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Classification of Nuclear Accidents

The widely accepted definition of the term "accident" is "a chance event that has more or less damaging effects on people and things". Depending on the severity of the damage, we instead use "catastrophe" when "the event causes significant disruption and deaths" or even "calamity" when the "affliction is public, the misfortune affects a region, a group of individuals". On the contrary, the term "incident" will be used for "a fact, an event of secondary, generally irritating, character, that occurs during an action and can disturb its normal function".

In this book, the term "nuclear accident" will cover both conventional accidents that occur in an involuntary manner following a large-scale natural event (earthquake, tsunami, etc.), a human error that has serious repercussions or an act of terrorism, but we will also find it used in reference to voluntary acts such as atmospheric nuclear bomb tests or war events such as atomic bombing of Hiroshima and Nagasaki. Effectively, for these various events, if the decision is voluntary and therefore not at all related to chance, the damage to the environment, to flora, fauna and to mankind is considerable.

1.1. Classification of nuclear events: incident or accident?

The definition of an accident is generally based on the existence of visible medical damage, morbidity or even mortality. Accidents caused by ionizing rays are very rare in comparison to other types of accidents (e.g. roads, construction). However, a certain number of serious accidents are perhaps totally unreported, since the number of accidents that have been discovered by chance is significant and even appears to increase over time [NEN 01a, NEN 07].

Following the accident in Chernobyl in 1986, the IAEA decided to create an international scale for nuclear events (INES, International Nuclear Event Scale). This scale was applied on a worldwide scale in 1991. It is made up of eight levels of severity graded from 0 to 7 (Table 1.1). For events that are quantifiable and that can be compared, the scale is logarithmic.

Several criteria are taken into account to define the severity level of a nuclear event. The reported events are analyzed as a function of their consequences on three levels: (1) wider effects on people or goods (human health of workers and/or the public), (2) on-site effects, and (3) impacts on defense-in-depth (multiple security systems). The change from an incident (levels 1–3) to an accident (levels 4–7) is characterized by a contamination of the environment that is likely to be damaging to public health. This will be detailed in Volume 2, which is dedicated to civilian, industrial and medical accidents. Effectively, in the military field, the INES classification is rarely applied except for nuclear facilities where a civilian activity is present. Thus, a second military accident has been classified as level 6 (serious accident), namely the Kyshtym catastrophe in the USSR (Mayak nuclear complex) in 1957. Another event (accident), the fire in the Windscale power station (that became Sellafield) in the United Kingdom in 1957, was considered to be level 5.

The American military uses a different classification (see below). The military classifications of other countries that possess atomic weapons remain unknown.

Type	INES	Wider effect	On-site effect	Damage to defense-in-depth
Major accident	7	Major release: widespread effects on health and the environment		
Serious accident	6	Significant release likely to require implementation of planned countermeasures		
Accident with wider consequences	5	Limited release likely to require implementation of some planned countermeasures	Serious damage to the reactor or to radiological barriers	

Accident with local consequences	4	Minor release: public exposure of the order of the statutory limits	Significant damage to the reactor or to radiological barriers, or lethal exposure of a worker	Loss of defense-in-depth and contamination
Serious incident	3	Very small release: public exposure represents a fraction of the statutory limits	Serious contamination or acute effects on the health of a worker	Near-accident. Loss of defense lines
Incident	2	No consequence	Significant contamination or overexposure of a worker	Incident combined with significant failure of safety provisions
Anomaly	1	No consequence	No consequence	Anomaly not included in the authorized modus operandi
Deviation	0	No safety significance	No safety significance	Insignificant anomaly from a safety point of view

Table 1.1. *The severity levels of a nuclear event. INES scale (source: adapted from [WIK 18a])*

1.2. Military classification

The authorities of countries that possess nuclear arms are very discreet about providing information concerning nuclear incidents and accidents. In the United States, a specific terminology has been made public. Thus, the term “Pinnacle” designates an incident of interest for the Chief of Staff of the Defense Department because it requires a higher level of military action, causing a national reaction, affects international relations, causes wide, immediate media coverage, affects current national policy and is clearly against national interests. Another term that defines the gravity of this nuclear event is then associated with this generic term.

The United States Defense Department considers that the most serious accident would be the unintentional and unauthorized launch of a nuclear weapon, creating a risk of war. It calls this a “Nuke Flash”; in other words, a “nuclear flash”. Slightly less serious accidents are those named “Broken Arrow” that involve nuclear weapons, warheads or components, but that do not create the risk of nuclear war. This includes unexplained nuclear accidents or explosions, non-nuclear detonations, combustion of a nuclear weapon, radioactive contamination, the loss of the active part of a nuclear weapon during transport with or without its transporting vehicle, and dropping a nuclear weapon or nuclear component that poses a real or implicit danger to the public. A significant incident that is not part of the first two categories is coded “Bent Spear”.

