

# **Nuclear Accidents - Chernobyl**

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The **Chernobyl disaster** was a nuclear reactor accident in the Chernobyl Nuclear Power Plant in the Soviet Union.

It was the worst nuclear power plant accident in history and the only instance of level 7 on the International Nuclear Event Scale, resulting in a severe release of radioactivity into the environment following a massive power excursion which destroyed the reactor.

Two people died in the initial steam explosion, but most deaths from the accident were due to fallout.

On the 26 April 1986 at 03:23:44 AM reactor number four at the Chernobyl plant, near Pripyat in the Ukrainian USSR, experience a steam explosion.

Further explosions and the resulting fire sent a plume of highly radioactive fallout into the atmosphere and over an extensive geographical area.

Five hundred times more fallout was released than had been by the atomic bombing of Hiroshima.

The plume drifted over extensive parts of the western Soviet Union, Eastern Europe, Western Europe, Northern Europe, and eastern North America.

Large areas in Ukraine, Belarus, and Russia were badly contaminated, resulting in the evacuation and resettlement of over 336,000 people.

According to official post-Soviet data, about 60% of the radioactive fallout landed in Belarus.

The 2004 report prepared by the Chernobyl Forum, led by the International Atomic Energy Agency (IAEA) and the World Health Organization (WHO), attributed 56 direct deaths (47 accident workers, and nine children with thyroid cancer), and estimated that there may be 4,000 extra cancer deaths among the approximately 600,000 most highly exposed people.

Although the Chernobyl Exclusion Zone and certain limited areas will remain off limits, the majority of affected areas are now considered safe for settlement and economic activity.[\[5\]](#)

The government committee formed to investigate the accident arrived at Chernobyl in the evening of 26 April.

By that time two people were dead and 52 were hospitalized.

During the night of 26 April / 27 April — more than 24 hours after the explosion — the committee, faced with ample evidence of extremely high levels of radiation and a number of cases of radiation exposure ordered the evacuation of the nearby city of Pripyat.

The evacuation began at 14:00, 27 April. In order to reduce baggage the residents were told that the evacuation would be temporary, lasting approximately three days.

Pripyat is within the Chernobyl Exclusion Zone and as a result, Pripyat still contains personal belongings.

The nuclear meltdown released a radioactive cloud that floated not over just the modern states of Russia, Belarus, Ukraine and Moldova, but also Turkish Thrace, Southern coast of Black Sea, Macedonia, Serbia, Croatia, Bulgaria, Greece, Romania, Lithuania, Estonia, Latvia, Finland, Denmark, Norway, Sweden, Austria, Hungary, the Czech Republic and the Slovak Republic, The Netherlands, Belgium, Slovenia, Poland, Switzerland, Germany, Italy, Ireland, France (including Corsica) the United Kingdom and the Isle of Man, and eastern North America.

The initial evidence that a major release of radioactive material was affecting other countries came not from Soviet sources, but from Sweden, where on 27 April workers at the Forsmark Nuclear Power Plant (approximately 1,100 km (680 mi) from the Chernobyl site) were found to have radioactive particles on their clothes.

It was Sweden's search for the source of radioactivity which led to the first hint of a serious nuclear problem in the western Soviet Union.

Like many other releases of radioactivity into the environment, the Chernobyl release was controlled by the physical and chemical properties of the radioactive elements in its core.

While plutonium is often perceived as particularly dangerous nuclear fuel by the general population, its effects are almost eclipsed by those of its fission products.

Particularly dangerous are highly radioactive compounds that accumulate in the food chain, such as some isotopes of iodine and strontium.

Two reports on the release of radioisotopes from the site were made available, one by the [OSTI](#), and a more detailed report by [OECD](#), both in 1998.[\[45\]](#)[\[46\]](#) At different times after the accident, different isotopes were responsible for the majority of the external dose. The dose that was calculated is that received from external gamma irradiation for a person standing in the open. The dose to a person in a shelter or the internal dose is harder to estimate.

