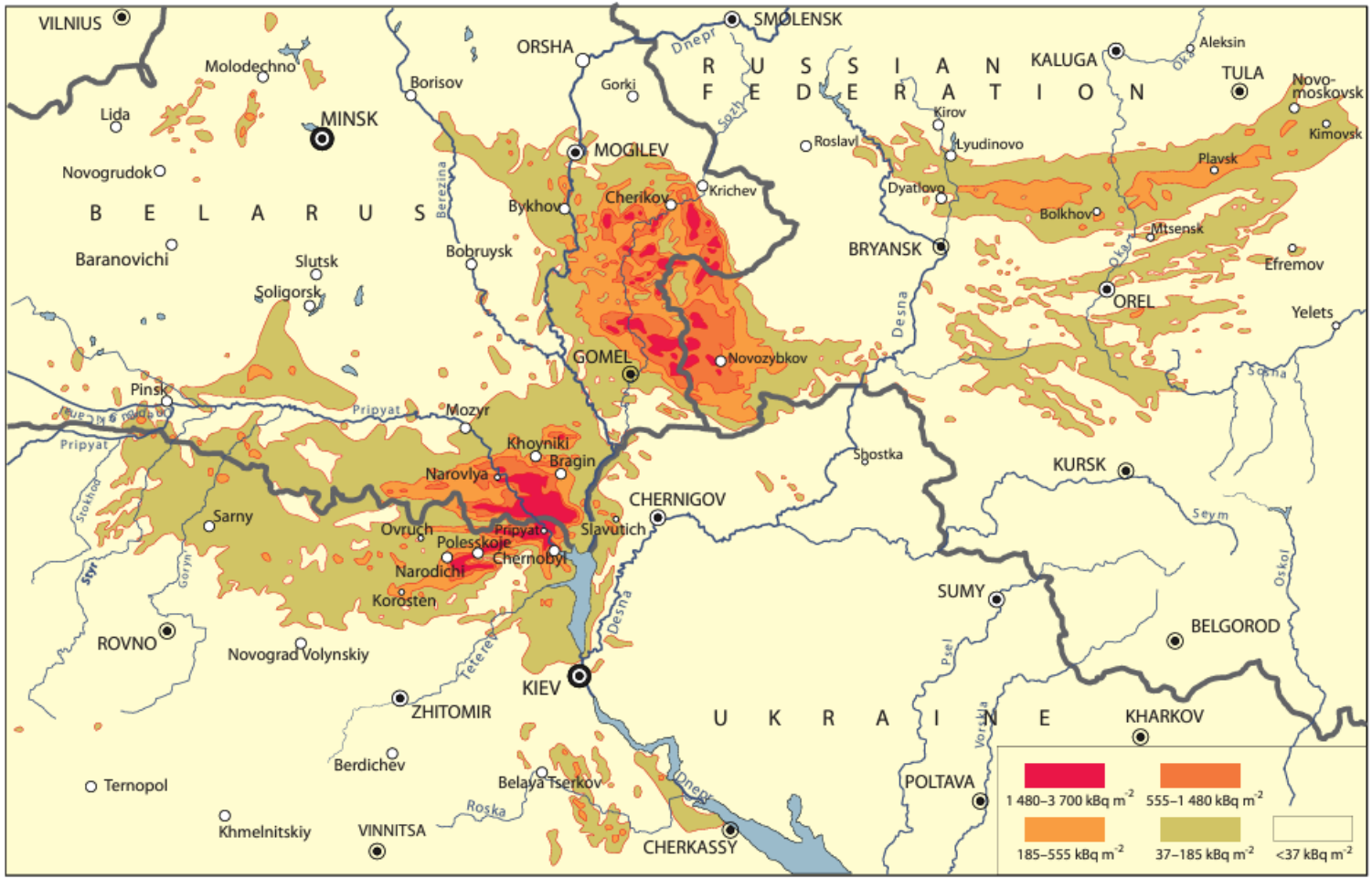


Figure II. Map of ^{137}Cs deposition levels in Belarus, the Russian Federation and Ukraine as of December 1989 [I28]



Speaker

Long term impact on health: Liquidators

- Ivanov et al. 2001: 66,000 liquidators from Russia. No increase in overall mortality from cancer or non-cancer.
- Rahu et al. 2006: 10,000 liquidators from Latvia and Estonia. No significant increase in overall cancer rate. Statistically significant increases in thyroid and brain cancer, authors believe it is due to better screening, not causal to dose.

