IAEA-TECDOC-867

Significant incidents in nuclear fuel cycle facilities

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The originating Section of this publication in the IAEA was:

Nuclear Fuel Cycle and Materials Section
International Atomic Energy Agency
Wagramerstrasse 5
P.O. Box 100
A-1400 Vienna, Austria

SIGNIFICANT INCIDENTS IN NUCLEAR FUEL CYCLE FACILITIES
IAEA, VIENNA, 1996
IAEA-TECDOC-867
ISSN 1011–4289

Printed by the IAEA in Austria
March 1996

FOREWORD

Two significant accidents have occurred in the history of nuclear power, namely, at Three Mile Island and Chernobyl. In order to prevent such accidents, causes were investigated and actions were taken. For example, reporting systems were established to accumulate and disseminate information on accidents such as INES (International Nuclear Event Scale) and IRS (Incident Reporting System). Operators of nuclear power plants also established an information system to share incident information. The purpose of INES is to facilitate prompt communication between the nuclear community, the media and the public. The purpose of IRS is to analyse causes of significant incidents. Those systems serve to promote safety culture in nuclear power plants.

In contrast to nuclear power plants, events in nuclear fuel cycle facilities are not well documented. The INES database covers all the nuclear fuel cycle facilities; however, it was developed in the early 1990s and does not contain information on events prior to that. The purpose of the present report is to collect significant events and analyse them in order to give a safety related overview of nuclear fuel cycle facilities.

Significant incidents were selected using the following criteria:

- release of radioactive material or exposure to radiation;
- degradation of items important to safety; and
- deficiencies in design, quality assurance, etc.

which include criticality incidents, fire, explosion, radioactive release and contamination. This report includes an explanation, where possible, of root causes, lessons learned and action taken.

Appreciation is expressed to all those who participated in the preparation of this report and also to the Member States that sent experts to assist the IAEA in this work.

EDITORIAL NOTE

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1. INTRODUCTION

Since the inception of the nuclear industry, the importance of nuclear safety has been clearly recognized and precautions have been taken to prevent severe accidents. Nuclear fuel cycle facilities have the following characteristics when compared with nuclear power plants:

- the temperature is much lower,
- the pressure is much lower,
- the potential energy in the process systems is much lower,

and therefore deviations from normal operations are less likely to develop rapidly into dangerous situations. On the other hand, the treatment in nuclear fuel cycle facilities involves fissile materials in a soluble form, inflammable solvents and toxic materials. Hence, criticality, explosion, fire and release of radioactive materials may occur. If incidents take place in shielded equipment, damage is restricted to a limited area. However if radioactive materials are blown out by explosion, they would cause wide contamination and serious damage to the public and the environment.

The objective of this report is to compile significant incidents in order to give a safety related overview of nuclear fuel cycle facilities. Some reports have already been published on incidents in nuclear fuel cycle facilities. Reference [1] reviewed 285 incidents up to the year 1969. It focused on the consequences of the incidents, rather than on the causes, and included measures taken and recommendations made. Japan is now collecting data on incidents in nuclear fuel cycle facilities and compiling these data into a database. It now stores 884 incidents. From those incidents Ref. [2] selected 43 significant incidents and assessed them from the viewpoint of whether similar incidents could occur in Japan. Reference [3] analysed the safety of the nuclear fuel cycle and described 23 major incidents.

The present report reviews 58 significant incidents. It includes the incidents described in Refs [2] and [3] as well as other incidents which occurred recently. The significant incidents are those of:

- criticality,
- explosion,
- fire,
- release of radioactive materials or contamination,

which caused serious damage to workers, property and the public. It also includes some potential incidents which were properly protected and did not cause any damage. But such incidents could also provide valuable lessons. The report includes incidents at military facilities as well, although they would not be likely to occur at modern commercial plants.

For each incident, the report describes an outline of the incident, important consequences, and where possible, root causes, lessons learned and action taken. Some incidents do not include these descriptions, because they occurred in the early history of the nuclear development or in military facilities, and therefore detailed information was limited. Some incidents which occurred recently also lack those descriptions. If further information is obtained, it will be incorporated into the report in the future.

The report does not rate the incidents by the INES scale, because it is difficult to rate past events and the INES scale is intended to indicate the significance of the incidents to the public and not to compare the significance of the incidents and analyse them. But if rated, the report includes the rating.

Table I shows the historical trend of these incidents. It shows that severe incidents such as criticality occurred between 1958 and 1964. It has been suggested that this represents a time when fissile material processing was being scaled up significantly, but without commensurate attention to nuclear criticality safety. Other kinds of incidents still occurred in the 1980s and 1990s.

Table II shows incidents in different kinds of facilities. It shows that most incidents were reported at reprocessing and chemical processing plants. Reprocessing plants deal with solutions of fissile materials and pyrophoric chemicals. Modern reprocessing plants are designed taking into account these incidents, therefore it is unlikely that the same kinds of incidents will occur at those plants in the future.

Table III shows major personnel damage resulting from the incidents. Criticality incidents caused radiation to workers, but no equipment damage, and negligible loss of fissile material. The general public was not in danger from any of the criticality incidents. Some incidents indicated that the prompt response to criticality accident alarm systems resulted in saving lives of people more than a few meters from the reaction vessel. When criticality occurred in automatic handling equipment and heavily shielded facilities, personnel were protected from direct radiation.

One death in a release incident resulted from UF_6 release. UF_6 reacts with moisture in the air to form uranyl fluoride and highly reactive hydrofluoric acid (HF). This reaction proceeds rapidly and liberates heat accompanied by a volume expansion. The worker died due to inhalation of HF.

Table IV shows the causes of the incidents. Many incidents were the result of a combination of causes; deficiencies in design or equipment, deficiencies in management or procedures, and operator errors. Contributions to the categorized causes of the incidents are:

Deficiencies of design or equipments (A1-A4, B1)	48 (30)%
Deficiencies of management or procedures (B7, B8)	12 (10)%
Operator or worker errors (B2-B6, B9, B10)	41 (44)%.

The numbers in the brackets are taken from Ref. [4] which analysed 8 criticality incidents using event trees. It should be noted that some incidents occurred in off-normal operating conditions (inventory, startup, or restart after plant maintenance). Written procedures did not cover unusual, non-routine operations. When true operator or worker errors (B3 and B9) are counted, they represent 15%. Therefore the occurrence of incidents would be reduced by preparing comprehensive procedures, improving management, training the work force thoroughly, and learning from past experiences.

TABLE I. HISTORICAL TREND OF INCIDENTS

	- 1950s	1960s	1970s	1980s	1990s	Total
Criticality Potential criticality	3	3	2	 1	 2	8 3
Explosion Potential explosion	3		2		3 1	8 1
Fire Fire danger	1	1		2	2 1	6 1
Release & contamination	2		12	9	6	29
Others			1	1		2
Total	9	4	17	13	15	58

TABLE II. INCIDENTS AND FACILITIES

	Reprocessing	Enrichment	Conversion	Fuel fabrication	Others	Total
Criticality Potential criticality	8 1			 2		8 3
Explosion Potential explosion	5 1			1	2	8 1
Fire Fire danger	5			1	 1	6 1
Release & contamination	16	3	5	4	1	29
Others	1	1				2
Total	37	4	5	8	4	58

TABLE III. MAJOR PERSONNEL DAMAGE

	Death	Injury	Exposure, contamination
Criticality	2 deaths [5, 11]		5 persons severely exposed [4] 12 persons significantly exposed {3[4], 2[5], 2[6], 3[9], 2[11]}
Explosion		1 person severely injured [49]	10 000 people evacuated [56]
Release	1 death [43]		

TABLE IV. CAUSES

Physical causes	A1. Mechanical failures, troubles (corrosion, vibration, pump trouble, etc.)	15
	A2. Electrical failures (short circuit, overvoltage, etc.)	1
	A3. Chemical failures (chemical reaction, fire, etc.)	5
	A4. Instrumentation failures (loss of signal, failure of indicators, etc.)	3
Human errors	B1. Deficiencies of design or safety analysis	9
	B2. Manufacturing, construction or installation errors or deficiencies	2
	B3. Operator errors	5
	B4. Carelessness	4
	B5. Misunderstanding, wrong decision	5
	B6. Maintenance or inspection errors	4
	B7. Management deficiencies	5
	B8. Deficiency of manuals or procedures	3
	B9. Violation of procedures	5
	B10. Communication problem	3

REFERENCES

[1] ONISHI, T., et al., Nuclear Accidents in Nuclear Installations, JAERI-4052 (1970).

[2] KANAMORI, M., SATO, H., "Incidents assessment of fuel cycle facilities", paper presented at IAEA Consultants meeting, January 1995.

[3] OECD/NEA, The Safety of the Nuclear Fuel Cycle (1993).

[4] TACHIMORI, S., SAKURAI, S., Review of the Criticality Accidents in Nuclear Fuel Cycle Facilities, JAERI-M 84-155 (1984).

Reprocessing plants

	Date	Facilities	Incident
1)	1953.01.12	Savannah River Plant South Carolina, USA	Chemical explosion at a TNX evaporator. While concentrating a uranium nitrate solution, a violent reaction took place with sufficient pressure to destroy an evaporator and cause extensive damage to the building. Two minor injuries to personnel. Causes: B1, B8, A4
2)	1955.09.- 1962.06.	Z-9 trench Hanford, Richland Washington, USA	Soil contamination caused by low-level radioactive waste liquid. Causes: B7
3)	1957.09.11	Rocky Flats, Golden, Colorado, USA	Metallic plutonium fire in a dry box. Causes: -
4)	1958.06.16	Y-12 plant, Oak Ridge, Tennessee, USA	Criticality. Criticality occurred when uranium solution drained into a drum of unfavorable geometry and was followed by fresh leak-test water. Five persons were exposed severely and three others significantly. Causes: B5, B10, B1, B6
5)	1958.12.30	Los Alamos Scientific Laboratory New Mexico, USA	Criticality. Residual plutonium and acid solutions from four vessels were transferred to a single tank. A criticality excursion occurred when the stirrer in the tank was started. One operator died 36 hours later and two others were significantly exposed. Causes: B3, B2
6)	1959.10.16	Idaho Chemical Processing Plant Idaho Fall, Idaho, USA	Criticality. The excursion was a result of inadvertently siphoning highly enriched uranium solution from a bank of geometrically sub-critical cylinders to a large waste tank. Causes: A4, B1