In the aftermath of the accident, 237 people suffered from acute radiation sickness, of whom 31 died within the first three months.

Most of these were fire and rescue workers trying to bring the accident under control, who were not fully aware of how dangerous the radiation exposure (from the smoke) was.

135,000 people were evacuated from the area, including 50,000 from Pripyat.

The Chernobyl nuclear power plant lies next to the Pripyat River which feeds into the Dnieper River reservoir system, one of the largest surface water systems in Europe.

The radioactive contamination of aquatic systems therefore became a major issue in the immediate aftermath of the accident.

In the most affected areas of Ukraine, levels of radioactivity (particularly radioiodine: I-131, Cs-137 and Sr-90) in drinking water caused concern during the weeks and months after the accident.

After this initial period however, radioactivity in rivers and reservoirs was generally below guideline limits for safe drinking water.

Bio-accumulation of radioactivity in fish resulted in concentrations (both in western Europe and in the former Soviet Union) that were significantly above guideline maximum levels for consumption.

Guideline maximum levels for radiocesium in fish vary from country to country but are approximately 1,000 Bq/kg in the European Union.

In the Kiev Reservoir in Ukraine, activity concentrations in fish were several thousand Bq/kg during the years after the accident.

In small "closed" lakes in Belarus and the Bryansk region of Russia, activity concentrations in a number of fish species varied from 0.1 to 60 kBq/kg during the period 1990–92.

The contamination of fish caused concern in the short term (months) for parts of the UK and Germany and in the long term (years-decades) in the Chernobyl affected areas of Ukraine, Belarus and Russia as well as in parts of Scandinavia.

After the disaster, four square kilometers of pine forest in the immediate vicinity of the reactor turned ginger brown and died, earning the name of the "Red Forest".

Some animals in the worst-hit areas also died or stopped reproducing.

Most domestic animals were evacuated from the exclusion zone, but horses left on an island in the Pripjat River 6 km (4 mi) from the power plant died when their thyroid glands were destroyed by radiation doses of 150–200 Sv.

Some cattle on the same island died and those that survived were stunted because of thyroid damage. The next generation appeared to be normal.

An international assessment of the health effects of the Chernobyl accident is contained in a series of reports by the United Nations Scientific Committee of the Effects of Atomic Radiation (UNSCEAR).

UNSCEAR was set up as a collaboration between various UN bodies, including the World Health Organization, after the atomic bomb attacks on Hiroshima and Nagasaki, to assess the long-term effects of radiation on human health.

UNSCEAR has conducted 20 years of detailed scientific and epidemiological research on the effects of the Chernobyl accident.

Apart from the 57 direct deaths in the accident itself, UNSCEAR originally predicted up to 4,000 additional cancer cases due to the accident.

