NUCLEAR SAFETY

A nuclear power reactor cannot explode like a nuclear bomb. The world has, however, experienced accidents involving severe damage to the reactor cores at Three Mile Island in the USA in 1979, at Chernobyl in the former USSR in 1986 and at Fukushima in Japan in 2011.

This Fact Sheet seeks to answer the question: how safe are nuclear power stations ***really***? It does so by examining the consequences of these accidents in the context of accidents elsewhere in the power generation industry. It also discusses additional measures taken to prevent major accidents in reactors operating today and in those now on the drawing board.

TYPES OF REACTOR ACCIDENT

NIASA Fact Sheet 2 describes the nuclear fission process and the creation of 'fission product' nuclei. These are fragments of 'split' uranium nuclei which form highly-radioactive isotopes such as xenon-133 and krypton-85, iodine-131, caesium-137, strontium-90 and many others. Being highly radioactive, these fission product isotopes continue to generate 'decay' heat (at a diminishing rate) within the nuclear fuel long after the reactor has shut down. If cooling is not restored, decay heat is sufficient initially to melt the fuel.

During normal operation the fission products remain confined within the uranium oxide fuel. If the fuel melts, however, fission products may escape into the reactor environment. This was the situation at Three Mile Island where fission products escaped from the reactor coolant circuit into the containment building. At Fukushima fission products escaped from the containment into the external environment.

A 'reactivity accident' accident, the second conceivable type of reactor accident, is an unplanned power surge. At Chernobyl, this was caused by a combination of operator error and bad design. The steam explosion caused by the power surge and the subsequent hydrogen explosion destroyed the reactor confinement and caused a massive release of radioactive material into the environment.

IMMEDIATE CONSEQUENCES

THREE MILE ISLAND, UNIT 2

The TMI accident was triggered by a maintenance error that caused the turbine and therefore the reactor to shut down. This led the steam pressure in the reactor coolant circuit to surge briefly while the reactor power level fell away. See Fact Sheet 6. Valves designed to vent steam in such a 'design-basis' event to a tank in the containment building opened as per design but one failed to close when the pressure dropped. Coolant water therefore continued to pour out of the reactor coolant circuit, through the stuck-open relief valve and out into the containment building.

According to design, the emergency core cooling system (ECCS) started automatically and would have terminated the incident had the operators not intervened.

The operators, however, had not been trained to recognise and deal with this sequence of events. Confused by misleading information in the control room, they misinterpreted what was going on and shut down the ECCS, thus leaving the core without cooling. Decay heat caused half the core to melt and released much radioactivity via the stuck open valve into the containment. Relatively little radioactivity escaped into the environment.

No one was killed or significantly irradiated either on- or off-site. Long-term radiological consequences are discussed below.

CHERNOBYL UNIT 4

RBMK reactors operated in the former USSR from 1970. Chernobyl Unit 4, however, had been in service for just a year. The control room operators had been instructed to complete an experiment left over from the original start-up tests. Owing to a mistake made in preparing for the test, the reactor power dropped almost to zero. Determined to rectify the mistake, the operators broke fundamental safety rules including disabling safety systems that would otherwise have shut the reactor down safely.

This placed the reactor into an unstable condition compounded by known design weaknesses which, when the operators finally realised their situation and tried to shut the reactor down, led to the sudden power surge that destroyed it. There was no containment building - in the Western sense of the word. The reactor was exposed to the atmosphere and fuel burnt for ten days. Radioactive material was released high into the atmosphere and spread over much of Europe.

116 000 people were evacuated from the immediate vicinity of the plant in the days and weeks following the accident. A further 234 000 were moved later. The area within approximately thirty kilometres of the plant remains essentially uninhabited.

Three men died in the accident (one of coronary thrombosis). Twenty-eight site staff, mainly firemen, died as a result of acute radiation exposure within the next few weeks. Longer term health effects are discussed below.

FUKUSHIMA UNITS 1, 2, 3 and 4

A Magnitude 9 off-shore earthquake caused the three operating reactors at the Fukushima Daiichi plant to shut down. It also destroyed power grid connections to the plant. Emergency diesels started up to supply power to the emergency cooling systems but were inundated by the tsunami waves that swept through the plant some forty minutes later. One diesel continued to operate and prevented fuel damage in units 5 and 6.

Fuel in Units 1, 2 and 3 reactors was left without emergency cooling and in due course melted. Fuel in the Unit 4 spent fuel pool appears also to have melted. Hydrogen is generated when excessively hot fuel interacts with steam and water. In all four units hydrogen explosions exacerbated the situation. Of the radioactivity released, estimated for major isotopes to vary between 10 and 42% of the Chernobyl release, 20% blew inland, the remainder out to sea. Much radioactivity, particularly radioactive caesium, was pumped into the ocean during the recovery phase.

The reactors, commissioned in the early 1970s, had been designed to withstand seismic accelerations comparable with those experienced at the start of the incident. The power station site, however, like the population surrounding it, was inadequately protected against the tsunami that followed. Some 20 000 people including two on the power station site were killed by the tsunami. No one died as a direct result of the nuclear accident but around 150 000 people were forced to evacuate an elongated area extending inland to some forty-five kilometres to the north-west of the site.