Reprocessing plants

	Date	Facilities	Incident
7)	1959.11.20	Thorex Pilot Plant Oak Ridge, Tennessee, USA	Explosion and plutonium release. A chemical explosion occurred in an evaporator containing plutonium within a shielded cell. A small residue of plutonium was blown out. Causes: B9
8)	1961.01.25	Idaho Chemical Processing Plant Idaho Fall, Idaho, USA	Criticality. The excursion occurred when a large air bubble forced enriched uranium solution from an evaporator into a large diameter vapor-disengagement cylinder. Causes: B1, B5, A1
9)	1962.04.7	Recuplex Plant, Hanford, Richland, Washington, USA	Criticality. Concentrated plutonium solution overflowed from a geometrically sub-critical tank and was sucked into a 45.7 cm diameter vessel. Causes: B6, B4
10)	1963.11.6	Plutonium processing facility, Hanford, Richland, Washington, USA	Exothermic reactions and fire. A fire and the venting of an overpressured plutonium anion-exchange contactor occurred due to chemical degradation and oxidation of the plutonium-loaded anion exchange resin. Causes: A3, B4
11)	1964.07.24	Wood River Junction Plant, Rhode Island, USA	Criticality. Concentrated enriched uranium was inadvertently poured into a 45.7 cm diameter tank. The first excursion resulted in a lethal exposure and the second caused significant radiation doses for two workers. Causes: B10, B5
12)	1970.08.24	Windscale, United Kingdom	Criticality. Organic solvent from unknown source entered a transfer tank where it floated on top of the aqueous solution. Causes: B1
13)	1973.04.-06.	Hanford, USA	Underground release of waste liquid. 115 kgal of liquid waste was lost from the tank due to corrosion. The waste contained 40 kCi of Cs-137, 14 kCi of Sr-90 and others. Causes: A1, B3

Reprocessing plants

	Date	Facilities	Incident
14)	1973.09.26	Windscale, United Kingdom	Release of airborne radioactivity. Exothermic reactions between high-temperature insoluble fission products and the acidified butex. 35 workers were contaminated from ruthenium-106. Causes: A3
15)	1975.02.12	Savannah River, USA	Explosion and fire. Tributyl-phosphate uranyl nitrate was thermally decomposed in a denitrator. The reaction ejected much of the denitrator contents and the gases ignited and caused an explosion and fire. Minor injury to two workers. Causes: A3
16)	1976.08.30	Hanford, USA	Explosion. Chemical reactions of nitric acid with cation ion-exchange resin. A worker was injured and other nine persons were exposed. Causes: A3
17)	1976.10.10	Windscale, United Kingdom	Onshore detection of tritium. While excavation work was in progress at the site, a level of radioactivity that made it necessary to limit access was detected due to the leakage of liquid waste from a silo. Causes: B7
18)	1977.09.2	Pond water treat-ment plant at La Hague, France	Overflow of high-level solution from a tank and contamination of the soil. Causes: A1
19)	1977.11.26	Plutonium condition-ing & storage plant at La Hague, France	Bellows became disconnected from the opening ring. A leakage of one box caused an air contamination in the room. Causes: A1
20)	1978.02.3	HAO building at La Hague, France	High contamination of the off-gas circuit at the High Activity Oxide building. Causes: B1, B10
21)	1978.05.10	HAO building at La Hague, France	A leakage from lead-shielded valves on the liquid line. Causes: B6
22)	1978.10.17	Idaho Chemical Processing Plant Idaho Fall, Idaho, USA	Criticality. The criticality occurred in the base of the scrub column where uranium concentration was built up by a gradual decline in the concentration of aluminum nitrate solution in the aqueous stream. No injuries, no release and no damage to equipment. Causes: A4

Reprocessing plants

	Date	Facilities	Incident
23)	1979.02.9	Tokai reprocessing plant, Japan	Leakage of waste liquid. A very small of radioactivity was detected in the water in the underground seepage receiving tank. Causes: A1
24)	1979.03.15	Sellafield, United Kingdom	Radioactive liquor filled a sump vessel and overflowed into a metal clad area and finally leaked into the ground. Causes: A1
25)	1980.04.15	La Hague, France	A fire caused by a short circuit destroyed a site power distribution board control room. Causes: -
26)	1981.01.6	La Hague, France	Fire. A fire occurred at the graphite claddings repository. Causes: A3
27)	1981.02.4	Tokai reprocessing plant, Japan	Inadvertent transfer of plutonium. The plutonium-contained solution was inadvertently transferred to the acid recovery line from the concentrate receiving tank. Causes: B4
28)	1983.11.10	Sellafield, United Kingdom	Radioactive aqueous liquor was released to the sea. Access to the beaches was temporarily closed. Causes: B4
29)	1986.01.23	Sellafield, United Kingdom	Release of 440 kg uranium into the Irish Sea. Causes: A1, B5
30)	1986.02.5	Sellafield, United Kingdom	Plutonium (in mist) release. Causes: B6
31)	1986.09.26	Hanford, USA	Potential criticality. Causes: B9

Reprocessing plants

	Date	Facilities	Incident
32)	1987.01.19	Sellafield, United Kingdom	12 employees were contaminated by a small plutonium leak. Causes: -
33)	1990	Hanford, USA	Possible explosion. Causes: -
34)	1992.09.8	Sellafield, United Kingdom	Plutonium nitrate spill into the steel clad. Causes: A1
35)	1993.04.6	Tomsk-7, Russia	Explosion. An exothermic chemical reaction occurred between an organic compounds and concentrated nitric acid in the stainless steel cylindrical tank where adjustment operations were carried out. Causes: A1, B8, B9, B1
36)	1993.12.27	Tokai Reprocessing plant, Japan	4 workers were exposed to plutonium. Causes: B9
37)	1994.08.31	RT-1 Reprocessing plant, Russia	Fire and damage to spent fuel elements. Causes: A2

Enrichment plants

	Date	Facilities	Incident
38)	1973	Portsmouth Gaseous Diffusion Plant, USA	Accumulation of solid uranium. Causes: A1
39)	1975.09.17	Oak Ridge Gaseous Diffusion Plant, USA	Release of uranium hexafluoride. Causes: A1
40)	1978.03.7	Portsmouth Gaseous Diffusion Plant, USA	Release of uranium hexafluoride. Causes: A1
41)	1981.05.27	Oak Ridge Gaseous Diffusion Plant, USA	Release of solid uranium compound Causes: B1

	Date	Facilities	Incident
42)	1977.07.1	Pierrelatte, France	Accidental release of UF_6. A valve of a cylinder was broken. 7.1 MT of UF_6 was released into the atmosphere, causing chemical damage to road surface and automobile chassis. Causes: A1
43)	1986.01.4	Sequoyah Fuels Corporation, Gore, Oklahoma, USA	Accidental release of UF_6. A UF_6 cylinder ruptured during being heated in a steam chest. One worker died due to inhalation of hydrogen fluoride fumes. Causes: B7, B5, B9, B8
44)	1987.04.12	Pierrelatte, France	Around 0.7 kg of U escaped into the atmosphere due to fault in a cylinder valve. 7 workers were slightly injured. Causes: B3
45)	1990.08.22	Sequoyah Fuels, USA	Uranium-contaminated water seepage into an excavation. Causes: -
46)	1992.11.17	Sequoyah Fuels, USA	Release of nitrogen dioxide gas. Causes: B3

Fuel fabrication plants

	Date	Facilities	Incident
7)	1987.02.27	Nukem, Hanau, Germany	14 workers were contaminated from plutonium. Causes: -
48)	1989.01.11	Asea Atom, Vasteras, Sweden	Release of uranium powder from a conversion furnace to a scrubber system. Causes: B2
49)	1990.12.12	Siemens uranium fuel element fabrication, Hanau, Germany	Explosion of an off-gas scrubber in the scrap recovery due to a rapid thermal decomposition of ammonium nitrate. Causes: A1
50)	1991.06.18	Siemens MOX plant, Hanau, Germany	3 workers inhaled plutonium. Causes: A1
51)	1991.05.29	GE fuel & component manufacturing facility, Wilmington, North Carolina, USA	Potential criticality accident. Higher than expected amounts of uranium was improperly transferred into an unfavorable geometry waste tank. Causes: B7
52)	1992.11.23	FBFC International MOX fuel fabrication Dessel, Belgium	Contamination around a machine and to workers. When pulling rods into the assembly, one fuel rod was broken and grinding dust was blown up. Causes: B1
53)	1994.06.29	B & W Naval fuel plant, Lynchburg, Virginia, USA	Potential criticality accident. U-235 exceeding allowable limits was used in a scrap recovery line. Causes: B3
54)	1994.07.7	B & W Naval fuel plant, Lynchburg, Virginia, USA	Fire. A fire started in a metallurgical lab. Pyrophoric zirconium chips and enriched uranium caught fire, with radioactive dust falling on six workers. Causes: -

Others (waste storage facility, spent fuel storage, isotope production plant)

	Date	Facilities	Incident
55)	1944 - 1947	Hanford Nuclear Reservation Washington, USA	High-dose irradiation by iodine release. 400 kCi of iodine had been released in 1940s. Causes: B7
56)	1957.09.29	Southern Urals, Russia	Explosion. A tank filled with a highly active solution exploded due to accidental interruption of the forced cooling for a prolonged period. Causes: A1
57)	1990 - 1991	Dry storage of Magnox fuel Wylfa, North Wales, United Kingdom	Fire danger. Only a fraction of Magnox fuel elements were found to corrode. If water react with the metallic fuel, it could be ignited. Causes: -
58)	1993.07.17	Pu-238 production facility, Mayak, Russia	Thermal-chemical explosion at an ion-exchange column. Due to the partial loss of solution from the column, selfheating of the resin caused thermal decomposition of the resin and the rupture of the column. Causes: B8

3. DETAILED DESCRIPTION

REPROCESSING PLANTS

1. Chemical explosion at a TNX evaporator

Type of facility Reprocessing (for research use)

Name of facility Savannah River Plant

Location South Carolina, USA

Incident date 1953 January 12

1.1. Description of the incident

At the time of the incident, a special series of evaporations was in progress to remove about 50 per cent of the nitric acid from 6,840 litres of uranium nitrate (UN) solution. Equipment size dictated that deacidification be carried out in several batches of approximately 1,900 litres and three batches had been successfully processed. The fourth and final charge consisted of the 265 litres heel of the original solution plus 600 litres of previously evaporated material which had been diluted with water. The additional 600 litres were required to make a minimum evaporator charge.

Because the liquid temperature recorder was broken and since the required degree of concentration was beyond the range of the specific gravity recorder, the evaporation was being carried out for a specified length of time based on experience. Five minutes prior to the scheduled completion of this fourth evaporation, a violent reaction took place with sufficient pressure to destroy the evaporator and cause extensive damage to the building.

1.2. Important consequences

Destruction of the evaporator and damage to the building. Two minor injuries to personnel.

1.3. Root causes

The incident appeared to be the result of the following series of events.

- presence of TBP (about 36 kg) in the aqueous uranium nitrate solution;
- concentration of the solution to greater than 78% UN/total aqueous at temperature greater than 130°C;
- build-up of a 3.6 to 7 bars back pressure due to partially plugged bubble trays.