PAPERS

MORTALITY AMONG THE CHERNOBYL EMERGENCY WORKERS: ESTIMATION OF RADIATION RISKS (PRELIMINARY ANALYSIS)

Ivanov, V. K.*; Gorski, A. I.*; Maksioutov, M. A.*; Tsyb, A. F.*; Souchkevitch, G. N.†

Epidemiology | Full Access

Cancer risk among chernobyl cleanup workers in Estonia and Latvia, 1986–1998

Mati Rahu, Kaja Rahu, Anssi Auvinen, Mare Tekkel, Aivars Stengrevics, Timo Hakulinen, John D. Boice Jr, Peter D. Inskip

First published: 17 April 2006 | https://doi.org/10.1002/ijc.21733 | Citations: 36

Long term impact on health due to radiation

A. Health risks attributable to radiation

99. The observed health effects currently attributable to radiation exposure are as follows:

- 134 plant staff and emergency workers received high doses of radiation that resulted in acute radiation syndrome (ARS), many of whom also incurred skin injuries due to beta irradiation;
- The high radiation doses proved fatal for 28 of these people;
- While 19 ARS survivors have died up to 2006, their deaths have been for various reasons, and usually not associated with radiation exposure;
- Other than this group of emergency workers, several hundred thousand people were involved in recovery operations, but to date, apart from indications of an increase in the incidence of leukaemia and cataracts among those who received higher doses, there is no evidence of health effects that can be attributed to radiation exposure;

Long term impact on health due to radiation

- The contamination of milk with ^{131}I, for which prompt countermeasures were lacking, resulted in large doses to the thyroids of members of the general public; this led to a substantial fraction of the more than 6,000 thyroid cancers observed to date among people who were children or adolescents at the time of the accident (by 2005, 15 cases had proved fatal);
- To date, there has been no persuasive evidence of any other health effect in the general population that can be attributed to radiation exposure.

SOURCES AND EFFECTS OF IONIZING RADIATION

United Nations Scientific Committee on the Effects of Atomic Radiation

UNSCEAR 2008
Report to the General Assembly
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VOLUME II
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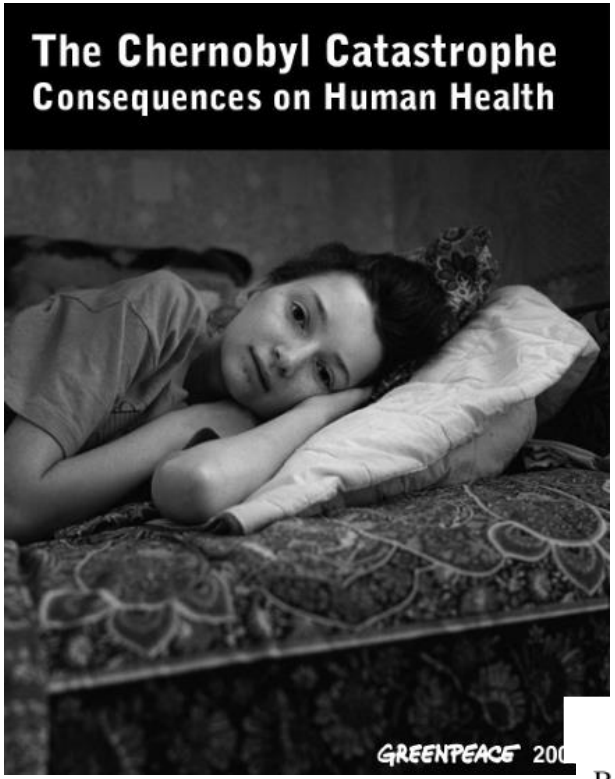
Wider impact



At the same time, however, this sheer range of health impacts described, combined with the variety of ways in which they have been detected and quantified, underscore the need for any proper evaluation to consider all available data and to reflect the diversity of both lethal and non-lethal effects. Any description which attempts to present the consequences as a single, 'easy to understand' estimation of excess cancer deaths (such as the figure of 4 000 much publicised by bodies such as the IAEA during 2005) will therefore inevitably provide a gross oversimplification of the breadth of human suffering experienced. Moreover, much of the evidence presented in the current report indicates that such figures may also greatly underestimate the scale of impacts as outlined earlier in the text.

- Cancer
  - Thyroid Cancer
  - Leukaemia
  - Other Cancers
- Non-Cancer Illnesses
  - Respiratory System
  - Digestive System
  - Blood Vascular System
  - Musculo–Skeletal and Cutaneous Systems
  - Hormone/Endocrine Status
  - Abnormalities of Immune Function
  - Genetic Abnormalities & Chromosomal Aberrations
  - Urogenital and Reproductive System
  - Premature Ageing
  - Sense Organs
  - Neurological and Psychological Disorders

The most recently published figures indicate that in Belarus, Russia and the Ukraine alone the accident resulted in an estimated 200,000 additional deaths between 1990 and 2004.