American inventories do not record any “nuclear flash” accidents. On the contrary, the United States Defense Department recognizes 32 “broken arrow” accidents [SCH 13]. Among these, we cite the accident in 1950 with a B-36 in British Columbia; in 1956, the disappearance of a B-47; in 1958, the accidental loss of a nuclear weapon by a B-47 in Mars Bluff (South Carolina) and the mid-air collision of aircraft at Tybee Island (Georgia); in 1961, the accidents in Yuba City and Goldsboro with a B-52; in 1964, another accident with a B-52 in Savage Mountain; in 1965 in the Philippines, the incident with a Sea A-4; and in 1980, the explosion of a Titan Missile in Damas (Arkansas). However, the two worst nuclear accidents took place in 1966 near Palomares, Spain, and in 1968 at Thule, Greenland, following two aerial accidents involving B-52 bombers.

There have been numerous incidents in the “bent spear” category. In particular, there have been several bombers that have crashed with their bomb load (Table 1.2). An example of “bent spear” is the loss in transit of six cruise missiles with armed nuclear warheads carried on a B-52 bomber from the Minot Air Force Base to the Barksdale Air Force Base in August 2007, when they should have been disarmed [WAR 07].

The term “Dull Sword” describes minor incidents involving weapons, components or nuclear systems, or which could compromise deployments of these. A selection of several nuclear military accidents is presented in Table 1.2 for aviation and in Table 1.3 for submarines. Two American submarines and seven or eight Soviet submarines sank; more details are provided in Chapter 4.

Date	Place	Accident
July 13, 1950	Ohio, United States	A B-50 bomber crashed. Explosion of the conventional charge. However, the nuclear stage remained inactive.
October 11, 1957	Florida, United States	A B-47 carrying an H-bomb crashed and burned but did not explode. However, alpha radiation was emitted, leading to evacuation of the population.
January 31, 1958	Morocco	A B-47 carrying an H-bomb crashed and burned. No nuclear explosion, but the emission of alpha rays caused the population to be evacuated.
March 11, 1958	Mars Bluff, North Carolina, United States	An atomic bomb was released by accident, fell into a garden and the conventional charge exploded. The house was destroyed and the inhabitants seriously injured.
June 7, 1960	McGuire Air Force, Base in New Egypt, New Jersey, United States	A helium tank exploded and cracked the reservoirs of an anti-aircraft missile BOMARC-A, carrying a nuclear warhead. The fire caused the missile and the plutonium in the nuclear warhead to melt. The complex and the underground waters were contaminated.
January 17, 1966	Palomares, Spain	Loss of bombs, accident described in Chapter 4.
January 21, 1968	Thule, Greenland	Loss of bombs, accident described in Chapter 4.

Table 1.2. *Some nuclear accidents in American military aviation classified as Bent Spear (source: selected from Villain [VIL 14] and Wikipedia [WIK 18b])*

Date	Place	Accident
1961	Unknown	The submarine USS Theodore Roosevelt (SSBN-600) attempted to get rid of the exhausted resin in its demineralization system. The vessel was contaminated when the wind blew the resin back towards it.
July 4, 1961	Off the coast of Norway	The Soviet submarine K-19 was the victim of a major accident after the failure of the cooling system in the starboard reactor. Temperatures in the core reached 800°C. The incident contaminated the crew, killing several seamen. The crew regained control thanks to emergency procedures.

April 10, 1963	To the east of Boston, MA	The nuclear attack submarine USS Thresher (SSN-593) sank with 129 men on board during sea trials.
May 22, 1968	Atlantic Ocean	The USS Scorpion (SSN-589) suddenly sank at great depths with 99 men on board, very probably due to the explosion of a torpedo.
April 12, 1970	Atlantic Ocean	K-8, a Project 627A, November-class nuclear attack submarine in the Soviet fleet, suffered simultaneous fires in two compartments when diving. The submarine re-surfaced and failed in its attempt to attach a towing cable to a Soviet merchant navy ship. The submarine sank, killing 52 men.
August 10, 1985	In Chazhma Bay, near Vladivostok	The nuclear reactor in the Soviet K-314 submarine (Project 675) exploded during reloading. The fire lasted for 2 hours and radioactivity (100,000 Ci) was projected several kilometers away. Ten crew members died immediately. A vast area that remains open to human activities will not be de-polluted. The 2,000 inhabitants of the Bay have never been evacuated. Demolition of the submarine began in September 2010, despite protests by locals.
August 12, 2000	Barents Sea	The Kursk, a Russian nuclear-propelled Project 949A Oscar II submarine, sank during an exercise, with 118 men on board.
January 7, 2005	Near the island of Guam, Pacific Ocean	An American submarine from the Los Angeles class, the USS San Francisco (SSN-711) violently hit an underwater mountain, but its thick hull was not pierced. A crew member was killed after being thrown against an auxiliary pump and several crew members were injured.