1.4. Lessons learned

1.5. Action taken

- The presence of TBP in quantities higher than dissolvable in water in the evaporator was prohibited.
- The liquid temperature in the evaporator should be maintained below 125°C. In a later reprocessing plant project in the USA, the use of saturated steam of 135°C was recommended.
- Heating should be slower.
- Concentrating equipment should be designed with a large vent or other pressure relieving devices such as rupture disk.

- Concentrating equipment should be designed with an accumulator least necessary to survive a sharp pressure rise.

Recommendations bearing on the radiation hazards were as follows:

1. Health Physics should be called immediately if radioactive contamination is spread outside a regulated area.
2. If noxious fumes or radioactive contamination are a possible result of an emergency in an area, a depot of clothing, gas masks, and other supplies should be established at a safe distance.
3. Areas covered by 2, above, should be so designated to the Fire and Patrol Departments and these groups should not approach closer than a predesignated distance without the express permission of the operating supervision.

1.6. Sources

(1) "A summary of accidents and incidents involving radiation in atomic energy activities, June 1945 through December 1955", US Atomic Energy Commission, TID-5360, 1956.
(2) "Nuclear Accidents in Nuclear Installations", Onishi, T. et al., JAERI-4052, 1970.

2. Soil contamination

Type of facility	Reprocessing (for military use)
Name of facility	Z-9 trench, Hanford
Location	Richland, Washington, USA
Incident date	1955 September - 1962 June

2.1. Description of the incident

The Plutonium Finishing Plant (PFP) was constructed to receive plutonium nitrate solution from a separation plant, purify the plutonium and convert plutonium to metal. Liquid wastes containing small quantities of plutonium from the PFP have been discharged to subsurface disposal facilities (enclosed trenches) since around 1950 when the facility was commissioned. The liquid waste flows from a pipe onto the soil floor of the enclosed trench. While a portion of water percolates through the soil, the plutonium in the waste is sorbed (retained) by the soil and held within a few feet vertically of the point of release. Careful surveillance using test wells has allowed this practice to be followed safely for 22 years.

One specific enclosed trench (Z-9) was constructed in 1955 and safely received liquid waste from PFP between July 1955 and June 1962. Monitoring indicates that the Z-9 enclosed trench contains about 100 kilograms of plutonium in the upper twelve inches of its soil floor. Due to the quantity of plutonium contained in the soil of Z-9, it is possible to postulate conditions which could lead to a nuclear chain reaction. These conditions would be (1) the rearrangement of the contaminated soil, (2) flooding of the enclosed trench following a record snowfall and (3) the failure to implement planned emergency actions (pumping of flood waters from adjacent terrain and addition of neutron absorbing material to the enclosed trench).

Although the probability of all of these occurrences happening in sequence is extremely remote and, even if a chain reaction did occur, the radiation would be primarily confined to the enclosed trench with no off-site effects, it is prudent to take special precautions for Z-9.

2.2. Important consequences

As a result of investigations conducted from 1976 through 1977, the US National Academy of Science concluded that radioactive waste at Hanford was adequately contained and that there was no threat of radioactivity to the people working at Hanford and the public living in the neighborhood. While no damage by soil contamination was reported, a "clean-up" program is under way.

2.3. Root causes

Since percolating through the soil was an established way of low-level radioactive waste liquid disposal, soil contamination was unavoidable.

2.4. Lessons learned

2.5. Action taken

An agreement was concluded in May 1989 between the Department of Energy (DOE) and the State of Washington concerning the "clean-up" program that covers the entire site at Hanford. DOE estimated the total cost of the program at US $57 billion.

The "clean-up" program includes the commissioning of a high-level radioactive liquid waste solidifying plant, closure of single-shell tank and disposal of stored liquid, decontamination of contaminated facilities, treatment of radioactive and toxic waste for disposal, discontinuance of the in-soil dumping of contaminated waste liquid, dismantling of 8 plutonium production reactors and enhancement of the safety of nuclear reactors.

2.6. Sources

(1) "Contaminated Soil Removal Facility" USAEC, April 1972, WASH-1520.
(2) "Radioactive Waste Management at the Hanford Reservation", National Academy of Science, Nuclear Safety, July-August, 1979.
(3) "30 years Hanford Cleanup Agreement approved by DOE, EPA, Washington State", Nuclear Waste News, March 2, 1989.
(4) "Daunting costs for clean-up at Hanford", Nature, 25 May 1989.

3. Metallic plutonium fire

Type of facility	Plutonium processing
Name of facility	Rocky Flats, Golden
Location	Colorado, USA
Incident date	1957 September 11

3.1. Description of the incident

At 10:10 pm, watchmen discovered a fire which appeared to involve plutonium within a dry box, polyethylene parts of the box itself, and rubber gloves (normally used to prevent skin contact during handling of plutonium). Knowing that plutonium was handled and stored in the area, and might be involved in the fire, fire fighting was delayed until personnel could put on protective clothing and evaluate the hazards involved. Portable carbon dioxide extinguishers, ranging up to 100-pound units, were emptied on the fire without effect.

Although there was considerable uncertainty regarding the criticality hazards involved if water should be applied, water was finally applied to the fire in the form of a spray, and this proved effective for control of the fire, with no nuclear event. Spontaneous ignition of plutonium chips in a container stored in the dry box was determined to be the origin of the fire.

About 13 hours after its inception, the last remnants of the blaze were extinguished. Virtually all of the units in the large filter bank were destroyed.

3.2. Important consequences

The fire had two serious consequences:

- It allowed the escape and dissemination of considerable amounts of plutonium oxide throughout the immediate area of the plant;

- It burned through the combustible CWS filter at the dry box, permitting flames and some unburned combustible gases to pass through primary exhaust air ductwork to the large main bank of filters which were of a combustible type.

No employees were overexposed to radiation. Fire damage and contamination cleanup losses were considerable.

3.3. Root causes

Material in the dry box was not properly managed.

3.4. Lessons learned

3.5. Action taken

3.6. Source

"A Summary of industrial accidents in USAEC facilities, TID-5360" Suppl.2., US Atomic Energy Commission.

4. Criticality

Type of facility Reprocessing

Name of facility Y-12 plant, Oak Ridge

Location Tennessee, USA

Incident date 1958 June 16

4.1. Description of the incident

The facility has responsibility for fabricating components from highly enriched uranium. The accident occurred in an area of the plant where highly enriched uranium was being recovered from scrap. The recovery solution was kept in storage vessels that were designed to be of favorable geometry.

During a material inventory, a bank of storage vessels was emptied, disassembled, and cleaned. They were to be leak-tested with water following reassembly and the water was to be drained into a 208 litre drum. However, before the leak testing, uranium solution accumulated in the manifold under the tanks through a leaking valve that was intended to isolate the tanks from the upstream process operations. The solution was subcritical in the tanks and manifold, but not so when it drained into the unfavorable geometry of the drum and was followed by fresh leak-test water.

Initial criticality occurred with about 2.1 kg of uranium-235 in 56 litres of solution. A succession of pulses produced a total of 1.3×10^{18} fissions over a period of about 2.8 min. before the continuing flow of leak-test water diluted the solution to a subcritical level. An initial "blue flash" was observed and there was no evidence that solution splashed out of the open container.

4.2. Important consequences

Five individuals received severe radiation exposure and three others exposure. However, the exposures were limited by prompt evacuation.

4.3. Root causes

4.4. Lessons learned

4.5. Action taken

Transfer lines that could contain fissile solution were disconnected rather than merely being valved-off. Only geometrically favorable containers were permitted in the facility, thereby treating all solutions and other material forms as if they contained highly enriched uranium. Administrative responses included requirements for written operating procedures, a comprehensive accident analysis for and criticality safety review of plant operations, and designation of emergency response teams.

4.6. Sources

(1) "A review of criticality accidents" Stratton, W.E., revised by Smith D.R., DOE/NCT-04, 1989.
(2) "Criticality Accident at the Oak Ridge Y-12 Plant", Nuclear Safety, Vol.1, No.2, 1959.
(3) "Nuclear Criticality Safety", Knief, R.A., 1985.

5. Criticality

Type of facility Reprocessing

Name of facility Los Alamos Scientific Laboratory

Location New Mexico, USA

Incident date 1958 December 30

5.1. Description of the incident

The facility was charged with recovering plutonium from various laboratory operations. The accident occurred in an area of the plant where residual plutonium (typically about 0.1 gram/litre) and americium were recovered from dilute raffinate. Because the normal plutonium inventory was only 0.1 kg, solvent extraction between aqueous and organic phases was conducted in large closed tanks. During a material inventory, it was intended that each tank be emptied and cleaned individually. Instead, residues and acid solutions from four vessels were transferred via interconnecting lines to a single 850-litre, 96.5 cm diameter tank. An excursion occurred when a stirrer in the tank was started.

A 20.3 cm thick, 160 litre organic layer floating on a dilute-aqueous solution contained 3.27 kg plutonium. It is presumed that the source of this plutonium was solids that had accumulated gradually in the tanks during the 7.5 years of operations and that the organic layer resulted from separation of the emulsion phases by added acids. The initial effect of the stirrer was to thicken the axial part of the organic layer sufficiently for super-criticality. Continued rapid stirring mixed the two phases, diluting the plutonium to a sub-critical concentration.

5.2. Important consequences

The excursion of 1.5×10^{17} fissions produced a flash that was seen from an adjoining room and activated a radiation alarm 53 m away. The operator, who was looking into the tank through a sight glass, received an exposure of 120(±60) Gy and died 36 hours later. Two men who went to aid him received doses of 1.3 Gy and 0.35 Gy. There was neither damage to equipment nor contamination, although a shock displaced the tank support 10 mm.

5.3. Root causes

The accident was directly attributable to errors on the part of the deceased operator in handling several batches of material together instead of one at a time.

5.4. Lessons learned

The procedures for this process were such that safety of operation depended substantially on the ability and judgement of individual operators but the incident might have been prevented had the organizational arrangements required closer supervision to ensure that normal procedures were followed.

5.5. Action taken

Written procedures and nuclear safety training were improved. Unnecessary solution transfer lines were blocked. Auxiliary vessels of large volume were "poisoned" with borosilicate glass raschig rings. Portable survey instruments were employed to detect the buildup of plutonium in various portions of the process. Radiation alarms were installed to warn of possible criticality and signal evacuation.

5.6. Sources

(1) "A review of criticality accidents", Stratton, W.E., revised by Smith D.R., DOE/NCT-04, 1989.
(2) "Nuclear Criticality Safety", Knief, R.A., 1985.
(3) "Los Alamos Criticality Accident", Nuclear Safety, Vol.1, No.1, 1959.

