MUNI
FSS

Nuclear Accidents and Disasters

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Contents

- Windscale Fire (UK, 1957)
- Kyshtym Disaster (SSSR, 1957)
- K-19 Nuclear Sumbarine Accident (SSSR/Greenland, 1961)
- Church Rock Uranium Mill Spill (USA, 1979)
- Goiânia Accident (Brazil, 1987)
- Lilo Accident (Georgia, 1997)
- Tōkai-mura Nuclear Accident (Japan, 1999)
- Nyonoksa Explosion (Russia, 2019)

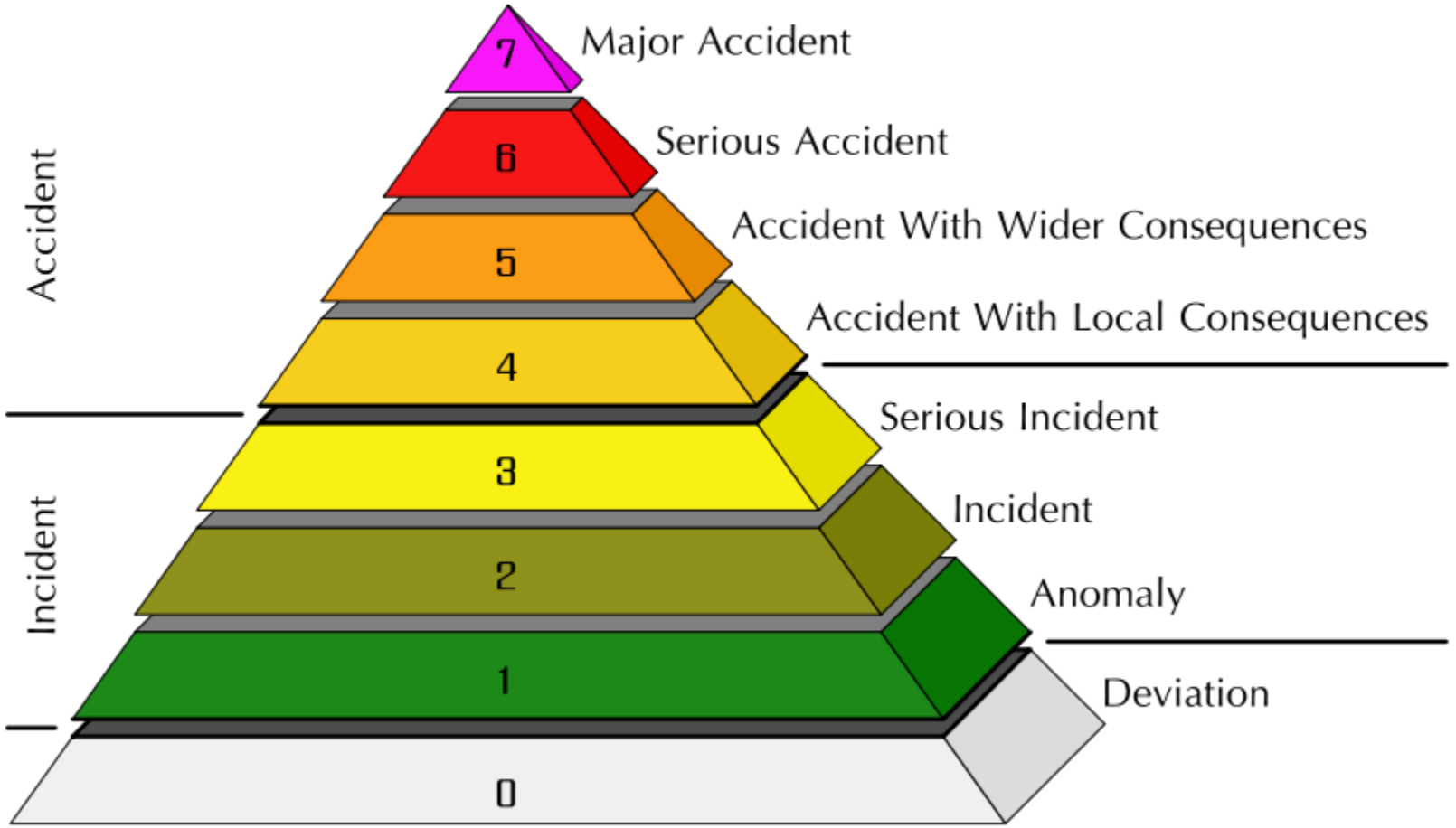
Units of Ionizing Radiation Dose

- **rad** (unit of absorbed radiation dose)

- **Gray** (Gy, unit of ionizing radiation dose in the International System of Units)
- 1 rad = 0.01 Gy = 0.01 J/kg

100-200 rad (1-2 Gy; 1-2 J/kg)	= in less than a day may cause ARS
200-1,000 rad (2-10 Gy; 2-10 J/kg)	= serious ARS, high probability of death
1,000+ rad (10+ Gy, 10+ J/kg)	= serious ARS, near-certain death

International Nuclear Event Scale



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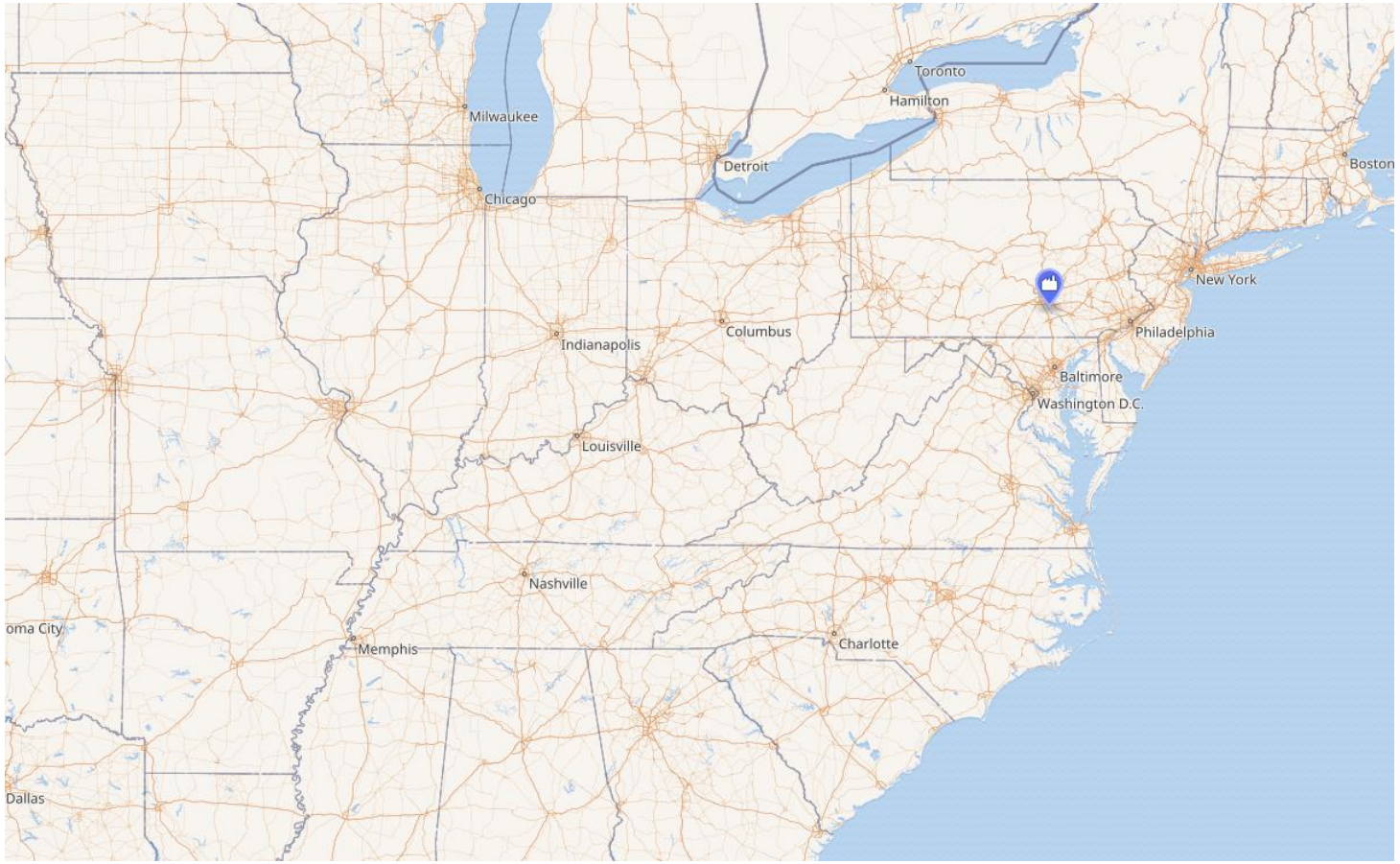
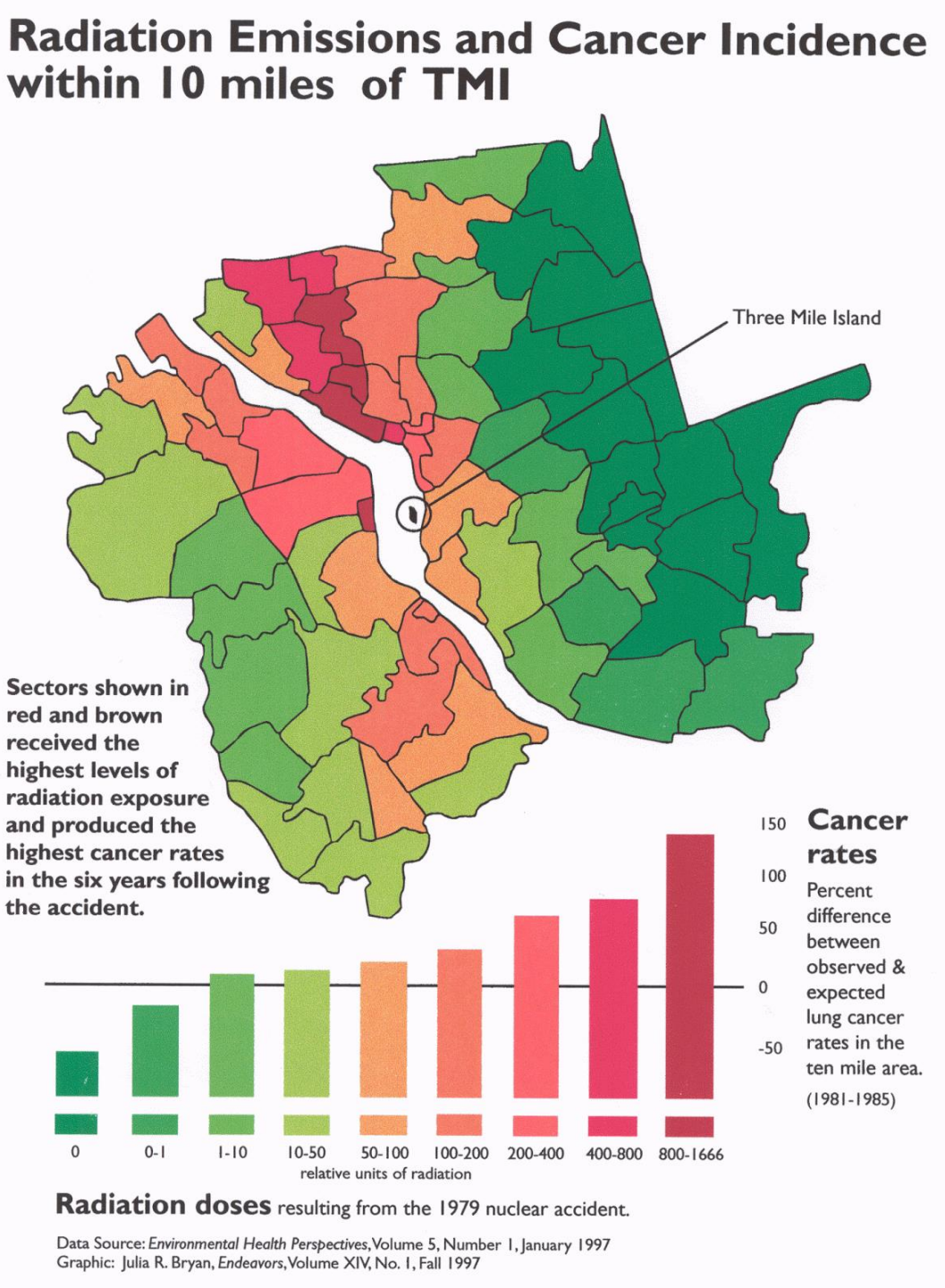
Three Mile Island NPP (INES 5)