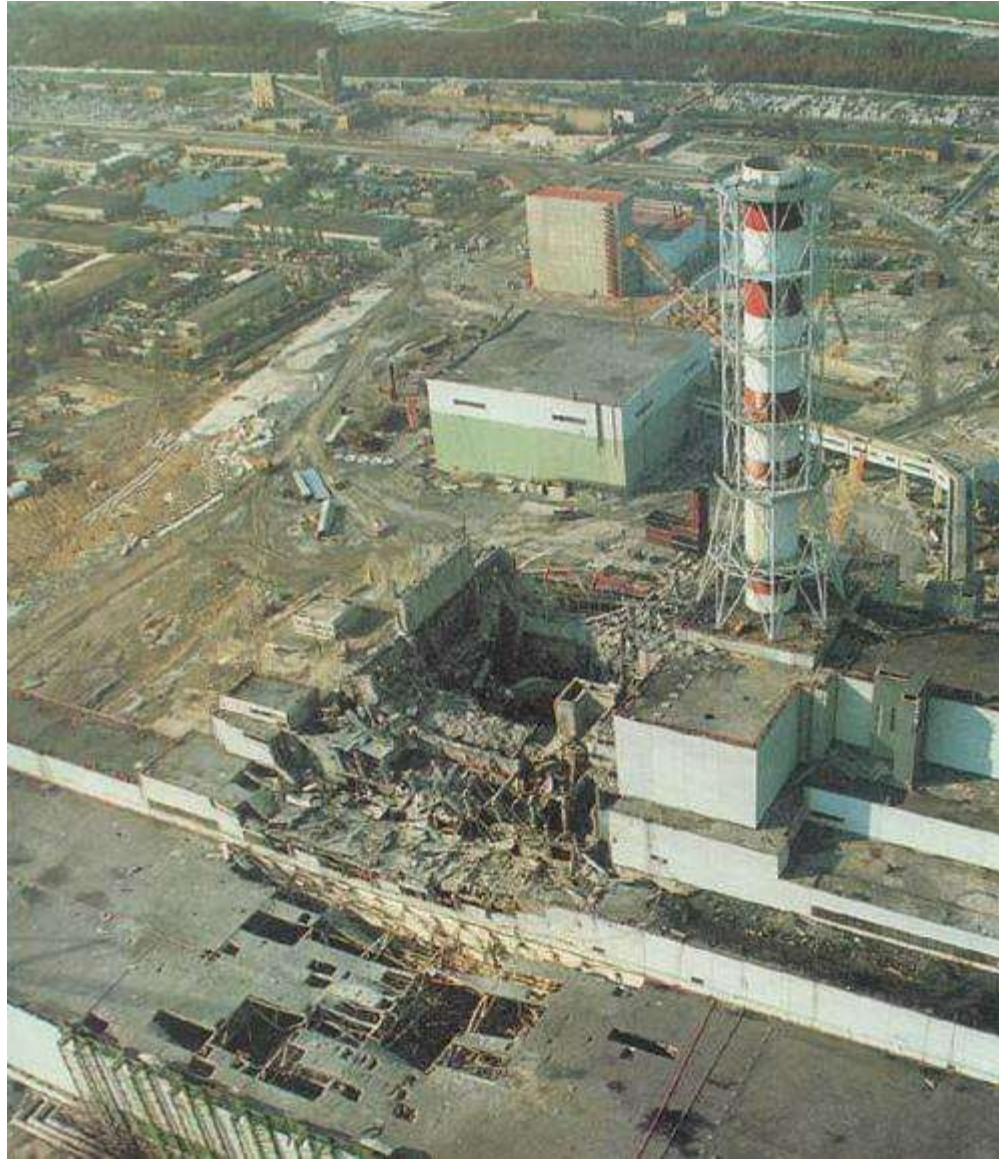
The IAEA states that there has been no increase in the rate of birth defects or abnormalities, or solid cancers (such as lung cancer).

Precisely, UNSCEAR states:

"Among the residents of Belarus, the Russian Federation and Ukraine there had been, up to 2002, about 4,000 cases of thyroid cancer reported in children and adolescents who were exposed at the time of the accident, and more cases are to be expected during the next decades.

Notwithstanding problems associated with screening, many of those cancers were most likely caused by radiation exposures shortly after the accident.

Apart from this increase, there is no evidence of a major public health impact attributable to radiation exposure 20 years after the accident."



# Nuclear Accidents

## Three Mile Island

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The **Three Mile Island accident** of 1979 was the most significant accident in the history of US nuclear power plants.

It resulted in the release of a significant amount of radioactivity, an estimated 43,000 curies of radioactive krypton, but less than 20 curies of Iodine-131.

However, there are no deaths or injuries to plant workers or members of the nearby community which can be attributed to the accident.

The accident began on Wednesday, March 28, 1979, and resulted in a partial core meltdown in Unit 2 of the Three Mile Island Nuclear Generating Station near Harrisburg, Pennsylvania.

The scope and complexity of this reactor accident became clear over the course of five days, as a number of agencies at the local, state and federal levels tried to solve the problem and decide whether the on-going accident required a full emergency evacuation of the local community.