6. Criticality

Type of facility Reprocessing

Name of facility Idaho Chemical Processing Plant

Location Idaho Falls, Idaho, USA

Incident date 1959 October 16

6.1. Description of the incident

The facility was designed to recover uranium from highly enriched irradiated fuel elements. The excursion was a result of inadvertently siphoning highly enriched uranium solution from a bank of geometrically favorable storage cylinders to a large waste tank. On the day of the accident, some of the storage cylinders were nearly filled and thus required sampling before their contents could be removed. Since the pump normally used for recirculation mixing was inoperable, the air sparge line in each cylinder was used instead. Excessively vigorous sparging, however, caused solution to flow over the siphon break directly to the waste tank.

Over a period of about 15 min, approximately 200 litres of solution containing 34 kg of highly enriched uranium-235 (93% U-235 in the form of uranyl nitrate concentrated to about 170 g U-235 per litre) were transferred to the 19,000 litre waste tank and mixed with the 600 litre of water that was already there. Criticality in this tank led to a total of 4×10^{19} fissions over a period of about 20 minutes. It is postulated that an initial spike of about 10^{17} fissions was followed by smaller pulses, then by more or less stable boiling. After nearly 400 litre of water boiled off to another tank, the system became subcritical.

6.2. Important consequences

Since the facility had heavy shielding for handling irradiated fuel, personnel were well protected from direct radiation exposure. Fission products vented into a working area along the evacuation route did result in some beta exposure to two workers (0.5 and 0.32 Gy). There was no equipment damage.

6.3. Causes

No specific instances of maloperation were found. However, significant errors of omission were:

- the lack of critical analysis of the operating equipment for possible sources of trouble (e.g., air lines without flow restricting orifices, valving of lines from critically safe to critically unsafe vessels, and pressure gauge installation unknown to operators using the equipment);
- the lack of careful attention to initial operations in seldom-used equipment

6.4. Lessons learned

The incident disclosed the need for improved evacuation procedures and demonstrated the value of radiation alarms in areas that might be affected by an excursion occurring elsewhere.

6.5. Action taken

Equipment and procedures were modified to establish several lines of defense against inadvertent transfer of fissile materials.

6.6. Sources

(1) "A review of criticality accidents", Stratton, W.E., revised by Smith, D.R., DOE/NCT-04, 1989.
(2) "Nuclear Criticality Safety", Knief, R.A., 1985.
(3) "Idaho Chemical Processing Plant Criticality Incident", Nuclear Safety, Vol.1, No.3, 1960.
(4) "A summary of industrial accidents in USAEC facilities, TID-5360" Suppl.3, US Atomic Energy Commission, 1961.

7. Explosion and plutonium release

Type of facility Radiochemical Processing Pilot Plant

Name of facility Thorex Pilot Plant

Location Oak Ridge, Tennessee, USA

Incident date 1959 November 20

7.1. Description of the incident

On November 20, 1959, a chemical explosion occurred in an evaporator containing plutonium within a shielded cell of Oak Ridge National Laboratory Thorex Pilot Plant. A small residue of plutonium was released throughout the Pilot Plant, and nearby streets and exterior building walls were contaminated

The cell in which the explosion occurred is one of four cells containing equipment for the solvent extraction processing of highly irradiated nuclear fuels. The evaporator, contained in a subcell that is walled off by concrete blocks within cell, consisted of a steam stripper, vapor separator, a natural-convection evaporator loop, and connecting piping.

The plant was on shutdown status at the time of the accident, except for the decontamination operations in progress. Two days prior to the accident, 200 litres of the decontaminant were added to the condensate tank and jetted to the steam stripper, which drains into the evaporator. After boiling for two hours (in the evaporator), the decontaminant was run out through the remotely operated normal drain, which was somewhat above the lowest point of the system, leaving an about 15 litre "heel". This could only be drained through a hand-operated valve on the extreme bottom of the system. High radiation levels in the cell would not permit entry by personnel.

Two hundred and seventy litres of 20% HNO_3 were then added directly to the evaporator (skipping the water wash and neutralizer recommended by the manufacturer), combined with the remaining decontaminant, and boiled for about 2 hours, concentrating the HNO_3. The remotely-operated evaporator drain valve was opened, and while draining, the explosion occurred. The explosion is considered to be the result of rapid reaction of nitrated organic compounds.

7.2. Important consequences

The explosion dispersed about 150 g (probably the entire contents of the evaporator) of the plutonium to the cell, and an estimated 0.6 g was blown through a cell door directly to the outside air. No one was injured or received an overexposure to radiation: however, plutonium contaminated nearby buildings, several vehicles, roadways, and grounds in an area of about four acres.

7.3. Causes

The explosion resulted from a complex combination of circumstances during decontamination of the evaporator:

(i) An unanticipated material was present, phenol in a decontamination agent.
(ii) The design of the evaporator was such that it could not be completely drained.
(iii) Due to a combination of operational error and procedure changes:
  (a) the evaporator containing residual decontamination was not flushed with water before the addition of dilute nitric acid, and
  (b) the nitric acid was allowed to boil and concentrate in the evaporator.

This series of circumstances resulted in the nitration of the phenol and an explosion.

7.4. Lessons learned

7.5. Action taken

All operations at the Laboratory involving significant quantities of radioactive materials have been examined to ensure that the maximum credible accident will be contained and that two lines of defense are present to prevent escape of radioactive materials via waste streams. The application of these containment criteria to the plant building indicates the need for structural changes to the building, modifications to the off-gas and ventilation systems, and additional equipment for fire and explosion protection.

7.6. Sources

(1) "Plutonium release incident of November 20, 1959", King L.J., McCarley W.T., ORNL-2989.
(2) "A summary of industrial accidents in USAEC facilities, TID-5360", Suppl. 3 Revised, US Atomic Energy Commission, 1961.
(3) "Theoretical Possibilities and Consequences of Accidents in U-233 and Pu-239 Fuel Fabrication and Radioisotope Processing Plants", ORNL-3441.
(4) "Plutonium release from the Thorex Pilot Plant", Nuclear Safety, Vol. 1, No. 3, 1960.

8. Criticality

Type of facility Reprocessing

Name of facility Idaho Chemical Processing Plant

Location Idaho Falls, Idaho, USA

Incident date 1961 January 25

8.1. Description of the incident

This excursion occurred when a large air bubble forced enriched uranium solution out from the top of a 12.7 cm diameter section of an evaporator into a 61 cm diameter vapor-disengagement cylinder above the normal solution level.

After several unsuccessful attempts to pump evaporator product solution to a storage bank, pressure was applied through the line at the bottom of the apparatus in an attempt to clear the postulated blockage. It is thought that an air bubble forced solution from the evaporator into the larger diameter head section. About 40 litres of solution containing 8 kg of uranium-235 produced the excursion. The reaction occurred very quickly as the air bubble passed through the cylinder and allowed the solution to drain back into the lower region and a subcritical configuration.

8.2. Important consequences

The incident produced 6×10^{17} fissions but resulted in no substantial radiation doses to personnel because of the shielding present for the operations with irradiated fuel. Fission product release was also prevented by systems installed after the first excursion at this facility.

8.3. Root causes

8.4. Lessons learned

8.5. Action taken

Steps were taken to prevent the inadvertent introduction of air into solution lines. Soluble poison was also added to process solutions before they entered the evaporator. The upper cylinder was replaced with one poisoned by a group of stainless steel plates containing 1% boron. (The cylinder was later replaced with a thin slab geometry.)

8.6. Sources

(1) "A review of criticality accidents", Stratton, W.E., revised by Smith, D.R., DOE/NCT-04, 1989.
(2) "Nuclear Criticality Safety", Knief, R.A., 1985.
(3) "Idaho Chemical Processing Plant Criticality Incident of January 25, 1961", Nuclear Safety, Vol.3, No.2, 1961.

9. Criticality

Type of facility Reprocessing

Name of facility Recuplex Plant, Hanford

Location Richland, Washington, USA

Incident date 1962 April 7

9.1. Description of the incident

The facility was used to recover plutonium from various processes conducted on the reservation. The excursion took place in a solvent-extraction area that was enclosed in a room-sized glove box. A general cleanup operation was in progress. Wash solutions were collected by suction and deposited in a 69 litre, 45.7-cm-diam vessel, which was normally used to store a dilute solvent-extraction side stream prior to secondary recovery.

Apparently the concentrated solution had overflowed from a geometrically sub-critical tank while the cleanup operations were still in progress. It was then sucked into the vessel through a temporary line used for cleanup operations. When the vessel accumulated between 1.4 and 1.5 kg of plutonium in a volume 46 litres, the excursion began.

A total yield of 8.2×10^{17} fissions occurred over 37 hours, with about 20 per cent of the energy released in the first half hour. An initial pulse of approximately 10^{16} fissions was followed by smaller pulses for about 20 minutes, after which boiling occurred, ultimately distilling off enough water to stop the reaction.

The initial pulse, accompanied by the usual blue flash, triggered a radiation alarm, and the area was evacuated promptly.

9.2. Important consequences

At the time 22 people were in the building, only three nearby operators received significant radiation exposures (110, 43 and 19 rem). The incident caused no rupture of process lines or damage to equipment, and the plutonium contamination problem.

9.3. Root causes

9.4. Lessons learned

In the modern plant, vessels that are not sub-critical by geometry usually contain neutron absorbers. The system is adaptable to a variety of uses without improvisation, and equipment is easier to keep clean. It is recognised that the flexibility needed in this salvage plant requires special effort to maintain realistic, up-to-date written procedures.

9.5. Action taken

9.6. Sources

(1) "A review of criticality accidents", Stratton, W.E., revised by Smith, D.R., DOE/NCT-04, 1989.
(2) "Nuclear Criticality Safety", Knief, R.A., 1985.
(3) "Accidental Nuclear Excursion in Recuplex Operation at Hanford in April 1962", Nuclear Safety, Vol.4, No.4, 1963.

10. Exothermic reaction and fire

Type of facility Reprocessing

Name of facility Final plutonium purification facility for the Redox plant, Hanford

Location Richland, Washington, USA

Incident date 1963 November 6

10.1. Description of the incident

An incident involving a fire and the venting of an overpressured plutonium anion-exchange contactor occurred in the final plutonium purification facility (Building 233-S) for the Redox plant at Hanford. The 233-S facility contains equipment for concentrating and loading out neptunium and for final purification of the plutonium by a moving-bed ion-exchange process.

A sudden reversal of air flow was noted in the 233-S (sulphur-233) building. The event was accompanied by a detectable vibration of the instrument panel board. Immediately the operation in the sulphur-233 facility was shut down by remote control. Approximately 30 minutes after the first event, radiation monitors noted the presence of a fire. It was considered advisable by the operators that the firemen not use water in combating the fire, unless absolutely necessary, because criticality control was a consideration in the system. Only dry chemical extinguishers were permitted in combating the fire. The fire was extinguished in 1.5 hours by the use of dry-chemical extinguishers. It was estimated later that if water fog had been used, the fire could have been extinguished in five minutes.