Table 1.3. *Some nuclear accidents (Dull Sword) on naval nuclear propulsion reactors (source: adapted from Villain [VIL 14])*

1.3. Acknowledged, unknown and secret accidents

Nénot and Gourmelon [NEN 07] proposed a different classification of accidents in three classes: acknowledged accidents, unknown accidents and secret accidents.

Most accidents are acknowledged immediately and good knowledge of the circumstances, the type of irradiation and its intensity, in addition to identification of victims and access to suitable logistics, allows the impact on health to be considerably reduced. However, two accidents have provoked management difficulties from a medical point of view. These are Yanango in Peru (February 20, 1999) when a source of iridium 192 lost on a construction site remained in contact for more than 10 hours with a worker who subsequently died, and Tokaï-Mura in Japan (September 30, 1999) when three workers in a fuel manufacturing factory received mixed gamma and neutron irradiation. Sometimes an accident is assimilated to a catastrophe, and in this category, typical accidents are, for example, Chernobyl where there was a significant number of victims, or Fukushima where the environment is widely contaminated in a long-lasting manner [NEN 07].

The second category includes unknown accidents or those acknowledged at a later date. Nénot and Gourmelon [NEN 07] stated that the number of accidents whose radiological origin is identified by chance seems to increase regularly over time. In addition, they ask questions about the number of serious accidents whose radiological cause remains known and whose consequences are attributed to more classical causes. This type of accident is very frequent and the origin is firstly industrial, then medical and military. These are mainly accidents related to linear accelerators or sealed radioactive sources (cobalt 60, cesium 137, iridium 192, etc.) lost in the environment and collected by individuals who know nothing of their nature, and whose dangers only become apparent later on. In fixed installations, accidents occur when elementary safety rules are not applied, when personnel are not properly qualified, and when regulations and instructions are not followed. Since none of the five human senses is capable of detecting ionizing radiation, humans in contact with or in close proximity to this source will receive high doses of radiation. It has been observed that their afflictions that occur within a few hours or a few days will cause more or less permanent effects, or in extreme cases, death. In this category, the number of victims becomes significant if the accident is caused by medical over-irradiation and the malfunction is discovered late or when the time period of loss of the radioactive sources is long. Three such accidents with very serious consequences for victims have also had serious repercussions on the environment. They are caused by the same factor and come from the abandonment of a source of radiotherapy followed by the dissemination of its radioactive components. These three accidents took place in Juarez, Mexico (December 6, 1983), in Goiânia, Brazil (September 10–13, 1987) and in Bangkok, Thailand (January 25, 2000). A fourth accident, which occurred in a hospital in San José in Costa Rica (August 26, 1996 to September 27, 1996), injured more than 100 sick people, and was a national tragedy. Radiotherapy overdose cases in French hospitals must also be added in this category.

The third category includes secret accidents that are almost solely of military origin and took place during the Cold War. The end of this episode by no means guarantees that the large nuclear powers have lifted the veil to reveal all the accidents that have been part of the weapons race. The number of nuclear military accidents is very high. Among the main military accidents, we point out the American or Soviet nuclear submarines highlighted above. Similarly, there were major implications of the Chelyabinsk accident in the Ural Mountains in the USSR (September 29, 1957) where in the months following the accident, 7,500 inhabitants of 20 villages had to be permanently evacuated. Two examples of massive contamination of extensive land areas are provided by nuclear weapons falling from American aviation accidents: the first one in Spain at Palomares (January 17, 1966), and the second one in Thule, Greenland (January 21, 1968).

1.4. Origin and frequency of accidents

1.4.1. *Origin of accidents*

The hindsight provided by the past 50 years demonstrates that the industrial sector is responsible for 51% of the total number of serious radiological accidents, followed by research responsible for 20%, the civilian nuclear sector for 13%, medicine for 11% and military activities for 5% [CHA 01a].

1.4.2. *Frequency of accidents*

Nénot and Gourmelon [NEN 07] concluded that the frequency of known serious accidents does not diminish over time; instead, it displays an increasing trend. The accidents affect all countries and appear to bear no relation to the degree of economic development. Many serious accidents remain without doubt entirely unreported, since a significant proportion was discovered by chance and this proportion could even increase over time.

For the 560 events identified in the ACCIRAD project, 70 caused at least one death. These radiological events have led to a total number of deaths due to acute radiation sickness of about 180 people [CHA 01a].