Although 25,000 people lived within five miles (8 km) of the site at the time of the accident, no identifiable injuries due to radiation occurred, and a government report (the "Kemeny Commission Report") concluded that;

"There will either be no case of cancer or the number of cases will be so small that it will never be possible to detect them. The same conclusion applies to the other possible health effects."

At 7:00 AM on the 29th a "Site Area Emergency" (the NRC's second highest accident level) was declared and at 7:24 a.m. the incident was upgraded to a "General Emergency" (the highest accident level).

It was later found that about half the core had been severely damaged, the cladding was burned off and the fuel pellets were melted on the surface during the accident; however, the reactor vessel maintained integrity and contained the damaged fuel.

The scientific community is largely agreed on the effects of the Three Mile Island accident.

The consensus is that no member of the public was injured by the accident.

"The average radiation dose to people living within ten miles of the plant was eight millirem, and no more than 100 millirem to any single individual.

Eight millirem is about equal to a chest X-ray, and 100 millirem is about a third of the average background level of radiation received by US residents in a year."



# Nuclear Accidents

## Tokaimura Japan

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In 1999 three workers received high doses of radiation in a small Japanese plant preparing fuel for an experimental reactor.

The accident was caused by bringing together too much uranium enriched to a relatively high level, causing a "criticality" (a limited uncontrolled nuclear chain reaction), which continued intermittently for 20 hours.

A total of 119 people received a radiation dose over 1 mSv from the accident, but only the three operators' doses were above permissible limits. Two of the doses proved fatal.

The cause of the accident was "human error and serious breaches of safety principles", according to IAEA.

The 1999 Tokaimura accident was in a very small fuel preparation plant operated by Japan Nuclear Fuel Conversion Co. (JCO)

The JCO plant was commissioned in 1988 and processed up to 3 tons per year of uranium enriched up to 20% U-235, a much higher than for ordinary power reactors. The plant supplied various specialized research and experimental reactors.

The approved nuclear fuel preparation procedure involved dissolving uranium oxide ( $U_3O_8$ ) powder in nitric acid in a dissolution tank, then its transfer as pure uranyl nitrate solution to a storage column for mixing, followed by transfer to a precipitation tank.

This tank is surrounded by a water cooling jacket to remove excess heat generated by the exothermic chemical reaction.

The prevention of criticality was based upon the general licensing requirements for mass and volume limitation, as well as upon the design of the process.

Key parts of the design process was the storage column with a criticality-safe geometry and by providing careful control of the amount of material transferred to the precipitation tank.

However, the company's work procedure was modified three years earlier, without permission from the regulatory authorities, to allow uranium oxide to be dissolved in stainless steel buckets rather than the dissolution tank.

It was then modified further by the operators to speed things up by tipping the solution directly into the precipitation tank.

The mixing designed to occur in the storage column was instead undertaken by mechanical stirring in the precipitation tank, thus bypassing the criticality controls.

Also there was no proper control of the amount tipped into the hundred-liter precipitation tank, and its shape (450 mm diameter and 660 mm high) enhanced the likelihood of criticality within it.

On 30 September 1999 three workers were preparing a small batch of fuel for the JOYO experimental fast breeder reactor, using uranium enriched to 18.8% U-235.

They had previously used this procedure many times with much lower-enriched uranium - less than 5%, and had no understanding of the criticality implications of 18.8% enrichment. At around 10:35, when the volume of solution in the precipitation tank reached about 40 liters, containing about 16 kg U, a critical mass was reached.

At the point of criticality, the nuclear fission chain reaction became self-sustaining and began to emit intense gamma and neutron radiation, triggering alarms.

There was no explosion, though fission products were progressively released inside the building.

The significance of it being a wet process was that the water in the solution provided neutron moderation, enhancing the reaction.

The criticality continued intermittently for about 20 hours. As the solution boiled vigorously, voids formed and criticality ceased, but as it cooled and voids disappeared, the reaction resumed.

The reaction was stopped when cooling water surrounding the precipitation tank was drained away, since this water provided a neutron reflector.

Boric acid solution (neutron absorber) was finally added to the tank to ensure that the contents remained subcritical.