10.2. Important consequences

Fire damage to the building and equipment, alpha contamination throughout the building.

10.3. Root causes

Pressurisation of the anion exchange contactor is believed to have been caused by chemical degradation and oxidation of the plutonium-loaded anion exchange resin. It is suggested that the degradation of the resin may have been triggered by the inadvertent addition of sodium dichromate to the system.

10.4. Lessons learned

It was recommended that criteria and guides be established which would assist firemen and operating personnel in assessing the degree of criticality risk in the use of water on fires in facilities handling fissile materials.

The most significant fact evident from the incident was the realization that the maximum safe operating temperature for plutonium anion exchange systems is substantially lower than previously thought.

10.5. Action taken

10.6. Source

"Incident in Plutonium Processing Facility at Hanford", Reactor Fuel Reprocessing, Vol.7, No. 4, 1964.

11. Criticality

Type of facility U-235 scrap recovery facility

Name of facility Wood River Junction Plant

Location Rhode Island, USA

Incident date 1964 July 24

11.1. Description of the incident

The facility was designed to recover highly enriched uranium from unirradiated solid scrap and solutions generated by fuel fabrication activities. The plant had commenced operations in March 1964, and the first product had not been shipped at the time of the accident. There were only five persons in the plant on the evening of July 24 a shift supervisor, three technicians, and a security guard.

The facility experienced some difficulties in startup operations, which resulted in the presence of large volumes of trichloroethane (TCE) with low uranium concentrations. Small amounts of uranium were recovered by tedious hand agitation of the TCE with sodium-carbonate solution. An easier process was improvised, in which the TCE was treated in the 45.7 cm diameter tank intended only for sodium carbonate solution preparation. This procedure was instituted with the knowledge of two of the three shift supervisors but unknown to the plant superintendent and the remaining supervisor.

The cleanout of plugged equipment elsewhere in the plant produced high-concentration uranium solutions, which were stored in 11-litre, 12.7 cm diameter bottles identical to those used for contaminated TCE. A bottle of the concentrated solution was mistaken for TCE and was poured into the sodium-carbonate solution being stirred in the make-up tank. The critical excursion knocked the operator to the floor, splashed part of the solution out of the tank and triggered a radiation alarm.

The final content of the tank appears to have been subcritical with the vortex produced by the automatic stirrer. However, when the stirrer was turned off about 2 hours later, a second, much less energetic excursion is thought to have occurred. The radiation alarm, still sounding after the first excursion, was not able to respond to this second event.

11.2. Important consequences

The first excursion appears to have consisted of a single pulse of 10^{17} fissions. One operator received a lethal dose (46,000 rads to the pelvic area and 14,000 rads to the head) and died 49 hours later. The smaller second excursion caused significant radiation doses for two other workers (estimated between 60 and 100 rads). Other persons in the plant received very minor doses. No physical damage was done to the system, although cleanup of the splashed solution was necessary.

11.3. Root causes

11.4. Lessons learned

11.5. Action taken

Emergency procedures, criticality limits and controls, uranium accountability and material balance practices, health physics procedures and controls, and operator training were all reviewed thoroughly and modified. Geometrically favorable equipment for recovering uranium from TCE was put into operation.

11.6. Sources

(1) "A review of criticality accidents", Stratton, W.E., revised by Smith, D.R., DOE/NCT-04, 1989.
(2) "Nuclear Criticality Safety", Knief, R.A., 1985.
(3) "Nuclear accident at Wood River Junction", Nuclear Safety, Vol.6, No.3, 1965.

12. Criticality

Type of facility	Reprocessing
Name of facility	Plutonium recovery plant
Location	Windscale, United Kingdom
Incident date	1970 August 24

12.1. Description of the incident

The facility was used to recover plutonium from several types of spent reactor fuel. The excursion took place at the head end of a solvent-extraction process employed to recover plutonium. When 40 litres of organic solvent from an unknown source entered the transfer tank, its lower density caused it to float in a layer on top of the aqueous solution. With continuing flow of the aqueous solution, the organic extracted plutonium until the concentration reached 55 g/l of plutonium. It appears that an aqueous-organic emulsion band between the two phases led to an excursion during the brief period after the flow stopped and before the emulsion constituents separated.

12.2. Important consequences

The excursion produced only in the order of 10^{15} fissions because the excess multiplication of the emulsion band was low and its time of existence short. Two people were in the plant at the time of the accident. One received an estimated exposure of 2 rads, the other less than 1 rad. Radiation exposure was negligible as a result of the protection afforded by shielding.

12.3. Root causes

12.4. Lessons learned

12.5. Action taken

Neutron monitors for detecting plutonium buildup were installed on all vessels of nonfavorable geometry. The drain traps were also modified to permit positive drainage and to facilitate washout procedures

12.6. Sources

(1) "A review of criticality accidents", Stratton, W.E., revised by Smith, D.R., DOE/NCT-04, 1989.
(2) "Nuclear Criticality Safety", Knief, R.A., 1985.
(3) "Criticality incident at Windscale", Nuclear Engineering International, February 1972.

13. Underground release of waste liquid

Type of facility	Reprocessing
Name of facility	Tank-106 at Hanford
Location	Hanford, Washington, USA
Incident date	1973 April - June

13.1. Description of the incident

The Hanford Plant was established to produce plutonium for nuclear weapons. The consequence of the operation of up to nine plutonium production reactors during and after the war years is about 65×10^6 gals of radioactive waste stored in 150 underground tanks.

On April 4, 1973, a routine operation, which involved moving liquid wastes from tank 107-T to tank 106-T, was initiated. Because of the piping arrangement, the transfer was to be made by first pumping the waste into tank 105-T, which was already essentially full, and then allowing it to overflow into tank 106-T in a cascade-type operation. On about April 20, when the level in tank 106-T had gone a little above 130 in., the tank started leaking. This leak could not have been detected at that time with existing instrumentation, since the leak rate was very small compared with the rate at which liquid was being transferred into the tank.

On April 24, emptying of tank 107-T was completed; however, because of the cascading effect of the intervening tank 105-T, liquid continued to run into tank 106-T until the following day, when the levels equalized at a depth of about 184 in. in tank 106-T.

Unfortunately, there was at this point a communications breakdown with respect to routine liquid-level and radiation-monitoring data, and the fact that the tank was leaking was not determined until late in the afternoon of June 8. By that time, approximately 115,000 gals. of liquid had been lost from the tank, which contained about 40,000 Ci of Cs-137, 14,00 Ci of Sr-90, and 4 Ci of Pu-239, along with other less biologically significant fission products.

13.2. Important consequences

The leaked material from the tank 106-T posed no threat to the workers, the surrounding population, or the Columbia River. Wells used for monitoring the groundwater at the Hanford site have shown no sign of radioactivity from the leak. Core samples taken in the area around the tank show that the maximum penetration is about 45 ft below the bottom of the tank, which is still more than 100 ft above the groundwater table in this area.

13.3. Root causes

The principal reason for the long time interval between the start of the leak and its detection was the result of one person's neglecting his assigned task of reviewing liquid-level and radiation-monitoring data.

The leak probably resulted from corrosion of the aging, approximately 30-year-old, carbon-steel tank, caused by the caustic waste solutions to which it had been exposed during its lifetime.

13.4. Lessons learned

13.5. Action taken

The AEC took steps to assure that the leaks are minimized in the future. Some of the steps taken were:

(i) to expedite the installation of computerized monitoring and readout of liquid levels in waste tanks, with visual alarms;
(ii) in the interim, to increase the frequency of tank level manual readout of every tank once a shift;
(iii) to strengthen the procedures for audit of the waste-management operations at Richland.

13.6. Source

"The leak of tank 106-T at Hanford", Nuclear Safety, Vol. 15, No. 4, 1974.

14. Release of airborne radioactivity

Type of facility	Reprocessing
Name of facility	Head End Treatment Plant of the Windscale Works
Location	Windscale, United Kingdom
Incident date	1973 September 26

14.1. Description of the incident

The facilities were modified to provide a head end initial treatment process for oxide fuels prior to feeding the product liquor to the operational reprocessing. The modifications were completed and the B204 head end plant fully commissioned in August 1969. This incident occurred just as a processing campaign was being started.

Exothermic reaction took place in a constant volume feeder (CVF) between high-temperature insoluble fission products containing large quantities of ruthenium-106, zirconium fines and other solids, and the acidified butex. It caused the decomposition of the butex and, possibly, ignition of the zirconium.

Air samples taken from the plant stack indicated that a release of ruthenium-106 to atmosphere of about 370 GBq had occurred. This was equivalent to less than one fifth of the then appropriate daily derived working limit for the stack.

14.2. Important consequences

The seventh floor was found to have the highest levels of surface contamination. Thirty-five persons in the head end building at the time of the incident were contaminated on the body. The external contamination produced no adverse health effects. The amounts inhaled have been measured on a whole body monitor for all 35 men. One man was estimated to have up to about 1.5 MBq in his lungs with a dose commitment in 50 years of approximately 10 Sv.

14.3. Root causes

14.4. Lessons learned

Proposals were made to reduce the likelihood of a recurrence of butex/solids reactions entailing monitoring the arising of solids in irradiated oxide fuel processing and removal of such solids in plant process vessels.

14.5. Action taken

14.6. Source

"The Safety of the Nuclear Fuel Cycle", OECD/NEA, 1992.

15. Explosion and fire

Type of facility	Reprocessing
Name of facility	Savannah River
Location	South Carolina, USA
Incident date	1975 February 12

15.1. Description of the incident

Depleted uranium is separated from plutonium by the Purex process at the Savannah River Plant. Uranyl nitrate solution is transferred to a facility called the A-Line, where the solution is concentrated by evaporation to molten uranyl nitrate hexahydrate, and is then fed to denitrators, where it is dehydrated and denitrated to UO_3 powder.

An uncontrolled reaction occurred at the A-Line when tributyl-phosphate uranyl nitrate was accidentally added to a denitrator, skin temperature of which was rising from 250 to 400°C. The decomposition of tributyl-phosphate uranyl nitrate began at about 170° C. The reaction forcibly ejected much of the denitrator contents. The room was filled with red-brown NO_2 fumes and with combustible gases from the decomposition of the tributyl-phosphate. The gases ignited and caused an explosion and fire.

15.2. Important consequences

Although one wall was damaged, no damage was done to the structural support of the building. The wall, the room ventilation system, insulation, lighting and painting were the major items in need of repair. Fire damage was confined to the processing room. Clean-up of the floor, overhead piping, denitrators, etc. was required before normal operations were resumed in August 1975.

Minor injury to two workers. One operator had a mild irritation of the lungs due to inhalation of acid fumes. There were no cases of skin or nasal contamination or of uranium assimilation.