Situation today

NEW SARCOPHAGUS

Capacity

Durability **100** years

Temperature range **-43°** min. **45°** max.

Wind speed **254 - 332** Km/h (level three tornado)

Resources

Workers on-site **1.200**

Nations **27** nations

Project cost **2.150** million euros

Screws used **500.000**

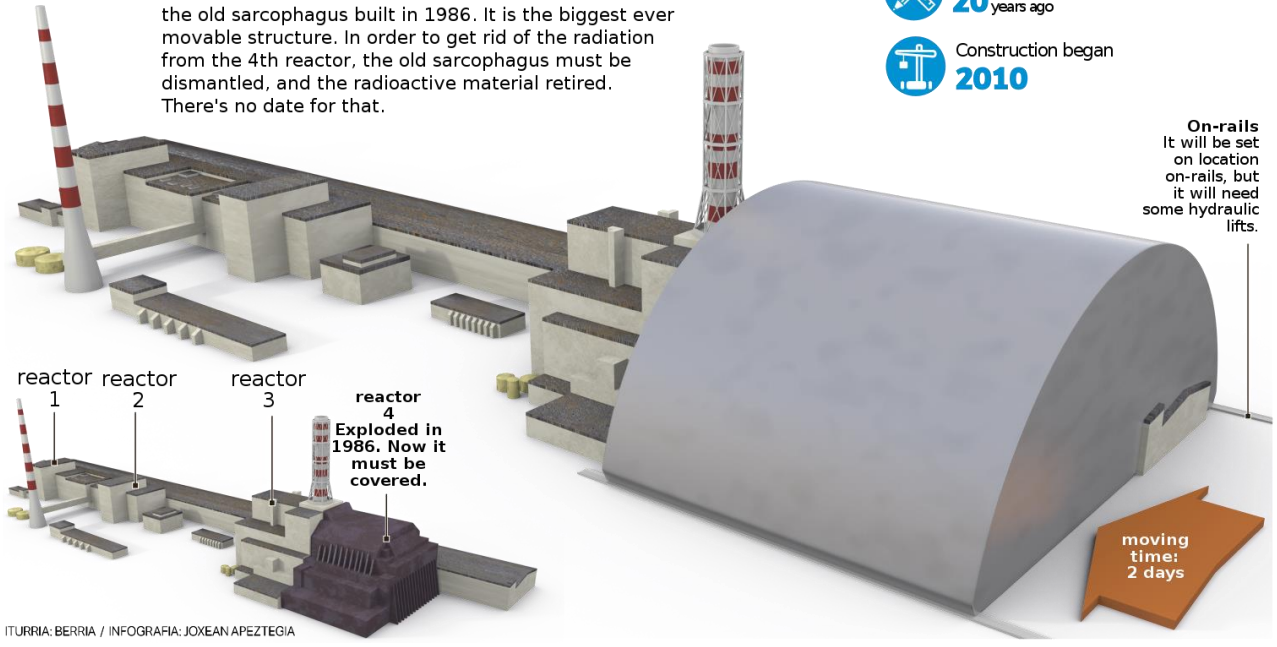
Timing

Project began **20** years ago

Construction began **2010**

The new one over the old one

The New Safe Continent steel-structure will cover the old sarcophagus built in 1986. It is the biggest ever movable structure. In order to get rid of the radiation from the 4th reactor, the old sarcophagus must be dismantled, and the radioactive material retired. There's no date for that.