These operations exposed 27 workers to some small amounts of radioactivity.

Five hours after the start of the criticality, evacuation commenced of some 161 people from 39 households within a 350 meter radius from the conversion building.

They were allowed home two days later after sandbags and other shielding ensured no hazard from residual gamma radiation.

Twelve hours after the start of the incident residents within 10 km were asked to stay indoors as a precautionary measure, and this restriction was lifted the following afternoon.

The accident was classified by the Japanese authorities as Level 4 on the International Atomic Energy Agency (IAEA) International Nuclear Event Scale (INES)\*, indicating an event without significant off-site risk.

It was essentially an 'irradiation' accident, not a 'contamination' accident, as it did not result in any significant release of radioactive materials.

# On the International Nuclear Event Scale Ranked 7 to 0

Level 7 – Major Accident	Chernobyl 1986
Level 6 – Serious Accident	None
Level 5 – Accident with Off-Site Risks	Windscale, UK 1957 Three Mile Island 1979
Level 4 – Accident Mainly in Installation	Saint-Laurent, France 1980 Tokaimura, Japan 1999
Level 3 – Serious Incident	Vandellos, Spain 1989
Level 2 – Incident	None
Level 1 – Anomaly	None
Level 0 – Below Scale	

The three workers concerned were hospitalized, two in a critical condition.

One died 12 weeks later, another 7 months later.

The three had received whole-body radiation doses of 10,000-20,000, 6,000-10,000 and 1,000-5,000 millisieverts dose.

Doses for a further 436 people were evaluated, 140 based on measurement and 296 on estimated values.

None exceeded 50 mSv (the maximum allowable annual dose), though 56 plant workers exposed accidentally ranged up to 23 mSv and a further 21 workers received elevated doses when draining the precipitation tank.

Seven workers immediately outside the plant received doses estimated at 6 - 15 mSv (combined neutron and gamma effects).

The peak radiation level 90 metres away just outside the nearest site boundary was 0.84 mSv/hr of gamma radiation, but no neutron measurements were made at that time.

The gamma reading dropped to about half that level after nine hours at which time 4.5 mSv/hr of neutron radiation was measured there, falling to about 3 mSv/hr after a further two hours, and then both readings falling to background at 20 hours from the start of the criticality.

Neutron dose rates within one kilometer are assumed to have been up to ten times the measured gamma rates.

Based on activation products in coins from houses near the plant boundary and about 100 m from the reaction, it was estimated that some 100 mSv of neutron radiation would have been received by any occupants over the full period of the criticality.

However, the evacuation of everyone within 350 meters of the plant had been ordered 5 hours after the start of the accident.

The final report on the accident said that the maximum measured dose to the general public was 16 mSv.

While 160 TBq of noble gases and 2 TBq of gaseous iodine were apparently released, little escaped from the building itself.

After the criticality had been terminated and shielding was emplaced, radiation levels beyond the JCO site returned to background.

Only trace levels of radionuclides were detected in the area soon after the accident, and these were short-lived ones.

Measurement of I-131 in soils and vegetation outside the plant showed them to be well under levels of concern for food.