15.3. Root causes

15.4. Lessons learned

15.5. Action taken

As a result of the incident, a number of process changes have been made to prevent a recurrence:

(i) All tanks downstream of the first evaporator are agitated continuously to prevent stratification of aqueous and organic layers.
(ii) Analyses for organics in the aqueous phase are required for all solutions before transfer through the system. Operating limits for the organics have been set to prevent an unsafe quantity from reaching the hydrate evaporators and denitrators.
(iii) The heating rate has been lowered so that any organic reacting in the denitrators would, upon decomposition, evolve gas at a relatively low rate.
(iv) The air flow through the denitrator off-gas has been increased to ensure that any evolved organic vapor has a concentration below its lower explosive limit.

New process instrumentation has been installed to determine whether or not the new limitations on denitration conditions are being met. The new instrumentation also provides for a more rapid response to violations of critical controls, either manually or automatically.

15.6. Source

"An Explosion and Fire During Conversion of Liquid Uranyl Nitrate to Solid Uranium Oxide", Nuclear Safety, Vol. 19, No. 1, 1978.

16. Explosion

Type of facility	Reprocessing
Name of facility	Americium Processing Facility of Pu-Finishing Plant, Hanford
Location	Richland, Washington, USA
Incident date	1976 August 30

16.1. Description of the incident

The facility is used for recovery of still-useful elements from high level liquid wastes stored at the site. In one room of the building, the Americium Recovery Process occupied a stainless steel "glove box". Within this glove box two stainless steel vessels were filled with nitric acid and ion-exchange resin; one of the vessels also contained about 100 g of Am-241, which had been collected on the resin before the plant shutdown.

During the reactivation of the recovery process a chemical reaction occurred generating heat and pressure in the americium-containing vessel. An explosion resulted, which injured and grossly contaminated the chemical operator standing in front of the glove box.

16.2. Important consequences

One worker was slightly injured and exposed to alpha contamination from the element americium-241. The injured worker was quickly removed from the highly contaminated area by his fellow worker, who received external contamination himself. It required 2 days of intensive decontamination; his internal americium deposition was less than 10% of the "maximum permissible" body burden.

The injured worker was removed to a Emergency Decontamination Facility where further decontamination and treatment for the internal deposition of americium was begun. An estimated 1-5 Ci of americium initially deposited on the injured worker and his clothing, which was reduced to approx. 6 mCi by on-site decontamination procedures, and to 1 mCi after intensive decontamination during the first day post-exposure. His thermoluminescent dosimeter indicated an external whole-body penetrating dose of about 500 mrem.

Several other persons involved in the on-site decontamination effort received minor skin contamination, which was readily removed.

16.3. Root causes

16.4. Lessons learned

16.5. Action taken

16.6. Source

"1976 Hanford americium exposure incident", Health Physics, Vol. 45, No. 4, 1983.

17. Onshore detection of tritium

Type of facility	Reprocessing
Name of facility	Windscale, United Kingdom
Location	Windscale, Sellafield, United Kingdom
Incident date	1976 October 10

17.1. Description of the incident

At Windscale, excavation work (20 feet deep) was in progress to install a new silo that would be used to mainly store magnesium alloy declad from spent natural uranium fuel. On October 10 a level of radioactivity, that made it necessary to limit access, was detected at the site. This incident had not been made public till it was reported to the Minister for Energy (a BNFL L600M expansion project was approved by the council on November 2), leaving the labour union of the Windscale Works and local residents considerably opposed to it.

17.2. Important consequences

It was assumed that contamination was limited to an underground area of several yards around the existing silo that leaked, without any evidence showing that water, both underground and surface, had been contaminated. Accordingly, the BNFL announced safety to the operators and the public.

17.3. Root causes

The high-level radioactive solid waste storage silo responsible for the leakage, which was of a concrete single-wall structure and had been in use since the beginning of the 1960s, had magnox stored in water to prevent its ignition. It was assumed that the waste liquid had oozed out from this silo (half of which is underground 30 feet deep) through the concrete wall.

17.4. Lessons learned

17.5. Action taken

The new silo is planned to be a double-wall structure with leak sensors installed between the walls for constant monitoring of leakage.

17.6. Source

"Incidents assessment of fuel cycle facilities", Sato, H., Kanamori, M.

18. Overflow of high-level solution

Type of facility	Reprocessing
Name of facility	Pond water treatment plant
Location	La Hague, France
Incident date	1977 September 2

18.1. Description of the incident

The incident happened during a filter declogging operation on a twin filtration circuit in the storage pond water treatment plant. A high level solution from badly closed short circuit tap flowed into the declogging effluent tank. This tank was quickly filled to overflowing before any emergency intervention could be made.

18.2. Important consequences

The incident caused a high contamination of the soil. The maximum dose rate level was 0.01 Gy per hour at one meter from the soil.

18.3. Root causes

The incident was caused by a defective valve.

18.4. Lessons learned

Checking of all stopcocks and the installation of control systems automatically closing the draincocks when the filter effluents have reached the upper level in the tank.

18.5. Action taken

18.6. Source

"The Safety of the Nuclear Fuel Cycle", OECD/NEA, 1992.

19. Air contamination

Type of facility	Reprocessing
Name of facility	Plutonium conditioning & storage plant
Location	La Hague, France
Incident date	1977 November 26

19.1. Description of the incident

Bellows of handling tongs became disconnected from the opening ring of one of the two twin boxes used for plutonium dioxide conditioning. This incident resulted in a rapid air intake in the glove boxes, so that for a few seconds there was no negative pressure in the glove boxes. The pressure regulation system was too slow to prevent this increase of pressure. An unsuspected leakage of one box thus caused an air contamination of 2,000 MPC-h (Maximum Permissible Concentration) in the room.

19.2. Important consequences

Nobody was involved in this incident.

19.3. Root causes

Disconnection of bellows.

19.4. Lessons learned

- improve the quality of the elastomer constituting the bellows of the tongs and the mechanical and thermal protection of these bellows;
- decrease the inertia of the pressure regulation system to improve the response to any sudden pressure variation.

19.5. Action taken

19.6. Source

"The Safety of the Nuclear Fuel Cycle", OECD/NEA, 1992.

20. High contamination of the off-gas circuit

Type of facility	Reprocessing
Name of facility	High Activity Oxide (HAO) building
Location	La Hague, France
Incident date	1978 February 3

20.1. Description of the incident

The incident happened in the area of a sampling circuit associated with a high radioactive process tank. This circuit comprises an air lift system which lifts the solution from the tank to a pot where samples are taken and sent to the laboratory. The lower end of the air lift tube should always be kept immersed in a dead volume of liquid at the bottom of the tank. The air lift system was accidentally left in service; the air flow generated by the air lift system carried radioactive aerosols in the upper circuit through the reflux column and the filter.

20.2. Important consequences

High contamination of the off-gas circuit, normally protected by the reflux column and the filter, resulted in high contact radiation but, in low dose exposure of the personnel.

20.3. Root causes

Design and/or construction defects which allowed the liquid to drop below the level of the air lift pipe. A lack of co-ordination between the laboratory staff and the plant operators during sampling.

20.4. Lessons learned

A review of the operating instructions concerning the air lift systems.

20.5. Action taken

20.6. Source

"The Safety of the Nuclear Fuel Cycle", OECD/NEA, 1992.

21. Leakage

Type of facility	Reprocessing
Name of facility	HAO building
Location	La Hague, France
Incident date	1978 May 10

21.1. Description of the incident

A leakage took place from lead-shielded valves on the liquid effluent line from the spent fuel chemical decladding plant. For unknown reasons the alarm connected to the effluent gauge did not work. About 2 m^3 of active liquid leaked through the shielding and spread over the cell floor.

21.2. Important consequences

21.3. Root causes

Loose valve flanges.

21.4. Lessons learned

21.5. Action taken

21.6. Source

"The Safety of the Nuclear Fuel Cycle", OECD/NEA, 1992.

22. Criticality

Type of facility	Reprocessing
Name of facility	Idaho Chemical Processing Plant
Location	Idaho Falls, Idaho, USA
Incident date	1978 October 17

22.1. Description of the incident

The incident occurred in the first cycle solvent extraction cycle where highly enriched uranium was recovered from salvage solution. A leaking valve in the water line to the aluminum nitrate makeup tank caused the solution to be diluted. This dilution went unnoticed because a low-density-solution alarm had become inoperable and the latest version of the operating procedure, which called for periodic sampling, was not being used.

The very low aluminum nitrate concentration caused the resulting aqueous solution in the scrub tank to act as a stripping agent. Thus, as organic solvent moved through the scrub column, much of its uranium content was left behind in the aluminum-nitrate-poor solution. This concentration resulted in a configuration that was apparently slightly delayed supercritical over an extended time. Eventual operator action in response to the resulting pressure buildup resulted in a radiation spike, which may have signaled a fission pulse.

22.2. Important consequences

The criticality occurred in a heavily shielded and suitably ventilated cell. There were no injuries; no release from a breach of containment; and no damage to equipment.

22.3. Root causes

22.4. Lessons learned

22.5. Action taken

A plant protective system was installed to provide automatic response to specified off-normal process parameters. Operator training and certification were also greatly enhanced. Plant safety limits were all reevaluated, revised, and incorporated into a technical specification format.

22.6. Sources

(1) "A review of criticality accidents", Stratton, W.E., revised by Smith D.R., DOE/NCT-04, 1989.
(2) "Nuclear Criticality Safety", Knief, R.A., 1985.

23. Leakage of waste liquid

Type of facility	Reprocessing
Name of facility	Low-Level Waste Liquid Storage Tank at Tokai Reprocessing Plant
Location	Tokai, Japan
Incident date	1979 February 9

23.1. Description of the incident

On February 9, 1979, the water in the underground seepage receiving tank in the waste disposal facility of the reprocessing plant was checked for radioactive material concentrations, detecting a very small amount of radioactivity. The contents of this receiving tank were immediately diverted to a low-level waste liquid storage tank.

23.2. Important consequences

The underground seepage water in the receiving tank was discharged through rainwater line within the site of the reprocessing facilities into an off-site river. To assess possible effects of the discharged water on the environment, samples of the riverbed soil and river water were analysed. It was found that they were within the limits of variance in natural radioactivity.

23.3. Root causes

The waste disposal facility has a circulation pipeline for stirring waste liquid in the underground low-level waste liquid storage tank. It is assumed that a loose flange joint of this pipeline let out 4 m^3 of waste liquid with radioactivity at 5×10^{-5} μCi/cm, which infiltrated through a gap in the epoxy coated surface in the cell into the interface of the floor concrete and carried 0.2 mCi of radioactivity into the underground seepage water.

23.4. Lessons learned

23.5. Action taken

(i) The pipe flange joint responsible for the leakage was changed for a welded joint.
(ii) Procedure was corrected to send underground seepage water to the low-level waste liquid storage tank and monitor radioactivity before it is discharged into the ocean.

25.6. Source

"Incidents assessment of fuel cycle facilities", Sato, H., Kanamori, M.