- 28 March 1979, Harrisburg, Pennsylvania, USA
- 2x PWR (800 and 906 MWe)
- Accident at Unit 2, malfunction in the secondary cooling circuit, partial reactor meltdown
- no deaths, no radiological health effects, psychological stress
- some hydrogen and radioactive noble gases were released to the environment, however with short half-life, these did not pose a health hazard
- it took nearly 12 years to clean the Unit 2, it was never restarted

Three Mile Island NPP





Chornobyl NPP (INES 7)

- 26 April 1986
- 4x RBMK-1000
- Accident at Unit 4, explosion and reactor meltdown
- 2 immediate deaths, 28 deaths as a result of ARS within a few weeks
- 134 workers with ARS, 600 emergency workers severely irradiated
- 116,000 evacuated immediately; 220,000 people in the following years
- vast territories contaminated with iodine-131; caesium-137; xenon-133; strontium-90; plutonium, and other radionuclides
- thyroid radiation dose by mainly iodine-131 and caesium-137 varied among population between 0.07 Gy to 2 Gy for infants

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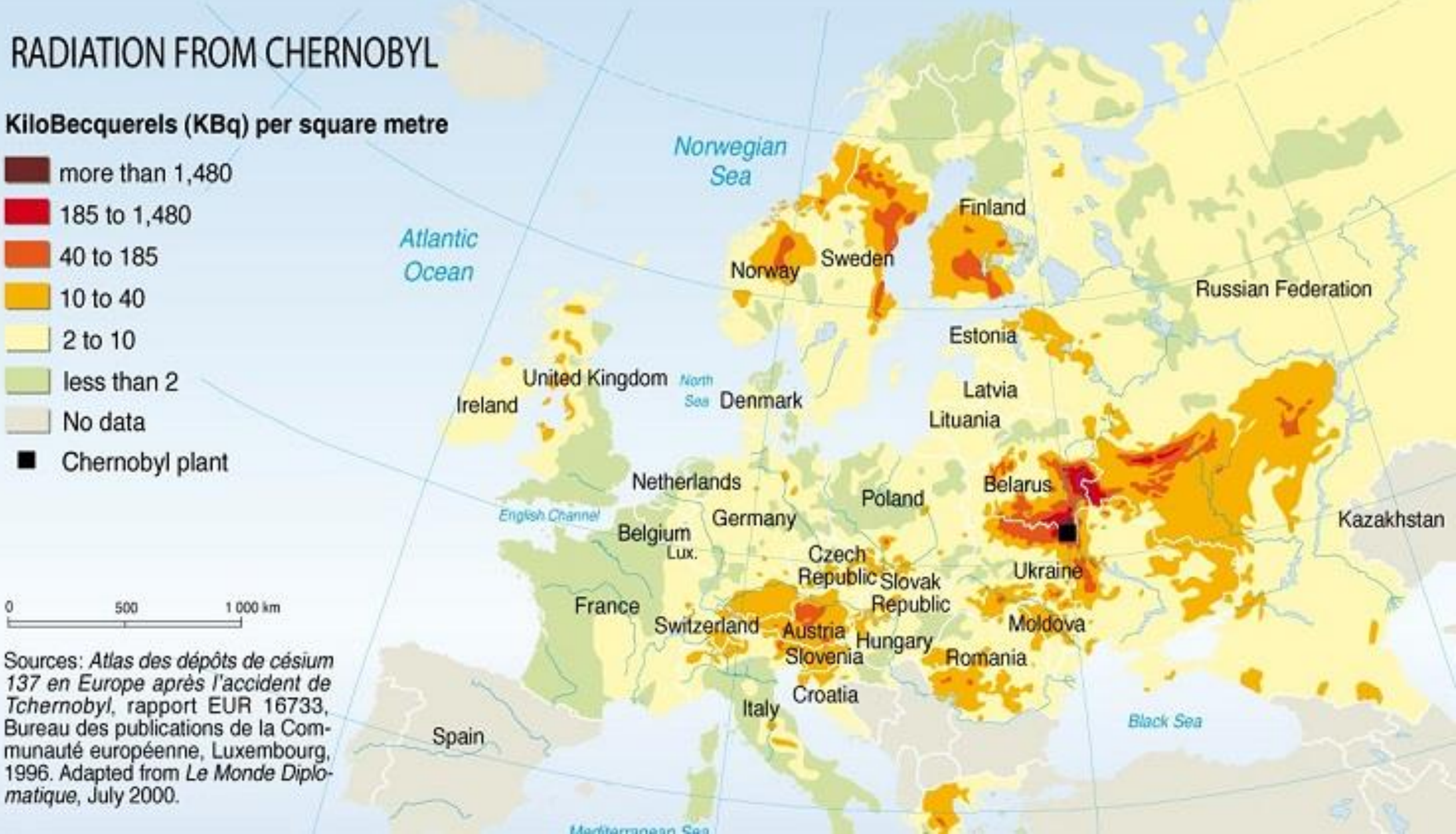
RADIATION FROM CHERNOBYL



Sources: *Atlas des dépôts de césium 137 en Europe après l'accident de Tchernobyl*, rapport EUR 16733, Bureau des publications de la Communauté européenne, Luxembourg, 1996. Adapted from *Le Monde Diplomatique*, July 2000.

Fukushima Daiichi NPP (INES 7)

- March 2011
- 4x BWR-5 1,100 MWe
- Earthquake and tsunami on March 11, 2011 followed by loss of cooling, explosions of hydrogen and fuel meltdowns
- 1 immediate death, 2 irradiations, 16 physical injuries due to explosion, over 1,000 deaths during evacuation
- 154,000 residents evacuated immediately within days, severe PSD
- Contamination of agricultural areas, seewater (in 2013 another 300 m^3 of radioactive water) and fish
- Thyroid radiation dose by mainly caesium-137 and caesium-134
- Decontamination and decommisioning will take 30-40 years

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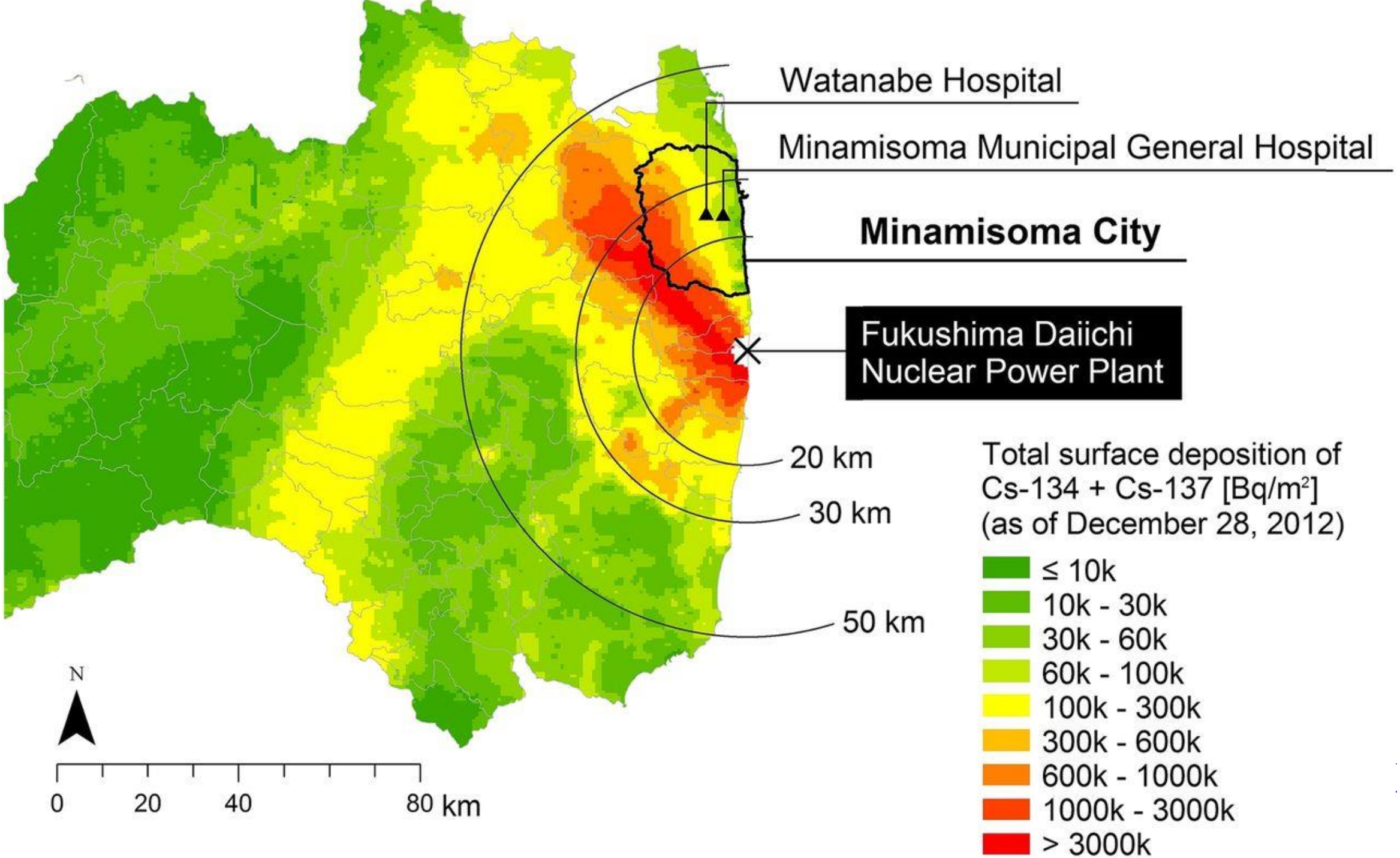
Watanabe Hospital
Minamisoma Municipal General Hospital
Minamisoma City
Fukushima Daiichi
Nuclear Power Plant
20 km
30 km
50 km
Total surface deposition of
Cs-134 + Cs-137 [Bq/m²]
(as of December 28, 2012)
≤ 10k
10k - 30k
30k - 60k
60k - 100k
100k - 300k
300k - 600k
600k - 1000k
1000k - 3000k
> 3000k
N
0
20
40
80 km