LONG-TERM CONSEQUENCES

The health effects of exposure to ionising radiation are discussed in NIASA Fact Sheet 4. High levels of exposure, measured in thousands of millisieverts (shortened to mSv), will cause deaths among an exposed population within a few weeks. Lower levels of exposure may cause death due to cancer in later life. No health effects have ever been observed below 100 mSv.

Radiation induced genetic disorders have never been observed in any human population.

Natural background radiation exposure varies from 1 to at least 260 mSv/year. The world average is 2.4 mSv/year.

The views of the authoritative American Health Physics Society on the possibility of adverse health effects following exposure to low levels of radiation were published in July 2010. The Society states that below 50 to 100 mSv 'estimation of adverse health effects remains speculative'. Also, below this dose 'risks of health effects are either too small to be observed or are nonexistent'. In the Society's view, the so-called linear no-threshold theory (LNT) which postulates that even the smallest exposure to radiation carries a finite risk of causing cancer may be used to establish safety standards but 'should not be used for the purpose of estimating population health risks'.

In 2008, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) stated that, 'During the last decade, the committee has avoided making projections of the health effects that might be caused by low-level exposure of large population groups, mainly because of the substantial uncertainties associated with any such projection and potentially serious misinterpretations in the communication with the public'.

In short, it is impossible to state with confidence that radiation exposure below 50 to 100 mSv does or does not have adverse health consequences. Merely, that if there are such consequences they are too slight to be observable.

THREE MILE ISLAND

No one off-site received more than 1 mSv of radiation exposure. (1 mSv is the allowed annual exposure limit for the general public). There is no reason to expect adverse long-term health effects in the local population.

CHERNOBYL

In 2006, the World Health Organisation, part of the international 'Chernobyl Forum' investigation, concluded that 65 people had by then died. This total included the 31 deaths mentioned above and 15 children who died later of thyroid cancer caused by inhaling or ingesting radioactive iodine. It also included 19 of those heavily irradiated who died later of causes not normally associated with radiation.

In the years following the accident, some 700 000 'liquidators' worked for short periods to clear up the site. In the early stages of the recovery operation some of these received doses in excess of 500 mSv. The average for those employed in the first four years was 100 mSv. Of the 116 000 people evacuated in the days and weeks following the accident, some received 'several hundred mSv'. Their average was 33 mSv.

Over 6 000 cases of thyroid cancer had been reported by 2005. This condition is normally treatable but, as indicated above, fifteen children had by then died. The numbers would have been smaller had the authorities acted more swiftly to ban the consumption of milk and contaminated vegetables.

FUKUSHIMA

The highest radiation exposures during the accident were between 600 and 700 mSv experienced by two control room operators, largely as a result of inhaling radioactive material. Six workers received more than the 250 mSv emergency limit. 167 received more than 100 mSv.

The risk to the two control room operators of developing cancer in later life may thus have been increased by perhaps 4% from around 20% to 24%. The risk to recovery personnel is proportionally less.

Because there was time to effect the evacuation, the exposure of the population was very low. Preliminary studies by WHO suggest that the most highly exposed members of the public received 10 to 50 mSv. Studies are ongoing. The population is to be permitted to return to contaminated areas when the dose they are expected to receive in the first year back home drops below 20 mSv.

Any attempt to quantify the health detriment, if any, due to Fukushima would be speculative. At the level of exposure considered it appears unlikely that there will be any observable detriment.

IMPACT ON NUCLEAR SAFETY

Before Three Mile Island in 1979, a core-melt accident was considered essentially incredible. The accident led to major improvements in safety analysis, accident management procedures, operator training and emergency planning. Numerous engineering modifications were introduced into most of the world's operating nuclear power stations.

Conscious that an accident at one site jeopardises the viability of all sites, American utilities combined to establish the Institute for Nuclear Power Operation, INPO. Regular peer reviews by INPO specialists and other INPO initiatives have substantially improved operating practice and safety at American power stations and a number outside the USA – including the two PWR units at Koeberg.

The Chernobyl plant differed so radically from Western designs that the accident had little relevance for reactor design. Subsequent investigations, however, revealed a lack of safety consciousness throughout the operating organisation. The major lesson for the West was therefore the need to promote a paramount, zero-tolerance safety culture at all levels. This remains the cornerstone of nuclear safety.

A further response to Chernobyl was the establishment of the World Association of Nuclear Operators (WANO) modelled on INPO. Both organisations have since made major contributions to safety. All nuclear power stations in the world are now subject to inspections by teams of specialists selected and led by either WANO or INPO. Safety culture is specifically assessed. In addition, at the invitation of governments, the International Atomic Energy Agency (IAEA) conducts inspections to ensure that its own library of Safety Conventions and guidelines are adhered to.

The principal lessons from Fukushima are the need to protect sites against 'incredible' off-site disasters, to keep elderly operating stations up-to-date with safety-related modifications and, in particular, to safeguard the provision of back-up electrical power under all circumstances.