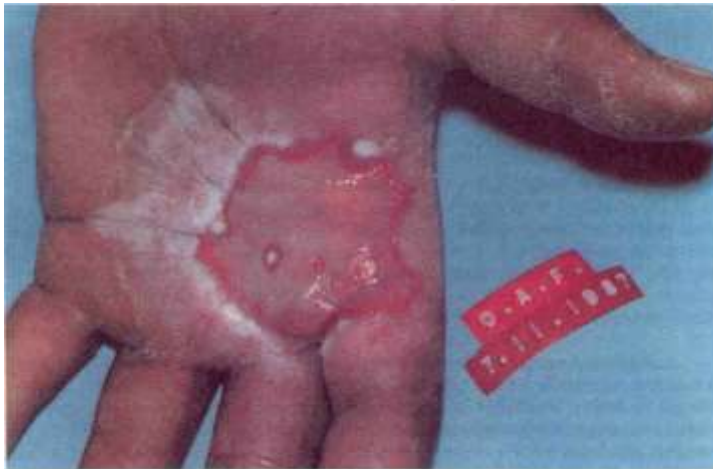


# Localized Radiation Effects - Organ System Threshold Effects

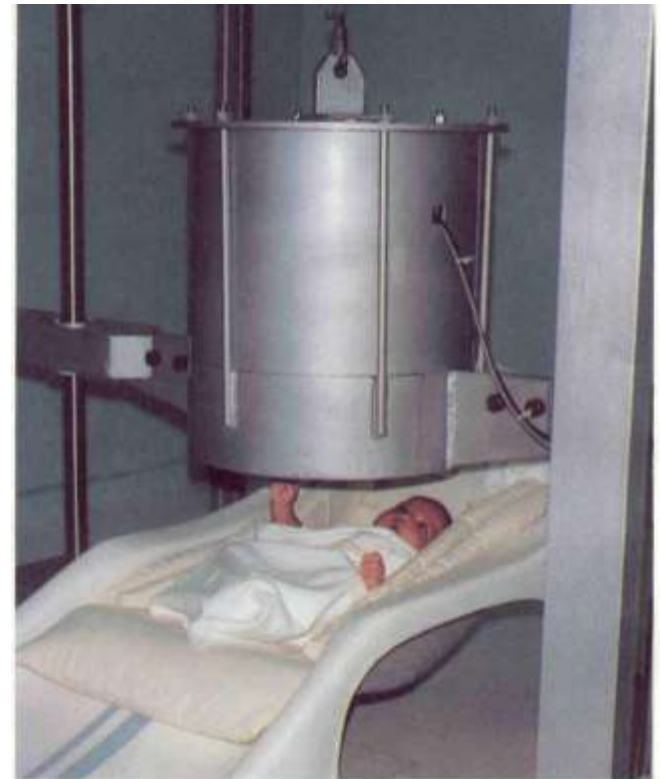


# Radiation Injuries and Uptakes

- 4 fatalities (2 men, 1 woman and 1 child)
- 28 patients had radiation induced skin injuries (they held/played with the source for extended periods)
- 50 people had internal deposition (ingestion)



*FIG. 9.3. 3-30 days after exposure. The skin was excised. A raw reddish surface is covered with a delicate layer of fibrinous exudate. Note the centripetal character of the healing process and the attempt of re-epithelialization.*





*FIG. 12. Patient 1 on 4 June 2001: Ulcerated subaxillary area (4.5 mm × 18 mm).*



*FIG. 13. Patient 1 in December 2001: Ulcerated lesion (3.5 cm × 1.5 cm) along the axis of the surgical scar.*



*FIG. 14. Patient 2 on 4 June 2001: Moist desquamation area measuring 5 cm × 10 cm in the centre of a 10 cm × 14 cm depigmented field in the zone of the mastectomy.*



*FIG. 15. Patient 2 on 1 December 2001: Depigmented area (14 cm × 10 cm) exhibiting poor epithelialization, marked exudation and multiple punctate areas of bleeding without obvious areas of necrosis or infection.*



*FIG. 16. Patient 3 on 4 June 2001: Superficial ulceration (3 cm  $\times$  7 cm) close to the medial edge of the irradiated field along the surgical scar.*



*FIG. 17. Patient 3 on 1 December 2001: A 16 cm × 8 cm area which had islands of re-epithelialization and small (less than 1 cm × 1 cm), scattered areas of necrosis and ulceration.*



*FIG. 19. Patient 4 on 4 June 2001: Moist desquamation in the irradiated area, following mastectomy to the left side.*



*FIG. 22. Patient 4 on 1 December 2001: Severe skin changes following a radiation burn. The wound covers an area of 14 cm × 8 cm; in its centre lies an ulcer of full thickness covering an area of 5 cm × 4 cm.*



*FIG. 23. Patient 4 in May 2002: Local injury before reparative surgery.*