Windscale Fire (INES 5)

- Sellafield - nuclear site on the coast of Cumbria
- Windscale Piles (1950), Windscale nuclear fuel reprocessing, nuclear waste storage, nuclear decommissioning of Calder Hall Magnox NPP (1956, 4x 60 MWe) and Windscale Advanced Gas Cooled Reactor prototype (1962, 30 MWe)
- today 1,000 buildings and 200 nuclear facilities
- Europe’s largest nuclear site

Windscale Fire

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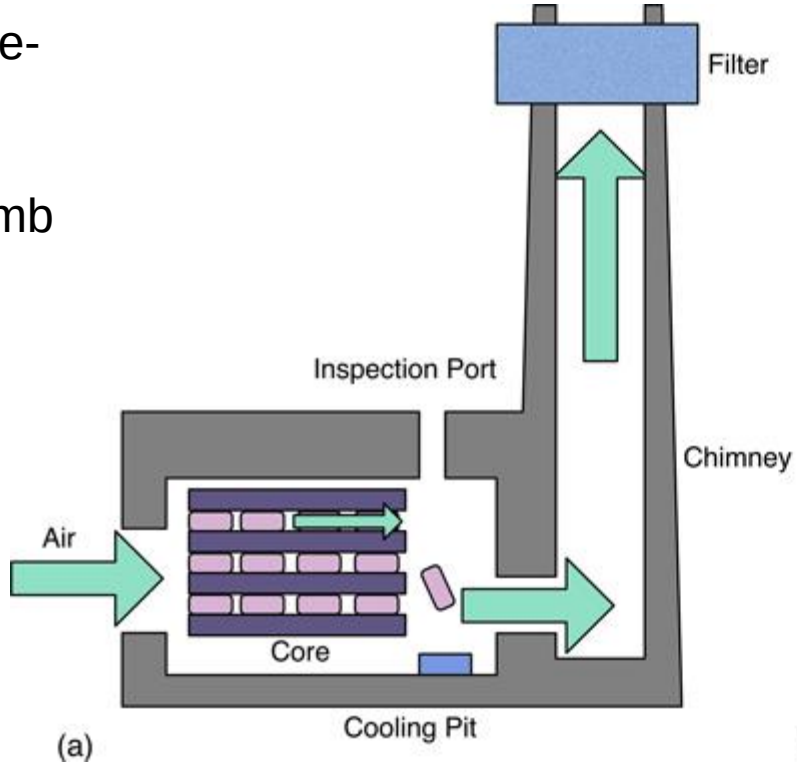
Windscale Fire

- Windscale Piles - 2 air-cooled graphite-moderated military nuclear reactors
- part of the British post-war atomic bomb project (USA divorced UK from the project after WWII)
- primary purpose was to produce weapons-grade plutonium

- accident on 10 October 1957




(b)

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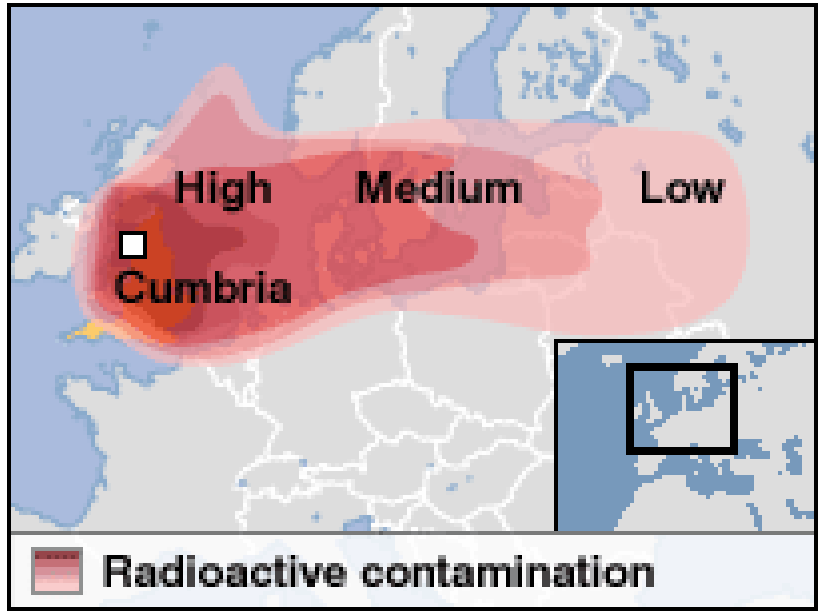
Windscale Fire

- in the night of 7th October 1957 there were problems with temperature – reactor was shut down; then again the following day
- on 9th October 1957 the temperature of one of the channel climbed to 405 ˚C, radioactivity was detected in the chimney – burst of a catridge
- even with the shutdown fans the temeprature was not dropping – visual inspection showed lithium-magnesium cartridges in 120 channels burn
- cooling efforts: fans at maximum spees, carbo dioxide fed in reactor, shutdown fans switched off + water (61 l/s) eventually brought the fire under control on 12th October 1957

Windscale Fire

- release of radioactive material, mainly iodine-131, caesium-137, xenon-133
- no evacuation (milk from 500 km^2 was dumped for about a month)
- no significant long term health effects (though it has been estimated that the incident caused 240 additional cancer cases)
- Reactor Manager Tom Tuohy provided visual inspections several times and lived to the age of 90, despite his exposure
- renamed Sellafield in 1981, the storage pond decommisioned in 2013
- around 8,400 catridges still remain inside the reactor
- the plan is to remove all fuels and isotopes by 2030
- the whole site will be clared and completely decommissioned in 2120



Kyshtym Disaster (INES 6)

- Mayak Plutonium plant built in 1945-1948 in a hurry as a reaction to US nuclear program
- built by Gulag prisoners and POWs, not insterted in maps, closed city of Ozersk built around
- facility and town called Chelyabinsk-40 (1948-1966), later Chelyabinsk-65 (1967-1994), codenamed City 40 (Город Сорок) or Sorokovka
- five nuclear reactors were built to produce plutonium for weapons


Ozersk/Ozyorsk
South Urals
Nuclear Power Plant
Left Bank Canal
Techa River
Lake Kyzyltash
(V-2)
Nanoga
Lakes
Koksharov
Pond (V-3)
V-4
Fissile Material
Storage Facility
V-10
V-11
Mayak Site
Staroe Boloto
(V-17)
Lake Karachai
(V-9)
Right Bank Canal
Tatysh
Ash
Disposal
Area
Mishelyak River
0 1 2 3 4 5 Kilometers

Kyshtym Disaster

- storage facility for liquid nuclear waste was added around 1953
- since the waste was heating itself due to severe radioactivity, cooling tanks were installed around
- in 1957 the cooling system in one of the tanks failed, the temperature has risen and eventually chemical explosion in the tank occured (29 September 1957, 70-100 tons of TNT), a 160-tonnes concrete lid was thrown into the air
- the tank was filled with 70-80 tonnes of liquid radioactive waste, which was released in the environment
- in some 10 hours the radioactive cloud reached distances of 300-350 km eventually contaminating area of 800-20,000 km^2
- contamination mainly with caesium-137 and strontium-90