ITURRIA: BERRIA / INFOGRAFIA: JOXEAN APEZTEGIA

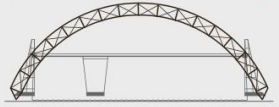
Weight

25.000 tonnes

"La Gaviota" gas-platform
10.000 tonnes

Length

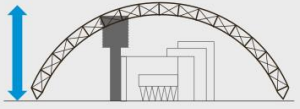
165 meters



Bizkaia Bridge
162 meters

Height

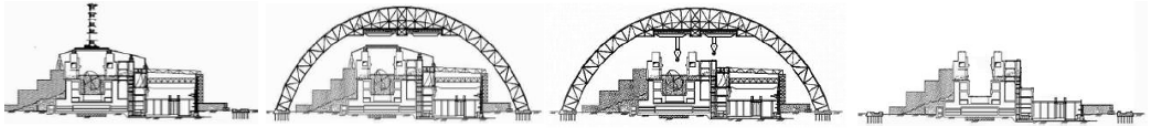
110 meters



BEC tower
98 meters

Speaker

Strategy of Shelter object Transformation into environmentally safe system



1998 | 2008 | 2017 | **2117**

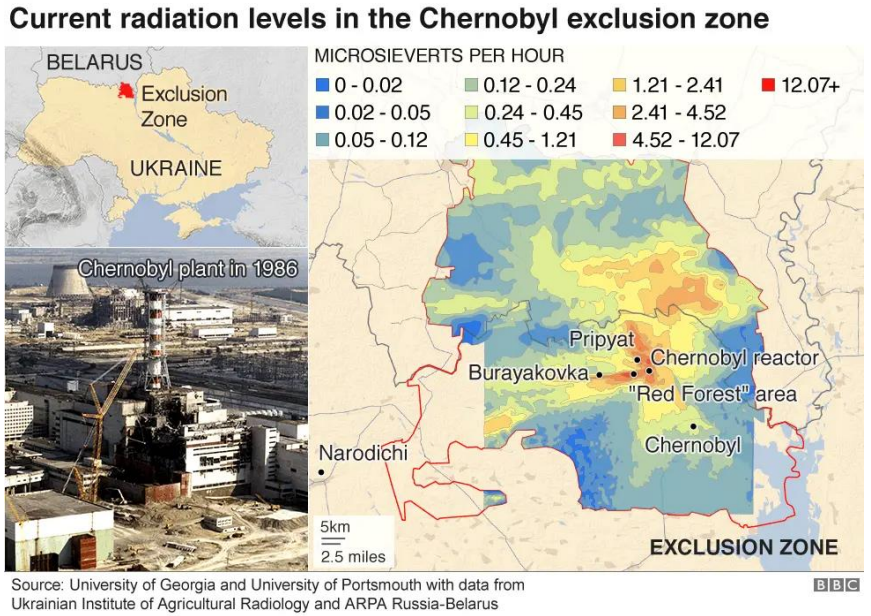
Phase 1: stabilization of existing object status

Phase 2: creation of the additional protective barriers

Phase 3: Fuel Containing Materials and Long Lived RAW retrieval from SO

Doses in the exclusion zone today

- Cleanup efforts have reduced contamination levels to close to background
- Radiation levels are close to background levels, few ‘hot spots’ remain
- Reactor internals remain highly radioactive, dismantling inside the New Safe Containment planned to take 100 years




Core lid: 1 Sv/hr
S. Koshelev: 500 mSv/hr

Speaker

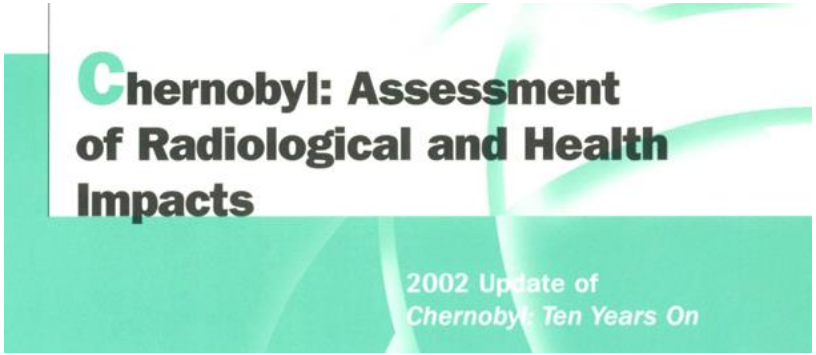
And you can see that radiation had a serious impact on photo, though I've set exposure time to 1.5 sec

Video by Alexandr Kupnyi (@chernobyl86 on youtube)

ЧАЭС. Заходим внутрь Саркофага 2006
“Chernobyl Nuclear Power Plant. We go inside the Sarcophagus”

Effects of the disaster not discussed in this lecture

Speaker



https://www.who.int/news/item/05-09-2005-chernobyl-the-true-scale-of-the-accident

The Chernobyl Forum

IAEA WHO UNDP FAO UNEP

UN-OCHA UNSCEAR WORLD BANK GROUP

- Poverty, "lifestyle" diseases now rampant in the former Soviet Union and mental health problems pose a far greater threat to local communities than does radiation exposure.
- Relocation proved a "deeply traumatic experience" for some 350,000 people moved out of the affected areas. Although 116 000 were moved from the most heavily impacted area immediately after the accident, later relocations did little to reduce radiation exposure.
- Persistent myths and misperceptions about the threat of radiation have resulted in "paralyzing fatalism" among residents of affected areas.

WELCOME TO I

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Literature

Speaker

Great explainer on why the reactor exploded: https://www.youtube.com/watch?v=P3oKNE72EzU&ab_channel=Higgsinophysics

HBO Chernobyl (careful, dramatized and sometimes inaccurate)

UN

https://www.unscear.org/unscear/en/areas-of-work/chernobyl.html

IRSN