24. Leakage of radioactive liquor

Type of facility	Reprocessing
Name of facility	Sellafield
Location	Sellafield, United Kingdom
Incident date	1979 March 15

24.1. Description of the incident

Unexpected radioactive contamination was discovered during a hydrogeological survey. Additional measurements in a pattern of new boreholes confirmed that building B701 was the source of the contamination. Radioactive liquor could splash-over into the Export Plant ageing tank. This tank then overflowed into the sump vessel. Because operating instructions for emptying the sump vessel, which included a requirement to monitor the level in the sump, were not complied with, the radioactive liquor eventually filled the sump vessel and overflowed into the metal clad area in the bottom of building B701.

The radioactive liquor then escaped through defects in the metal cladding and finally leaked into the ground at about the foundation level of the building, four meters below the surface. It is estimated that more than 100 000 Ci of radioactivity escaped over a period of some years.

24.2. Important consequences

The result of the leak is that a layer of soil, about one meter thick at a minimum depth of about three meters, is contaminated. The maximum radiation level was nearly 6 Gy per hour at a depth of four to five meters. Radiation is not significant at the ground surface and there is no hazard to workers or members of the public.

24.3. Root cause

24.4. Lessons learned

24.5. Action taken

24.6. Source

"The Safety of the Nuclear Fuel Cycle", OECD/NEA, 1992.

25. Loss of power supply

Type of facility	Reprocessing
Name of facility	La Hague
Location	La Hague, France
Incident date	1980 April 15

25.1. Description of the incident

A short circuit in the electric cable run from the medium voltage (15 kV) station caused a fire which essentially destroyed the site power distribution board control room; this short circuit also put out of use one of the two transformers which transmit the power to the plant from the EdF grid. This fire made it impossible to use the site internal power supplies, which consist of four sets of installed generators. The sensitive installations, i.e. fission product storage and plutonium oxide conditioning, were successively connected within about 30 minutes to mobile generating sets. The controlled zones were also evacuated to prevent any risk of personnel contamination associated with the stoppage of the ventilation system. Within two hours the fire was completely extinguished by the site firemen.

25.2. Important consequences

The accident and the subsequent evacuation from the controlled zones caused no physical damage to the operating and maintenance personnel. The systematic air sampling showed no general contamination of the buildings except for slight air activity in one room of one building. This disappeared as soon as the ventilation system was restarted. The air samples also demonstrated that there had been no discharge of radioactivity from the stacks.

25.3. Root causes

25.4. Lessons learned

25.5. Action taken

25.6. Source

"The Safety of the Nuclear Fuel Cycle", OECD/NEA, 1992.

26. Fire caused by spontaneous ignition

Type of facility	Reprocessing
Name of facility	Graphite claddings and magnesium scraps repository
Location	La Hague, France
Incident date	1981 January 6

26.1. Description of the incident

Around 4 p.m. on January 6, minor air pollution was discovered. Analysis revealed that caesium was responsible for it. Around 11 p.m., it was found that a fire in the graphite claddings repository located in the northwest of the site released caesium. The repository, which consists of two semi-underground airtight cells, is for storage of graphite claddings and magnesium scraps generated in the decladding process for spent uranium fuel from graphite gas-cooled reactors.

The fire was extinguished with water poured into the repository before dawn on January 7. The total release of Cs-137 was estimated at less than 0.6 Ci.

26.2. Important consequences

- Monitoring showed that the air pollution was between 1/10 and 1/100 CMA.
- The rainfall on the afternoon of January 6 allowed the ground surface to be slightly contaminated. An area of approximately 10 000 m^2 was contaminated beyond the external release limit.
- Analysis of the rainwater samples collected on January 9 showed that their contamination was 3.5×10^{-6} Ci/m^2. Caesium and strontium were detected. No alpha radionuclides were detected.
- Examination showed that the grass samples collected on the morning of January 17 had been contaminated at levels up to 3×10^{-6} Ci/m^2.
- Five workers were externally irradiated (5 to 7 rem in one and 200 to 400 mrem in four others). A further 35 slightly contaminated persons underwent decontamination treatment.
- The contamination of the people, vehicles, etc. was removed by washing with water.

26.3. Causes

It was suggested that a minuscule amount of uranium deposited on graphite claddings, etc., was present on pieces of cloth saturated with phosphoric acid-based decontaminant liquid which were heated to the point of ignition, starting the fire.

Another possibility is that graphite claddings had been left in airtight packaging for 7 days before they were stored in the repository and uranium deposited on them had been heated to ignition point during this period.

26.4. Lessons learned

26.5. Action taken

26.6. Source

"Incidents assessment of fuel cycle facilities", Sato, H., Kanamori, M.

27. Inadvertent transfer of plutonium

Type of facility	Reprocessing
Name of facility	Tokai reprocessing plant
Location	Tokai, Japan
Incident date	1981 February 4

27.1. Description of the incident

A plutonium-containing solution was inadvertently transferred to the acid recovery line.

The plutonium-containing solution from the refining line was transferred to the evaporator before the evaporator had been heated to a proper temperature. The liquid was also transferred so rapidly that nitrous acid in the evaporator lost its activity. Because of these two facts, nitrous acid did not react with hydrazine contained in the feed liquid, resulting in an accumulation of hydrazine in the evaporator.

The acid concentration in the evaporator gradually increased and a sudden reaction started between nitrous acid and accumulated hydrazine. This reaction caused a rapid rise in the pressure of the evaporator and a part of the solution was transferred to the concentrate receiving tank.

As the concentrate receiving tank filled up, the solution was sampled and then, without analysing the data, transferred to the acid recovery line.

27.2. Important consequences

The operation of the extraction line was stopped to recover plutonium from the acid recovery line. Workers and the area around the plant were not contaminated. Plutonium was not released to the environment.

27.3. Root causes

Concentrate was transferred to the acid recovery line before the solution data was analysed.

27.4. Lessons learned

27.5. Action taken

- To prevent a sudden reaction of nitrous acid on hydrazine in the evaporator, the operating procedures were reviewed and corrected where necessary to ensure that the liquid transfer from the refining line to the evaporator is not started until the evaporator temperature has reached a proper point.
- Operators were retrained to ensure that the liquid transfer to the acid recovery line is performed upon verification of safety of the solution.

27.6. Source

"Incidents assessment of fuel cycle facilities", Sato, H., Kanamori, M.

28. Release of radioactive liquor

Type of facility	Reprocessing
Name of facility	Sellafield
Location	Sellafield, United Kingdom
Incident date	1983 November 10

28.1. Description of the incident

The reprocessing plant was shut down for routine annual maintenance. This involved the emptying and washing out of the plant in accordance with written operating instructions. The resulting liquors were collected in a number of plant wash tanks. One of the wash tanks contained radioactive aqueous liquor with lighter radioactive solvent floating on top of it and with a layer of highly radioactive interfacial crud at the boundary between the two liquors.

Unfortunately, the tank was assumed to contain aqueous liquor only and its transfer to the sea tanks was commenced. Transfer proceeded normally until the gamma radiation monitors on the transfer pipework set off an alarm and the transfer was terminated.

It was decided to discharge most of the aqueous liquor in the sea tank to the sea before transferring the much smaller quantity of aqueous liquor, solvent and crud remaining, up an emergency return line to a tank.

28.2. Important consequences

A total of 1,600 Ci including 1,214 Ci ruthenium-106 had been released to the sea. Maximum irradiation levels were 270 mSv per hour on dried organic material deposited on the beach. A great number of measurements resulted in dose rate >0.1 mGy/h. The access to the beaches was temporarily closed.

28.3. Root causes

28.4. Lessons learned

28.5. Action taken

28.6. Source

"The Safety of the Nuclear Fuel Cycle", OECD/NEA, 1992.

29. Release of 440 kg uranium into the Irish Sea

Type of facility	Reprocessing
Name of facility	Sellafield
Location	Sellafield, United Kingdom
Incident date	1986 January 23

29.1. Description of the incident

Uranyl nitrate solution is concentrated prior to being fed to the next stage of the process. The evaporated steam is separated from the boiling uranyl nitrate solution, condensed and then drained via diverter valves to either a drain line to the effluent treatment plant, or to a "save-all" tank from which the condensate can be recycled if necessary. A uranium monitor is fitted downstream of the diverter valves on the drain line and provides a reading of the uranium concentration. The meter reading is logged at hourly intervals by an operator who is required to inform line management if the reading has gone from the lower to the higher scale.

Following start-up of the evaporator on 22 January, the condensed steam was routed to the drain line. A fault then arose in the evaporator, which gave rise to uranyl nitrate being carried over in the steam. This was noted by the night shift line management who became aware of a high reading on the uranium monitor, but it was not realized that the condensed steam was being sent to the drain and no action was taken to correct this. The fault on the evaporator was cured. The condensed steam passed through the neutralizing plant and then into a sea tank. After the sea tank had been filled, a sample of effluent taken from it revealed an estimated 413 kg of uranium in the tank.

Since the material was of a very low level of activity, about 0.5 Ci in total, BNFL and safety authorities agreed that it could be discharged. The contents of the tank were discharged to sea on the afternoon of 23 January.

29.2. Important consequences

This incident did not cause significant radiation doses on the site or to workers.

29.3. Root causes

29.4. Lessons learned

29.5. Action taken

29.6. Sources

(1) "Safety Audit of BNFL Sellafield 1986", Health and Safety Executive, HM Nuclear Installations Inspectorate.
(2) Nuclear Engineering International, March 1986.

30. Plutonium (in mist) release

Type of facility	Reprocessing
Name of facility	Sellafield
Location	Sellafield, United Kingdom
Incident date	1986 February 5

30.1. Description of the incident

A sample of radioactive process liquor is required to control the reprocessing operation. The pump uses two compressed-air driven primary diaphragms linked by pipes to two secondary diaphragms which act on the process liquor. Following a pump failure, maintenance staff were requested to replace the primary diaphragms. Because of the possibility of a concurrent failure of a secondary diaphragm, the replacement was carried out within a temporary plastic tent erected around the work place with the objective of retaining any release of radioactivity.

The pump was then restarted while the tent was still erected, but it failed again within a few hours. Alarm signals sounded in the control room at 8.50 a.m. on 5 February indicating high levels of activity in the air. Standard response measures were initiated which led to the evacuation of personnel from the building.

Following indications that the source of the activity was local to the tent, a careful re-entry was made by an employee in protective clothing. He found the air supply to the pump was blowing a stream of air across the surface of some liquor in the drip tray, splashing the tent walls and producing a mist and some leakage of liquor out of the tent. The air was turned off at about 11.30 a.m. and the liquor subsequently mopped up.

30.2. Important consequences

Sixteen employees were judged to have exceeded the criterion for initiating detailed investigation into the radiation doses received. The personal air sampler result of one employee indicated a potential intake of about the annual limit. The other results were lower.