Kyshtym

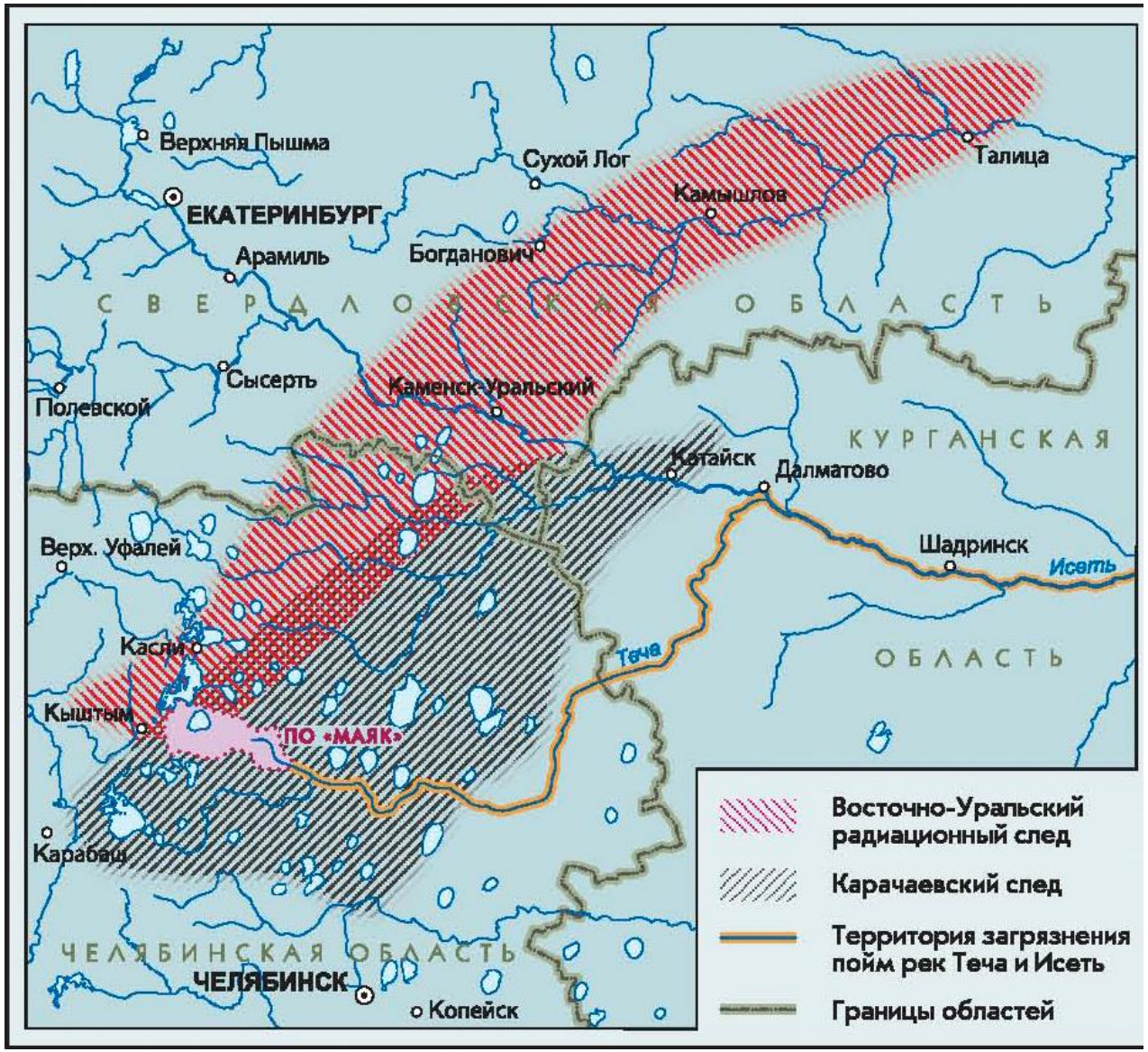

Р.ТЕЧА

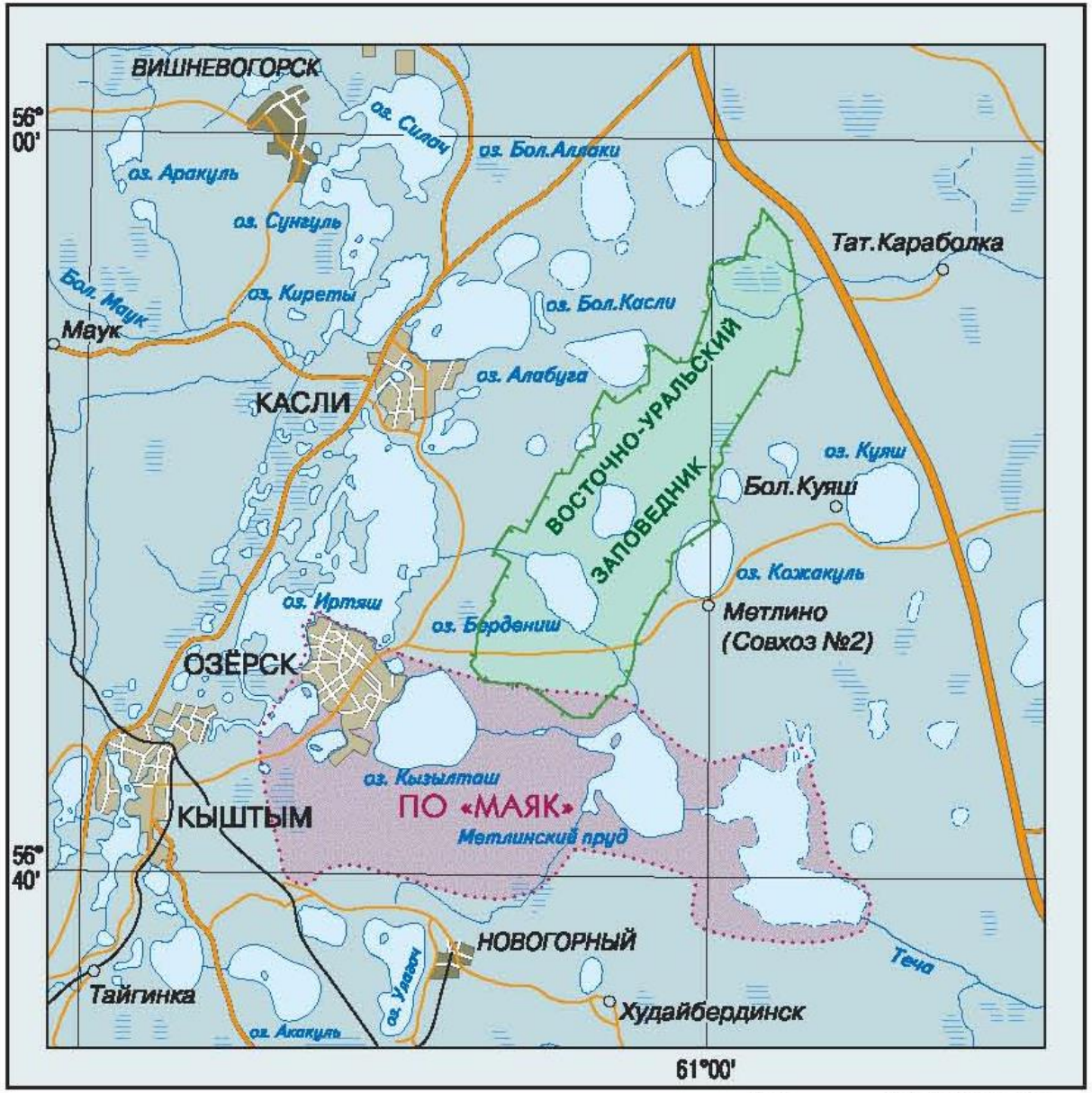
Oblast Swerdlowsk
0,2 Ci/km²
0,1 Ci/km²
Tjumen
Pionerski
Pyschma
Suchoi Log
Taliza
Pyschma
Jekaterinburg
Saretschny
Bogdanowitsch
Kamyschlow
Oblast Tjumen
> 2 Ci/km²
0,5 Ci/km²
1 Ci/km²
Kamensk-Uralski
Isset
Sinara
Sneschinsk
Bagarjak
Kasli
Tetscha
Oblast Kurgan
Osjorsk
Kyschtym
Kerntechnische Anlage Majak
Miass
Oblast Tscheljabinsk
Russland
0 10 20 30 40 50 60 70 80 90 100 km
Tscheljabinsk

Kyshtym Disaster

- population was not informed, a week later started the evacuation of 10,000 people without telling them the reason (22 small towns); the vacuation took place one week to two years after the accident
- the world got to know about the disaster in 1976
- 50-8,000 people had died due to cancer as a result of the accident
- contaminated soil was excavated and stockpiled in fenced enclosures
- the Soviet government in 1968 disguised the area by creating the East Ural Nature Reserve, which prohibited any unauthorised access to the affected area

- windstorm scattered radioactive materials coming from sediments of Lake Karachay in 1967
- the area is currently owned, controled and monitored by Rosatom





Масштаб 1:500 000

Расположение Восточно-Уральского заповедника

Kyshtym Disaster

- river Techa was used for household purposes by 124,000 people in a number of villages down the river even before the disaster, already in 1951 evacuation of 1,200 people took place
- during 1950s eleven communities was resettled, but the biggest one remained – Muslyumovo
- people complained of a range of symptoms—chronic fatigue, sleep and fertility problems, weight loss, increased hypertension, three times greater frequency of birth defects and complications at birth
- doctors called it the "special disease" because they were not allowed to note radiation in their diagnoses as long as the facility was secret

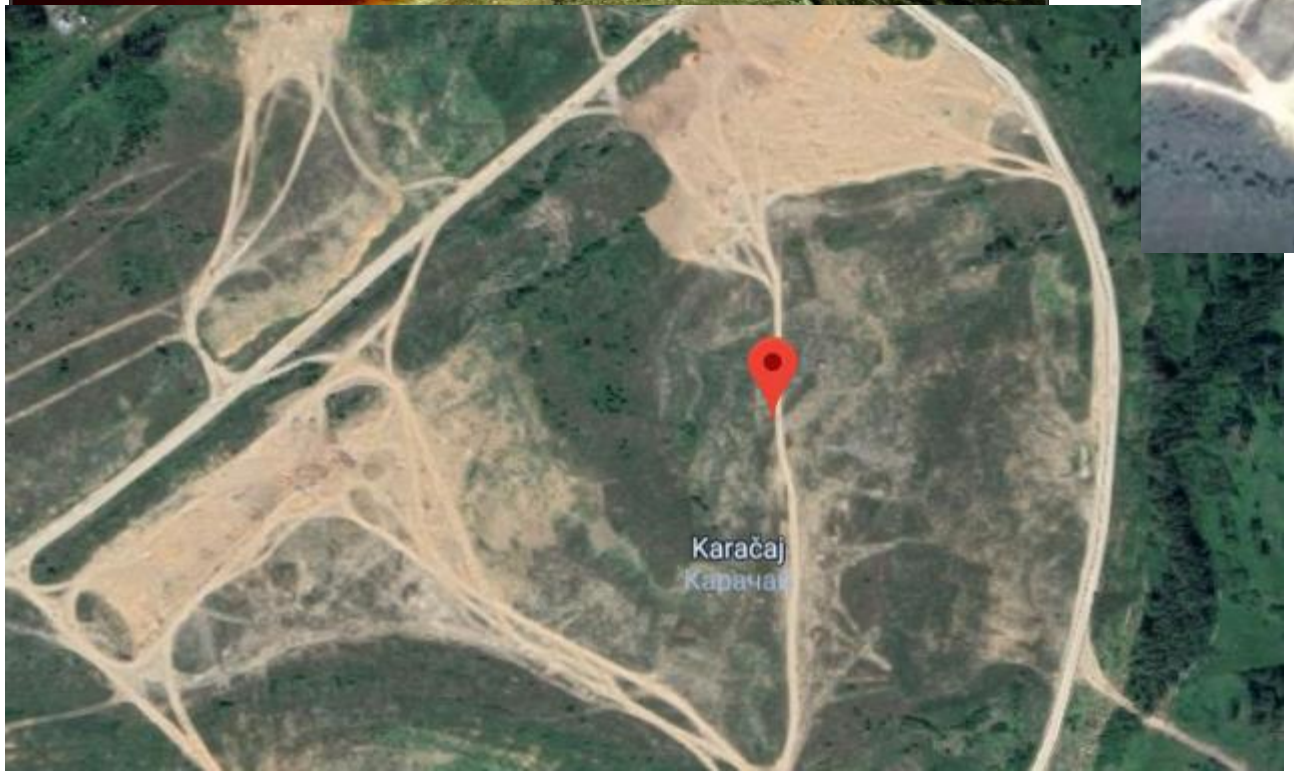
- lake Karachay remains the most highly radiation-contaminated place on Earth

Kyshtym Disaster

- the total radioactivity of Lake Karachay is estimated at 30-50% of the total radioactivity of Chernobyl disaster
- however, Lake Karachay‘s radioactivity is dispersed over less than one square mile, Chernobyl‘s radioactivity is dispersed over thousands of square miles

- after droughts on 1960s, when the wind carried radioactive dust away from the dried area of the lake, irradiating half a million people, SSSR desided to fill the lake with concrete to prevent sediments from migrating (10,000 hollow concrete blocks)
- in 1990 it was enough to stand one hour at the lake to receive lethal dose of radiation
- as of 2016 the lake is completely infilled with concrete


A
Карачай


Karačaj
Карачай

K-19 Nuclear Sumbarine Accident

- Soviet submarine built in 1958-1960
- part of Project 658 - first Soviet submarine equipped with submarine-launched ballistic missiles (3 pieces, 650 km range, 1.4 megaton warhead) AND first Soviet nuclear submarine (2x 72 MWe)
- built in haste as reaction to the USA (Nautilus in 1955, George Washington in 1957 - 16 Polaris SLBMs)
- 10 deaths during construction, breakdowns and accidents shortly after commissioning
- a major accident occured during the initial voyage

K-19 Nuclear Sumbarine Accident

- on 4 July 1961 a major leak was found in the reactor coolant system
- reactor was automatically shut down
- reactor temperature rose uncontrollably - decay heat from the fission products heated the reactor to 800 °C
- ship captain Zateev order the construction of a provisional water-supply cooling system from scrapped pipes from the ship
- the engineering crew worked in high radiation in the reactor
- the captain refused help from US warships and waited for Soviet S-270 diesel submarine; the crew then boarded the sbumarine and the ship was towed to port