SAFETY COMPARISON WITH OTHER POWER SOURCES

There have been accidental deaths in experimental and military nuclear installations, most of them prior to 1980. Other than at Chernobyl, however, there have been no fatal radiation accidents associated with nuclear power station operation.

Three aspects must be considered in any safety comparison with other power sources. They are the numbers of 'immediate' fatalities caused at the time of the accident, the possibility of 'latent' deaths long after the accident, and socio-economic consequences. The complete fuel chain must be considered from mining, extracting and transporting the fuel to disposal of the waste.

'IMMEDIATE' FATALITIES

There were no deaths associated with the accident at Three Mile Island. As discussed above thirty-one died in, or soon after, the Chernobyl accident. There were no radiation-related deaths at Fukushima.

It should be noted that, in its 2011 assessment of comparative risks, the OECD's Nuclear Energy Agency (NEA) warns against extrapolating (Chernobyl) nuclear risks to current OECD countries 'because OECD plants use other safer technologies that are operated under a stricter regime than was in force in Ukraine at the time of the Chernobyl accident'.

Concerning non-nuclear power sources, the Swiss Paul Scherrer Institute has examined the consequences of major accidents in the energy industry for the period 1969 to 2000. The Institute defines as a major accident one that causes five or more deaths. It also differentiates between OECD and non-OECD countries, there being far more accidents in the latter.

Energy chain	OECD Countries			Non-OECD Countries		
	Accidents	Fatalities	Fatalities per GWy	Accidents	Fatalities	Fatalities Per GWy
Coal	75	2259	0.157	1044	18 017 (1)	0.597
Oil	165	3713	0.132	232	16 505	0.897
Natural gas	90	1043	0.085	45	1000	0.111
LPG	59	1905	1.957	46	2016	14.896
Hydro	1	14	0.003	10	29 924 (2)	10.285
Nuclear	0	0	-	1	31	0.048

(1) 13 186 of these were due to accidents in China.

(2) The great majority of these were due to major dam failures in India and, more particularly, China.

Judged by the yardstick of immediate fatalities, it is clear from the Table that nuclear power with just 31 'immediate' fatalities has been by far the safest of the major technologies listed. Liquefied petroleum gas (LPG) has been by far the most dangerous.

'LATENT' FATALITIES

The comparison in respect of long-term or 'latent' fatalities is confused by conflicting reports published by 'official' national and international health organisations and other, often anti-nuclear, organisations. At issue are diverse claims concerning the health effects, if any, of radiation exposure below about 100 mSv.

As indicated above, there is no good reason to associate 'latent' deaths with Three Mile Island. Concerning Fukushima, it is not impossible that there will eventually be deaths among the operators and recovery personnel who received more than about 100 mSv – although this is by no means certain. There is no good reason to anticipate deaths among the general public.

With respect to Chernobyl, over 6 000 cases of thyroid cancer have been reported. This condition is normally treatable but by 2005, fifteen children had died. The Chernobyl Forum reported in that year that the initial toll of thirty-one deaths attributable to the accident had risen to fifty-eight – later increased to sixty-five (see above).

Many 'liquidators' and some evacuees received more than 100 mSv. Their risk of contracting cancer, particularly leukaemia, in later life may therefore have been increased. There are unconfirmed reports of leukaemia deaths among the Russian contingent of liquidators.

Except for the reported cases of thyroid cancer, there is no persuasive evidence of detrimental health effects among the general population that can be attributed to radiation exposure.

Concerning fossil fuels emission, the OECD has estimated that worldwide 288 000 premature deaths per year can be attributed to particulates from fossil fuel generation. The number of deaths likely to be caused by climate change often linked to carbon dioxide emission is a matter for speculation.

There is little doubt that the number of lives shortened by burning fossil fuels vastly exceeds that due to nuclear generation.

SOCIO-ECONOMIC IMPACT

The socio-economic impact of Fukushima and, particularly, Chernobyl in terms of lives uprooted and land interdicted far outweighs the health detriment due to radiation, grievous though the Chernobyl legacy has been.

Chernobyl and Fukushima have shown the potential for harm that resides in the core of a nuclear reactor. Judged by the socio-economic yardstick, nuclear generation will not be generally acceptable while any possibility of this magnitude of impact remains.

This aspect is being addressed in the design of current and future reactors.

THE FUTURE

NIASA Fact Sheet 5 demonstrates that there is enough uranium and thorium in the Earth's crust to power the Planet far into the future. Nuclear generation is still at an early stage of its evolution.

Successive generations of nuclear reactors, like successive generations of airliners, embody accumulated experience and become progressively safer.

It is convenient to define Generation I reactors as the earliest prototypes and Generation II as the next generation of workhorse reactors today delivering 14% of the world's electricity. The shock of Three Mile Island (Generation II) and the forced acceptance that core-melt accidents are credible, led to the design of Generation III systems typified by ample volumes of emergency cooling water held high in the reactor buildings. Generation III+ systems now being built incorporate 'passive' safety features that provide emergency cooling to the reactor core without the need for emergency power.

The design criteria for the smaller Generation IV reactors now on the drawing board include the requirement that there must be no need for off-site emergency planning. In other words the probability of a large release of radioactivity from future systems will be effectively zero.

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