K-19 Nuclear Sumbarine Accident

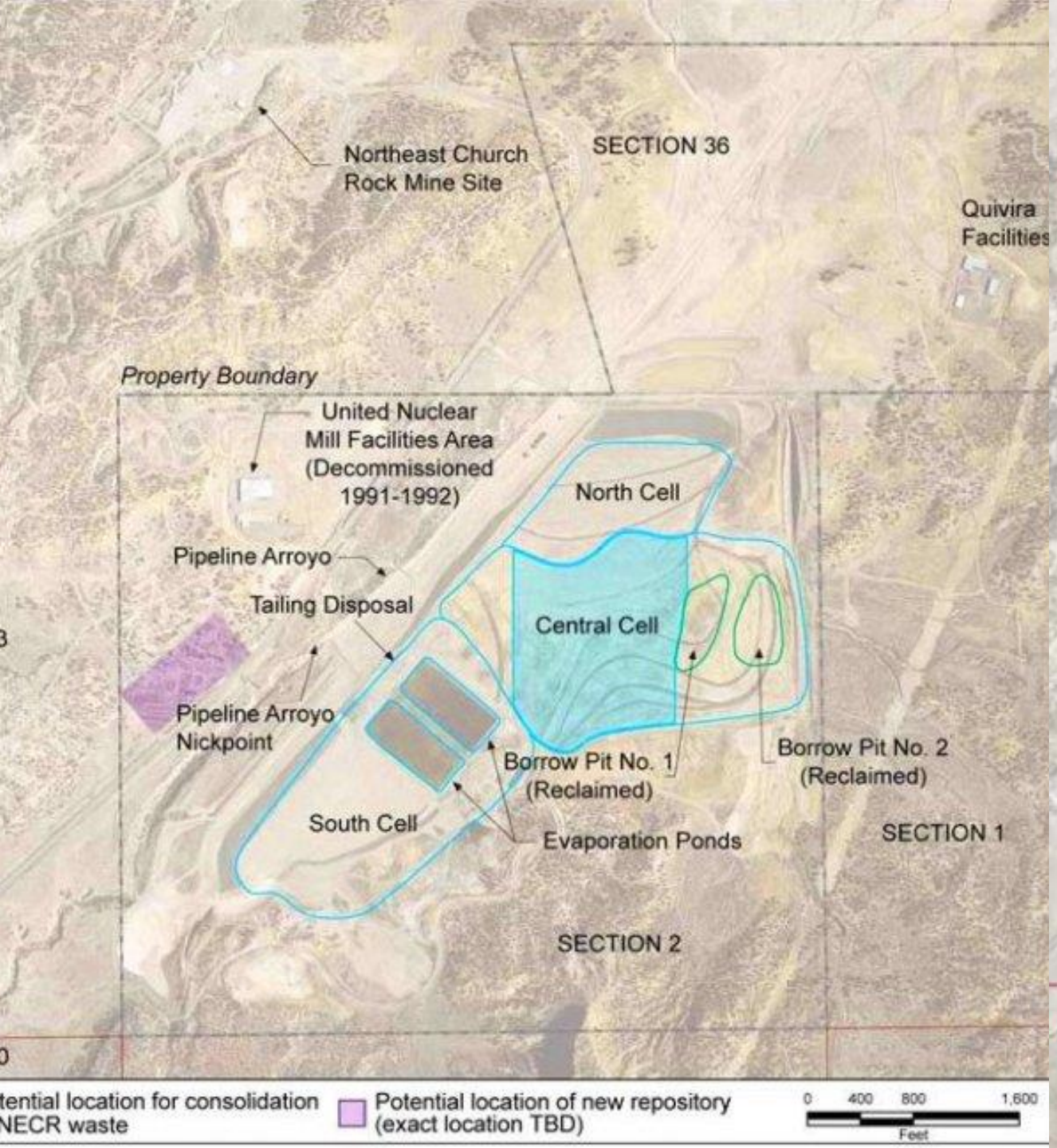
- accident released radioactive steam containing fission products that were drawn into the ship's ventilation system and spread to other compartments of the ship - the entire crew was irradiated
- repairs contaminated 700 m2 of the port, the nearby environment and the repair crew
- the original radioactive compartment was dumped into the Kara Sea
- all 7 members of the engineering crew and their commander died within a month receiving radiation doses between 7.5 and 54 Sieverts (fatal doses are considered 4-5 Sv)
- fourteen other crew members died within two years
- many experienced chest pains, numbness, cancer, and kidney failure
- treatment included also bone marrow transplantation and blood transfusion
- diagnosis was kept in secrecy

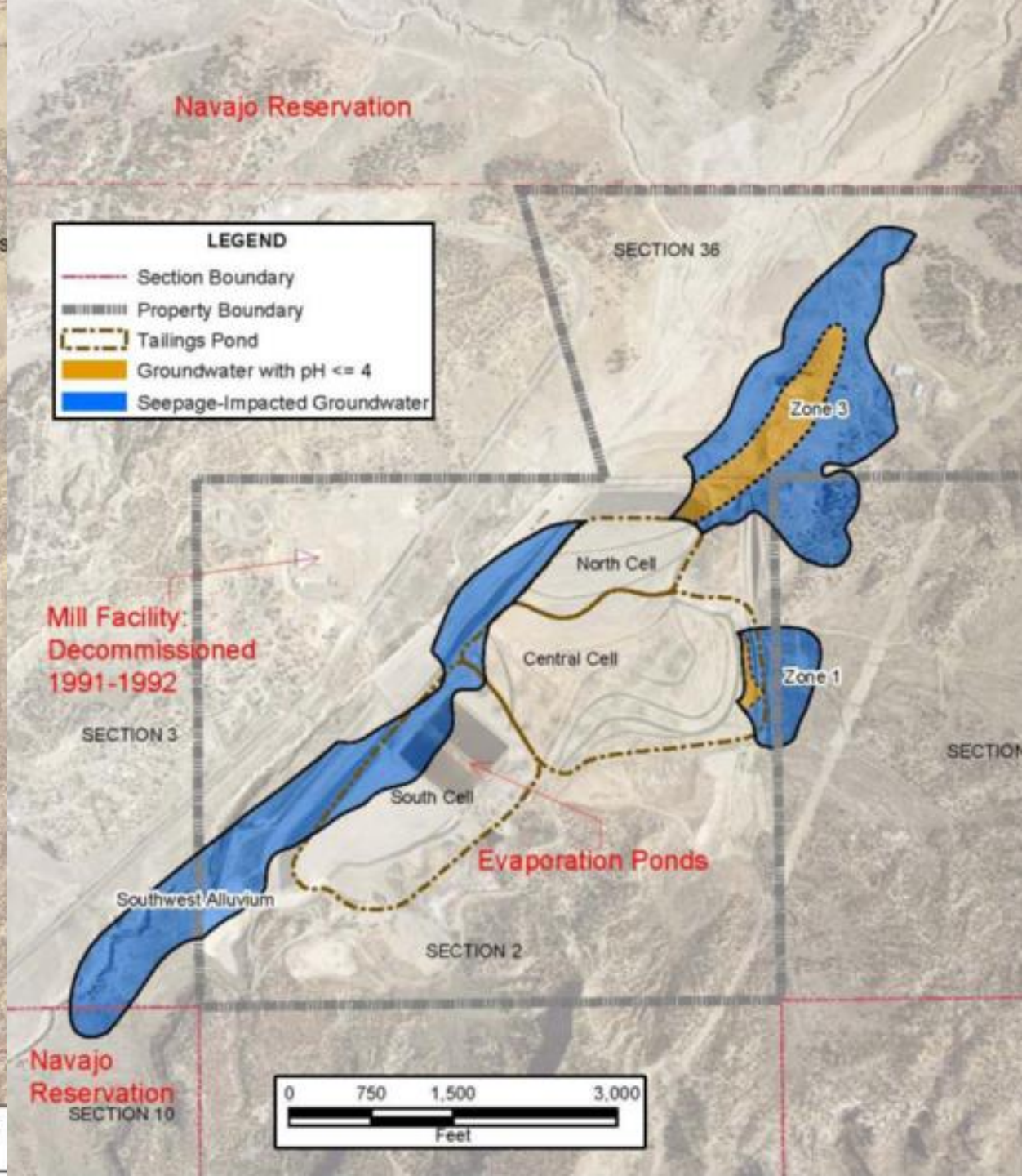
Church Rock Uranium Mill Spill

- New Mexico, 16 July 1979
- UNC's (United Nuclear Corporation) tailings disposal pond breached its dam
- the largest release of radioactive material in US history, more severe than Three Miles Island

Church Rock Uranium Mill Spill

- a crack in the dam of the south cell opened into a 6 m breach
- the crack was know for more than 2 years
- 1,000 t of solid radioactive mill waste and 350,000 m^3 of acidic, radioactive tailings solution flowed into Pipeline Arroyo, from where it flowed into the Puerco River
- the waste contained acids and tens of different radioactive and poisonous elements
- the heavily contaminated water travelled 130 km downstream and reached Navajo County (Indian reservation)


Northeast Church Rock Mine Site
SECTION 36
Quivira Facilities
Property Boundary
United Nuclear Mill Facilities Area (Decommissioned 1991-1992)
North Cell
Pipeline Arroyo
Tailing Disposal
Central Cell
Pipeline Arroyo Nickpoint
Borrow Pit No. 1 (Reclaimed)
Borrow Pit No. 2 (Reclaimed)
South Cell
Evaporation Ponds
SECTION 1
SECTION 2
tential location for consolidation NECR waste
Potential location of new repository (exact location TBD)
0 400 800 1,600
Feet


Navajo Reservation
LEGEND
Section Boundary
Property Boundary
Tailings Pond
Groundwater with pH <= 4
Seepage-Impacted Groundwater
SECTION 36
Zone 3
North Cell
Mill Facility: Decommissioned 1991-1992
Central Cell
Zone 1
SECTION 3
South Cell
Evaporation Ponds
Southwest Alluvium
SECTION 2
Navajo Reservation
SECTION 10
0 750 1,500 3,000
Feet

Church Rock Uranium Mill Spill

- Puerco river was used by residents for drinking, irrigation, and livestock
- they were not warned for days of the contamination - the spill contaminated all this
- 1,700 people lost access to clean water after the spill
- residents who walked in the water suffered from serious burns of the feet, together with infections some required amputations
- herds of sheep and cattle died after drinking the contaminated water

- major reluctance to cleanup - after pressure from the residents, just 3 inches of sediment from the river bed was removed ignoring rains, spills, and other pollutants than uranium
- UNC made a $525,000 out-of-court settlement with the Navajo Nation a year after the spill

Goiânia Accident (INES 5)

- Institute Goiano de Radioterapia in Goiania, private radiotherapy institute, in 1985 moved to new premises leaving a caesium-137 (half-life 30 years) teletherapy unit in place
- two people entered the abandoned premises and removed the source assembly thinking it may have some scrap value
- they tried to dismantle it at home, but the source capsule was ruptured
- caesium chloride salt contaminated the environment, the two people, the scrapyard owner and all the people visiting the scrapyard facinated by the fact that the source material glowed blue
- after five days, when people started to have the symptoms of irradiation, one of the persons visited hospital and took the fragment of the source material with him (he was given it as a gift as many others were)

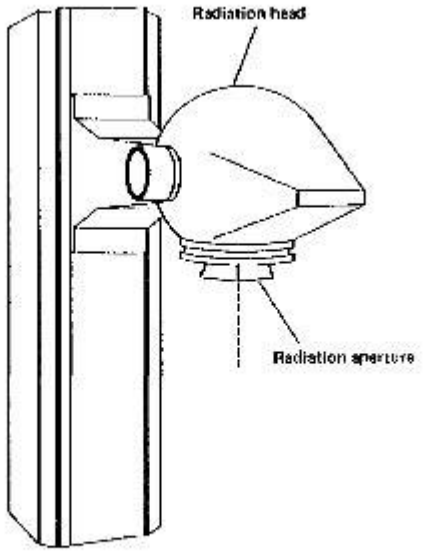


FIG. 4. Schematic view of a teletherapy machine similar to the one from which the source assembly was removed in Goiânia. The radiation head is adjustable vertically and can be rotated about two horizontal axes.

Goiânia Accident

- major operation started immediately, two areas evacuated
- significant contamination found in 85 houses, and 200 people were evacuated from 41 of them (30 reoccupied in 2 weeks, the rest demolished), 42 houses required decontamination
- over the period of just 2 days 67 km2 were monitored and all major sources of contamination found (one of them being the scrapyard with dose level of 2 Sv/h)
- food and water conatmination countermeasures required only around the main source (within a 50 metre radius)
- 112,000 people were monitored, 249 were contaminated, 4 patients died within 4 weeks (radiation doses of 4.5-6 Gy)

Goiânia

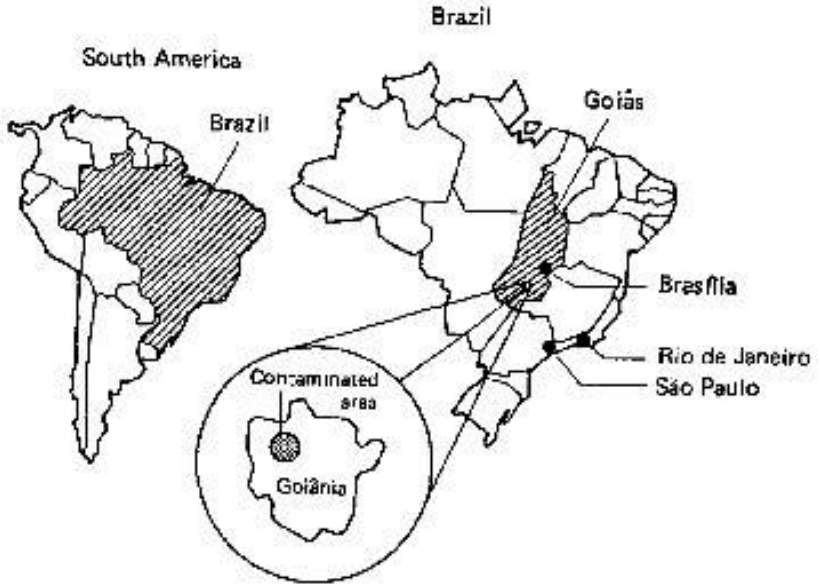


FIG. 1. Plan showing the location of Goiânia in relation to Rio de Janeiro (1348 km) and São Paulo (919 km), where the major radiological protection resources are situated, and giving an impression of the relative size of the contaminated area of the city.

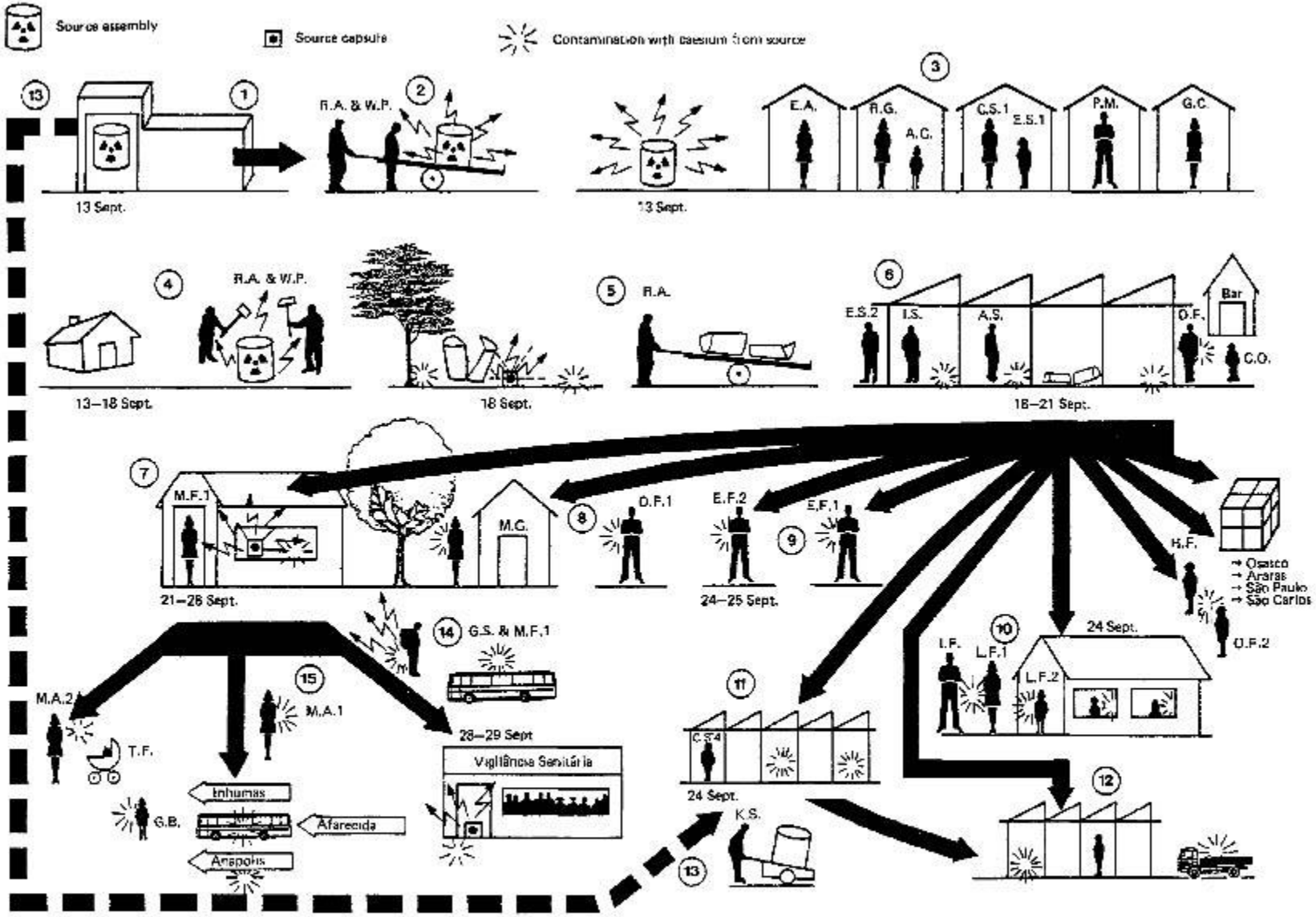
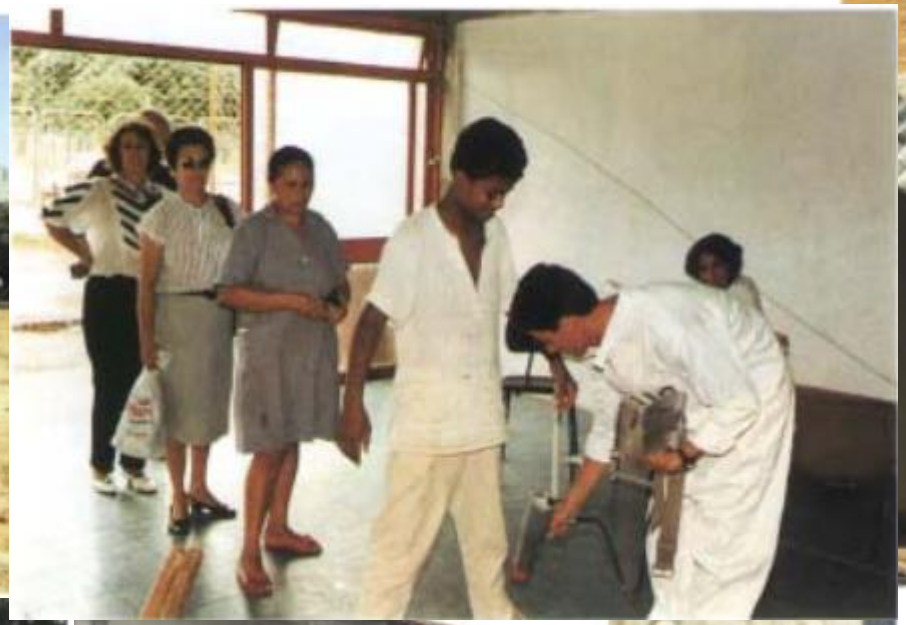


FIG. 8. Schematic diagram of the dispersal of caesium-137 in the accident in Goiânia. The diagram is based on a drawing made shortly after the discovery of the accident in attempting to reconstruct what had happened. It is reproduced in the format in which it was originally drawn even though it differs in minor details from what is now considered to be the best description of events (see the text of the report). Key: (1) the derelict clinic of the IGR; (2) removal of the rotating source assembly from an abandoned teletherapy machine by R.A. and W.P.; (3) source assembly placed in R.A.'s yard near houses rented out by R.A.'s mother E.A.; (4) R.A. and W.P. break up source wheel and puncture source capsule; (5) R.A. sells pieces of the source assembly to Junkyard I; (6) Junkyard I, the caesium chloride is fragmented and dispersed by I.S. and A.S. via public places; (7) D.F.'s house; contamination is further dispersed; (8) visitors and neighbours, e.g. O.F.1, are contaminated; (9) E.F.1 and E.F.2 contaminated; (10) I.F.'s house; other arrows indicate dispersion via visitors and contaminated scrap paper sent to other towns; (11) contamination is spread to Junkyard II; (12) contamination is spread to Junkyard III. (13) K.S. returns to the IGR clinic to remove the rest of the teletherapy machine to Junkyard II; (14) M.F.1 and G.S. take the source remnants by city bus to the Vigilância Sanitária; (15) contamination transferred to other towns by M.A.1. (By courtesy of CNEN, Brazil.)

Full report: https://www-pub.iaea.org/MTCD/Publications/PDF/Pub815_web.pdf

Goiânia Accident



Lilo Accident

- military base, 25 km East from Tbilisi
- in February 1997 eleven Georgian soldiers developed severe radiation burns (skin peeled, bleeding)
- on August 26 a radiological team from the Georgian Army detected high levels of radiation near an underground shelter at the base
- it was discovered Lilo base had been used by the Soviet military for nuclear war training
- when they left the base in 1992 they left behind scores of radioactive sources and failed to tell anyone about them

Lilo Accident

- on September 13, the source of the radiation was discovered in the pocket of a winter jacket that the soldiers had been sharing for guard duty (small caesium-137 metal cylinder that had a dose rate of about 45 millisieverts per hour at a distance of one meter)
- later other sources were found (20 cm beneath a soccer field, at the smoking area, eventually 8 sources of different activity was found)

- in the following 2 years other radioactive sources were found in other former Soviet-bases around Georgia (Vaziani, Matkhoji, Kuthaisi, Poti, Khaishi, Tbilisi, Rustavi)

- Full report: https://www.nrc.gov/docs/ML0037/ML003768309.pdf

Lilo Accident

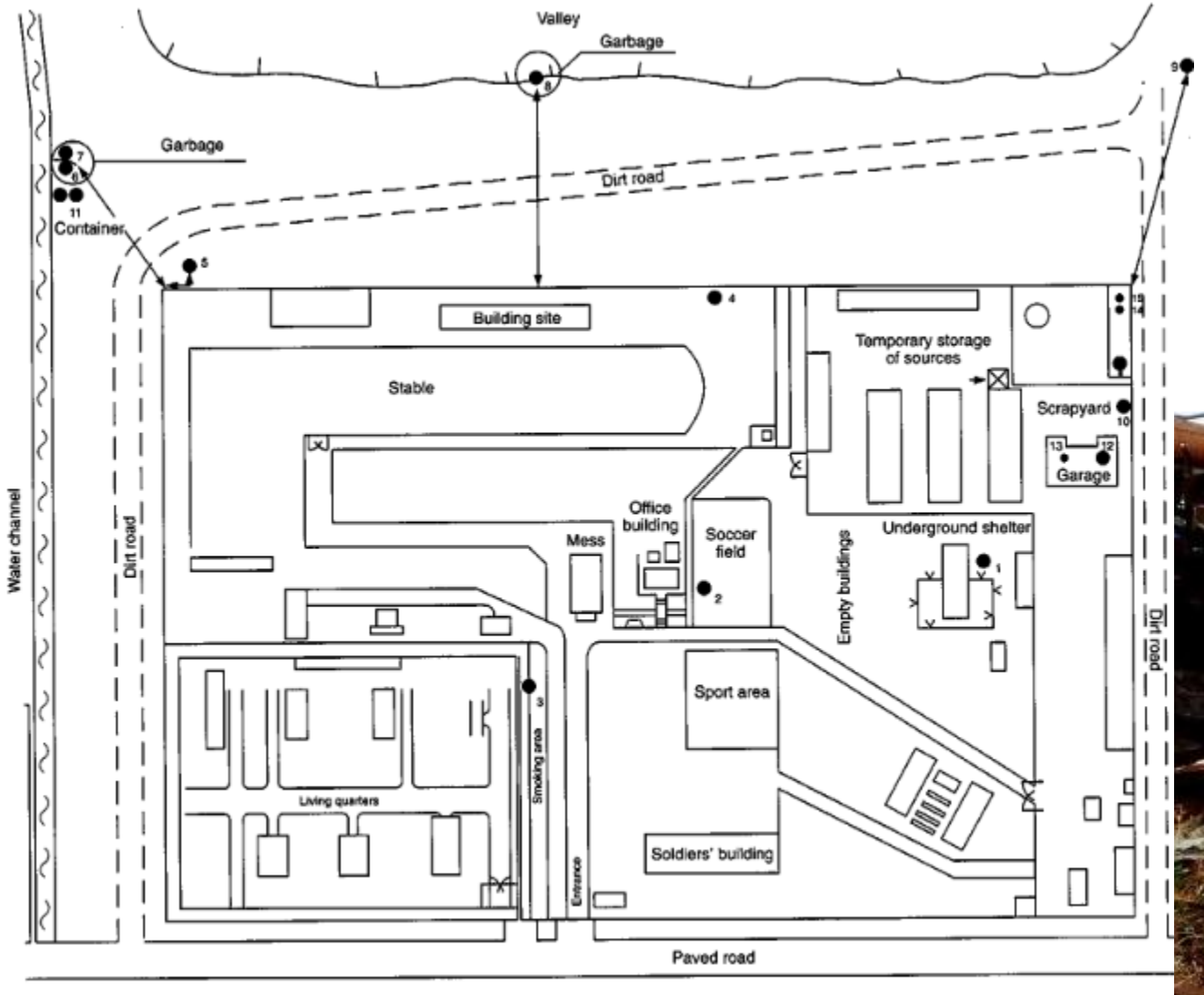


FIG. 1. Schematic diagram the Lilo Training Centre.

Tōkai-mura Nuclear Accident (INES 4)

- heart of Japan nuclear industry
- Japanese Atomic Energy Research Institute
- complex fo nuclear facilities incl. first Japan's power plant, uranium reprocessing facility, research facilities, fuel conversion plant etc.
- incident on 30 September 1999 during preparation of fuel for the Jōyō experimental fast breeder reactor (uranium enriched to 18.8%)

Tōkai-mura Nuclear Accident

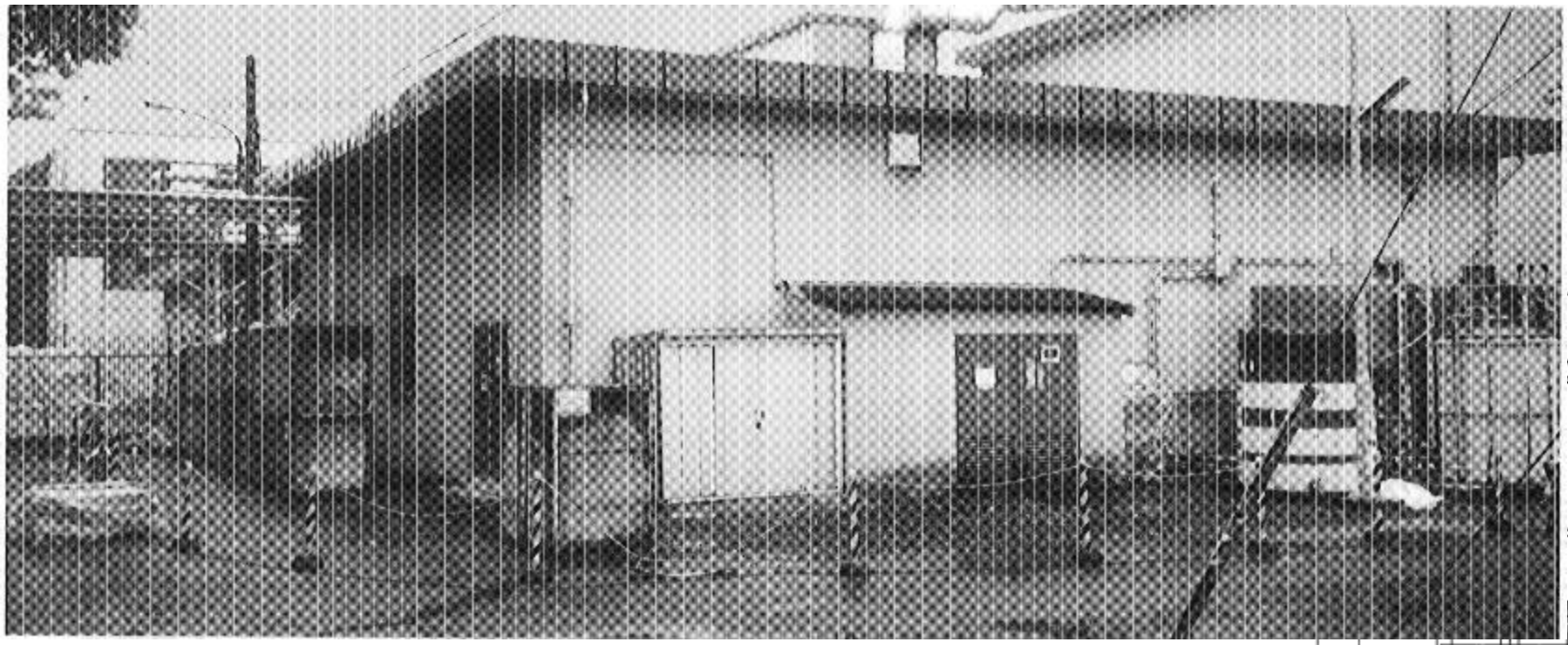
- unqualified personnel was preparing fuel by dissolving yellow cake in precipitation tank (using aqueous uranyl nitrate solution)
- 2.4 kg of uranium was permitted in the tank, they poured 16.6 kg in stainless steel buckets
- critical mass was creted and chain reaction started on its own and became self-sustaining
- massive amount of neutron- and gamma-radiation over a period of 20 hours was released, building contaminated with fission products as the tank boiled vigorously
- immediate reactions - pain, nausea, difficulty breathing, vomiting

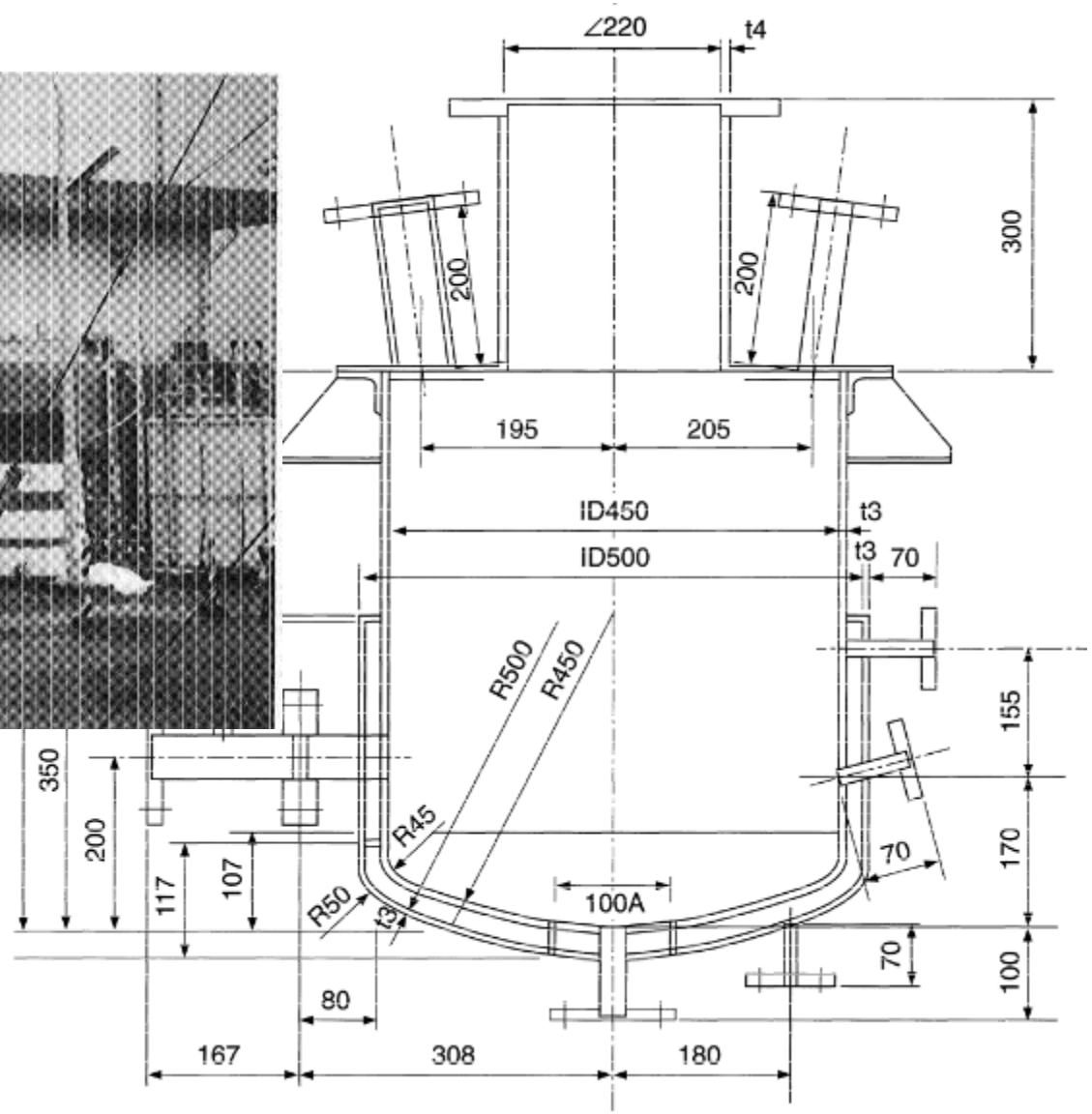
- incident mitigated by removal of water from the tank and injection of liquid boric acid to ensure subcriticality of the mass
- Sandbags and other shielding material (concrete) was placed around the building
- HEPA filters filtered the air in the budiling‘s ventilation systems

Tōkai-mura Nuclear Accident

- the three workers received 16-20, 6-10, and 1-4.5 Sv, the first two died in the following months (multiple organ failur, immunodeficiency)
- five hours after the start of the criticality, 39 households within a 350-meter radius were evacuated (161 people), residents within 10 km zone were asked to stay indoors (310,000 people); all restrictions lifted the following day
- 169 other employees were irradiated with up to 48 mSv
- 235 residents were irradiated with up to 16 mSv
- 260 rescue workers and journalists were irradiated with up to 9.2 mSv

Tōkai-mura Nuclear Accident

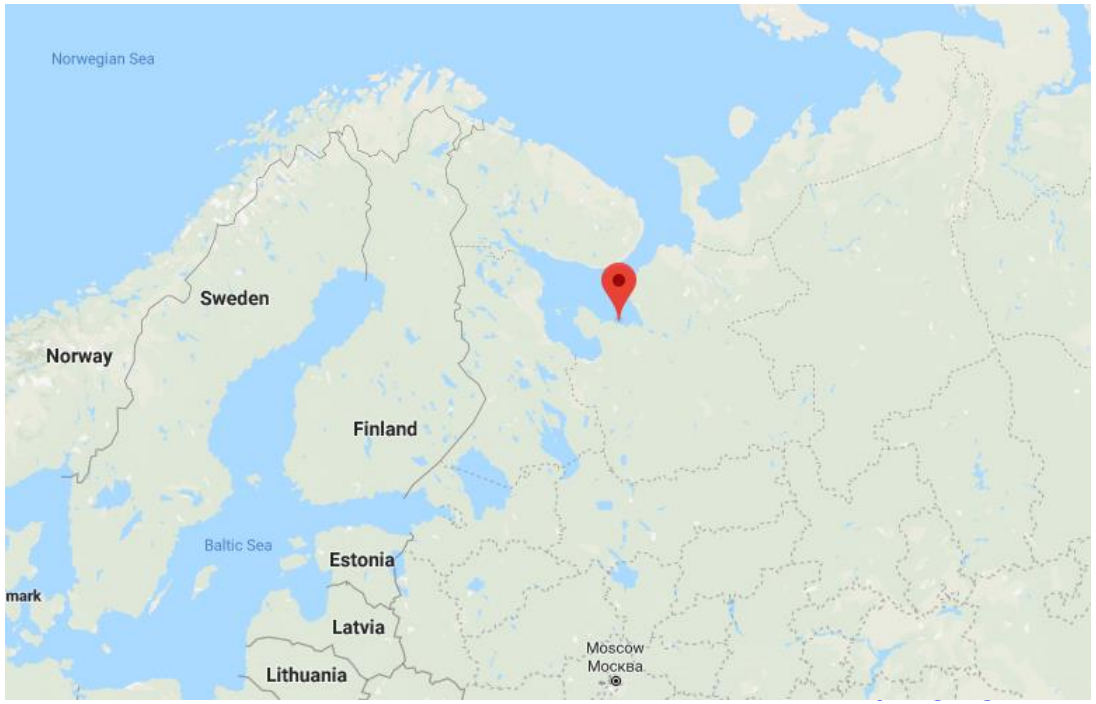




Full report: https://www-pub.iaea.org/MTCD/publications/PDF/TOAC_web.pdf

Nyonoksa Explosion

- main rocket launching site of the Soviet and Russian Navy established in 1954
- the cause of the on 8 August 2019 accident unknown
- either failed test of 9M730 Burevestnik nuclear-powered cruise missile or test of another nuclear liquid-fuelled rocket engine or accident during recovery efforts of the failed test of 9M730 Burevestnik

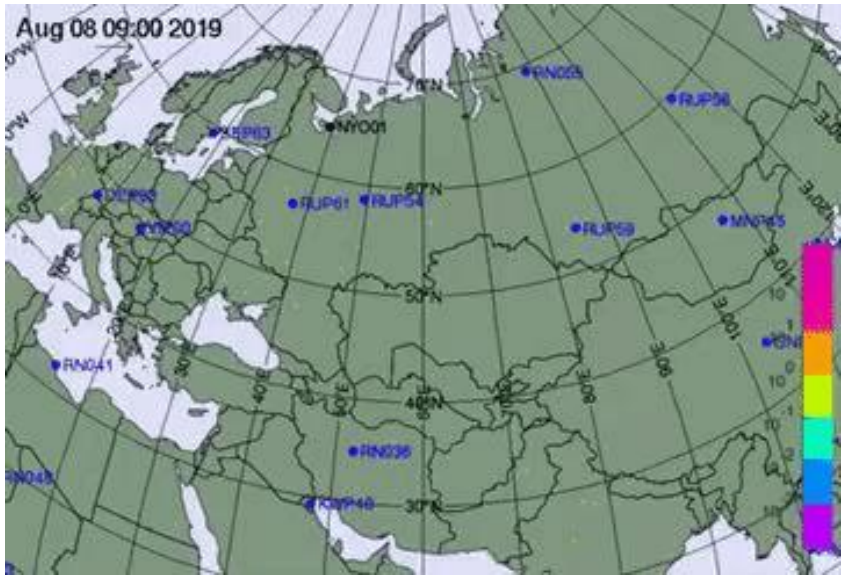


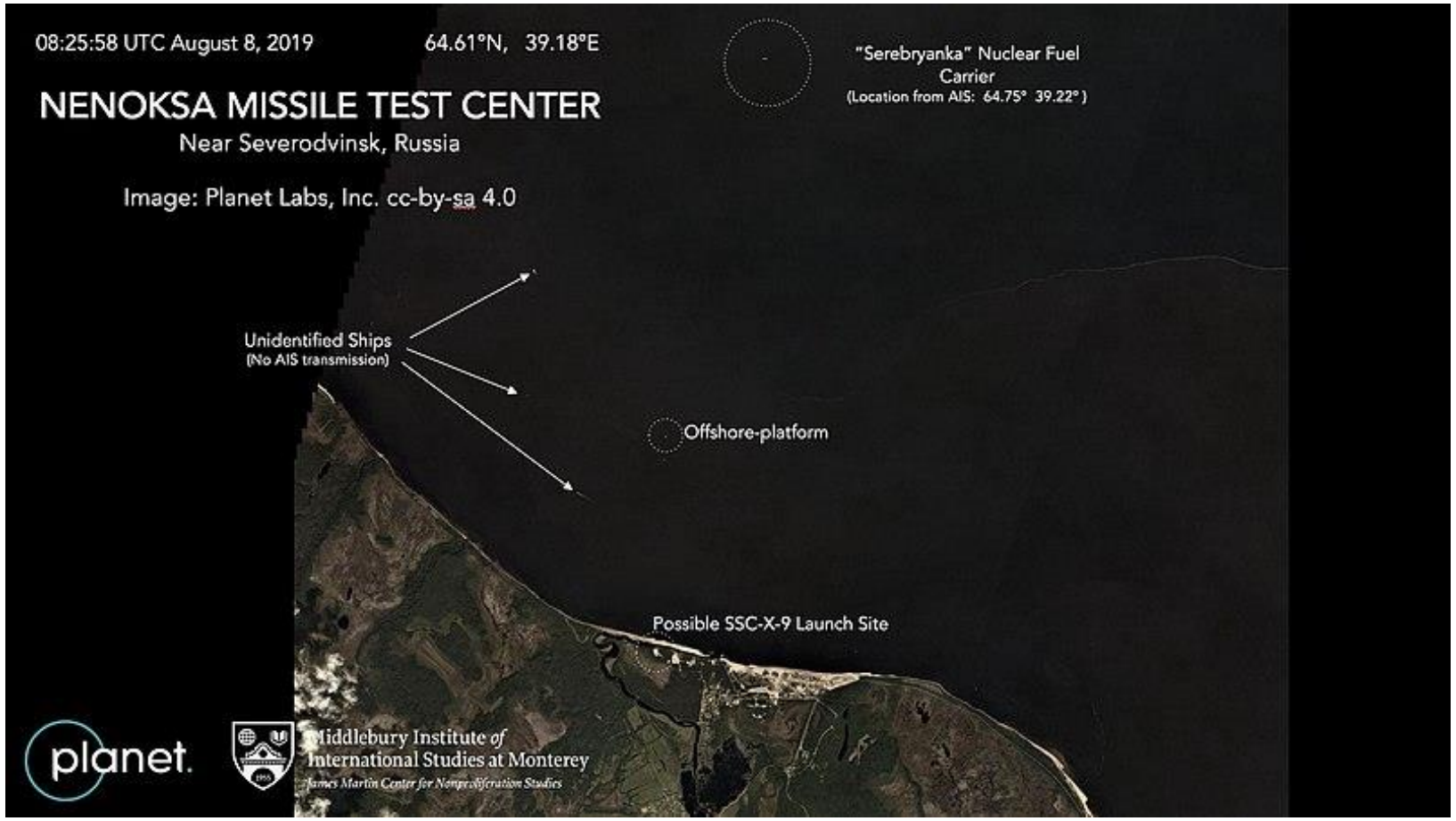
Nyonoksa Explosion

- explosion at sea close to the village of Nyonoksa
- two Russian special purpose ships were at the Nyonoksa test range when the explosion occurred
- five Rosatom specialists were killed during and immediately following the explosion
- three other people injured, taken to the Arkhangelsk hospital, where the doctors were not informed about the radiation exposure (caasium-137 contamination were later found with one of the doctors)
- it was announced that about 450 inhabitants of the Nyonoksa village had to be evacuated by train for two hours on 14 August then this evacuation would have been canceled
- the radioactive cloud contained strontium-91, barium-139, barium-140, lanthanum-140

- the eighth people were decorated with the Order of Courage by the order of V. Putin

Nyonoksa Explosion





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Summary

Three Mile Island NPP	technology malfunction
Chornobyl NPP	major violations of operating rules and regulations
Fukushima Daiichi NPP	failure to meet basic safety requirements such as risk assessment, preparing for containing collateral damage, and developing evacuation plans; lax oversight
Windscale Fire	violations of operating rules and regulations
Kyshtym Disaster	safety and work culture, total disrespect for the environment
K-19 Nuclear Sumbarine Accident	safety and work culture (faulty welds)
Church Rock Uranium Mill Spill	safety and work culture, disrespect for the environment
Goiânia Accident	safety and work culture, violations of operating rules and regulations
Lilo Accident	safety and work culture, violations of operating rules and regulations
Tōkai-mura Nuclear Accident	safety and work culture, violations of operating rules and regulations
Nyonoksa Explosion	technology malfunction, safety and work culture

Recommended:

Tomsk-7, Russia

Mailuu-Suu, Kyrgyzstan

Semipalatinsk, Kazakhstan

Thule, Greenland

Thank you for your attention.

Sources:
https://www.iaea.org/
https://www.nrc.gov/
https://hibakusha-worldwide.org/
https://en.wikipedia.org/

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