30.3. Root causes

30.4. Lessons learned

30.5. Action taken

30.6. Sources

(1) "Safety Audit of BNFL Sellafield 1986", Health and Safety Executive, HM Nuclear Installations Inspectorate.
(2) Nuclear Engineering International, March 1986.

31. Potential criticality

Type of facility	Reprocessing
Name of facility	Hanford
Location	Hanford, USA
Incident date	1986 September 26

31.1. Description of the incident

The Richland Operation Office of the Department of Energy, as a result of its investigations into the September 29 violation of the criticality prevention specification at the plutonium finishing plant, concluded that the cause of the incident was poor management and ordered the Rockwell Hanford Operation entrusted with the operation of the Hanford facilities at Richland, Washington on October 8 1986 to shut down the plutonium finishing plant and Purex plant until proper corrective measures were taken.

The departure from the criticality prevention specification took place when the worker, attending to the transfer of plutonium nitrate solution from the conversion process for metallic plutonium to the criticality safety storage tank in the plutonium recovery facilities, chose the pipeline route to a non-criticality safety tank by mistake.

While the solution transfer to that non-criticality safety tank never took place, the Richland Operation Office took the error seriously in the light of the possibility that it might have led to a misrouting, and ordered the plant shut down. The shutdown order was lifted on February 21, 1987.

31.2. Important consequences

There was neither human nor physical damage.

31.3. Root causes

- A wrong pipeline route for plutonium solution to a non-criticality safety storage tank was chosen by mistake in violation of the DOE's criticality prevention specification. Actually, however, the misrouting never took place.

- Violation investigations revealed that multiple management to prevent criticality had been neglected and that proper management, evaluation and approval systems to prevent recurrence of similar incidents were not in place as a whole.

31.4. Lessons learned

31.5. Action taken

31.6. Source

"Incidents assessment of fuel cycle facilities", Sato, H., Kanamori, M.

32. Contamination

Type of facility	Reprocessing
Name of facility	BNFL's Sellafield reprocessing plant
Location	Sellafield, United Kingdom
Incident date	1987 January 19

32.1. Description of the incident

Twelve employees were believed to have been contaminated by a small plutonium leak. They inhaled a small amount of uranium and plutonium oxide powder while working in the B277 building, which produces fuel elements for the prototype fast reactor at Dounreay.

32.2. Important consequences

32.3. Root causes

32.4. Lessons learned

32.5. Action taken

32.6. Source

Nuclear Fuel, January 26, 1987.

33. Possible explosion

Type of facility	Reprocessing
Name of facility	Hanford
Location	Hanford, USA
Incident date	1990

33.1. Description of the incident

High-level radioactive waste liquid generated from military reprocessing facilities in the USA is stored underground. In the 1950s, ferric potassium cyanide was added to some waste liquid as a reagent to remove caesium from it. In the 1970s, organic substances were added to waste liquid to recover radioactive strontium. The removal of radioactive strontium and caesium was intended to control heating because the waste liquid storage tanks at Hanford have no cooling coil inside. It is said that in the storage tank involved in the possible explosion problem, the waste liquid has a very thick crust on its surface and the hydrogen and NOx gases accumulated under the crust are released periodically. Sampling analysis is under way to determine the composition of the crust.

33.2. Important consequences

According to DOE, the probability of ignition or explosion is reasonably low. In response to the expressed concern that an explosion could occur, similar to the one experienced at Kyshtym in the former Soviet Union, DOE denies the possibility explaining that in the Russian case, the waste liquid was evaporated resulting in an explosion of sodium nitrate and acetate, which is totally different in nature from what is being investigated at Hanford.

33.3. Root causes

33.4. Lessons learned

33.5. Action taken

33.6. Source

"Incidents assessment of fuel cycle facilities", Sato, H., Kanamori, M.

34. Plutonium nitrate spill

Type of facility	Reprocessing
Name of facility	Sellafield
Location	Sellafield, United Kingdom
Incident date	1992 September 8

34.1. Description of the incident

Plutonium nitrate leaked from a corroded pipe to the containment cell and accumulated as a crystalline solid mass. There was no release to the Operations Area nor to the Environment. The spillage was removed, the plant repaired and restarted. The installed safety devices were not monitoring adequately under the existing circumstances.

34.2. Important consequences

34.3. Root causes

34.4. Lessons learned

34.5. Action taken

34.6. Sources

INES scale: Level 3

35. Explosion

Type of facility	Reprocessing
Name of facility	Tomsk-7
Location	Russia
Incident date	1993 April 6

35.1. Description of the incident

Tomsk-7 nuclear site is located to the northwest of the city of Tomsk in Western Siberia. The site combines several different nuclear and civil facilities, e.g. two dual-purpose uranium-graphite reactors, a uranium enrichment plant, a radiochemical plant to reprocess spent metal uranium fuel and civil pure materials and chemical production facilities.

The reprocessing plant was originally designed based on uranyl acetate precipitation technology. In 1983 the plant was reconstructed for Purex process with nitric acid - 30% TBP in paraffin hydrocarbon diluent extraction system.

An exothermic chemical reaction occurred in a stainless steel cylindrical process tank where adjustment operations were carried out. As a result of a rapid pressure increase, the tank ruptured. The ejected gas-aerosol mixture blew away the concrete cover of the cell and exploded in the above-the-canyon maintenance corridor.

The tank was used for the solution's technological adjustment for temperature, composition and activity before the next processing stage of solvent extraction purification. Two and a half hours before the accident, 1.5 m^3 of concentrated nitric acid was added to the uranylnitrate solution which had been transferred to the tank previously. An exothermic chemical reaction happened between organic compounds and concentrated nitric acid.

35.2. Important consequences

The mixture ejection and explosion damaged the section of the roof above the cell, blew out a part of masonry wall and glazing. Some radioactivity released into the environment through the stack and openings in the building. Estimated release of radioactivity was 10% of the tank content (560 Ci).

Beyond the border, the contaminated area was 28 km long; the area with a gamma-radiation level of 15 mRem/hour and higher was 123 km^3.

Thanks to the snow-fall during the event, a major part of the radioactivity fell out close to the plant building. The contaminated snow was quickly collected at a special place and the resulting wastes were subsequently buried.

35.3. Causes

- Lack of sparging in the tank after nitric acid was transferred;
- Presence of degraded organic matter in unreasonable amounts in the tank due to deficiency of an organic phase control system;
- Deficiency of temperature control in the upper part of the vessel;
- The control vent valve was open only to 70% of its area;
- 14.2 M nitric acid was used instead of 12 M nitric acid limited by process documentation.

35.4. Lessons learned

- Limiting the concentration of nitric acid that is used for solution adjustment.
- Implementation of reliable interlock system to prevent addition of nitric acid without proper mixing/sparging of the solution.
- Improvement of the temperature control system in the large/high vessels.
- Limiting the tank solution temperature to less than 70°C.
- Providing a visible alarm signal to the personnel when technological limits are exceeded. Additional personnel training was conducted to cover emergency situations.
- Improvement of liquid waste solution treatment to prevent mixing of head-end and back-end solutions.
- Improvement of organic compounds control in the tanks, development of a reliable direct remote control of organics in the highly radioactive solutions.
- Maintaining constant ventilating of the tanks to prevent hydrogen accumulation.

35.5. Action taken

35.6. Source

"Tomsk-7 Nuclear Event — Causes, consequences and lessons learned", E.G. Kudriavtsev, presented at the OECD/NEA topical meeting, September 1994.

36. Radiation exposure of workers

Type of facility	Reprocessing
Name of facility	PNC Tokai Reprocessing Plant
Location	Tokai, Japan
Incident date	1993 December 27

36.1. Description of the incident

Four workers were exposed internally while they were replacing a filter element of the vacuum filter installed in the sampling system connected to the plutonium receiving vessel of the rework process of the plant.

Workers were supposed to seal the vacuum filter in multiple vinyl bags after removal of the filter element. However, a vinyl sheet was used instead, resulting in insufficient containment.

The conveying of the insufficiently wrapped filter element with the vinyl sheet from the vacuum distribution room and the second wrapping of the filter element in the airlock area resulted in the spread of plutonium particles from the filter element.

36.2. Important consequences

The bio-assay results showed that the maximum estimated internal exposure was 90 mSv of effective dose equivalent and 1700 mSv of tissue equivalent for one of four workers. Both dose equivalents exceeded the legal dose limit (50 mSv/year and 500 mSv/year), respectively.

The floors of the vacuum distribution room and subsequent airlock area were contaminated by the radioactive release.

36.3. Root causes

The root cause of this event was basically a violation of rules concerning working procedure.

36.4. Lessons learned

- Containment system such as bag-in/bag-out system shall be used when replacing a filter element;
- Manuals shall be revised in accordance with the changeover to containment system;
- Manuals concerning work with unsealed plutonium materials shall be revised;
- Safety education shall be performed to ascertain manual directions following the revision of the manual;
- A radiation safety checklist shall be developed for the improvement of preliminary evaluation of any possible contingencies.

36.5. Action taken

36.6. Sources

INES scale: Level 2

37. Fire and damage to spent fuel elements

Type of facility	Reprocessing
Name of facility	RT-1 Reprocessing plant
Location	Russia
Incident date	1994 August 31

37.1. Description of the incident

In the hot cell of the RT-1 reprocessing plant, a spent fuel assembly was prepared for chopping before dissolution. During the end cutting by the electric rotary tiller an electric arc (short circuit) was formed at the place of the station clamp of the assembly and the assembly jacket caught fire. Personnel stopped the process and switched off the installation.

37.2. Important consequences

The electric arc and fire caused thermal damage to several fuel elements. As a result fine radioactive particles contaminated the hot cell and they were partially released to the environment. Estimated release of Cs-137 was 0.218 Ci (4.36% of permissible limit). There was no exposure of personnel, nor contamination of the plant area or of the environment above the authorized limit.

37.3. Root causes

37.4. Lessons learned

37.5. Action taken

37.6. Sources

38. Accumulation of solid uranium

Type of facility	Enrichment
Name of facility	Portsmouth gaseous diffusion plant
Location	Ohio, USA
Incident date	1973

38.1. Description of the incident

A 1/4 inch diameter copper process pressure line was physically contacting a similar 1/4 inch diameter hydraulic oil line to a stage control valve. As a result of normal process vibrations, mutual abrasion resulted in small holes in both lines. With holes in both lines, oil from the hydraulic system entered the pressure sensing line and travelled to the below-atmospheric process system. Once inside the process system, the oil reacted with UF6 forming solid compounds. The slow leakage to the process system continued for an undetermined period of time.

In time, the cell began to behave in an unusual manner, and process control became virtually impossible. Abnormal control valve behavior coupled with high gamma radiation readings from the cell indicated a solid uranium deposit in the piping and one compressor. Neutron probe measurements yielded an estimate of a sizable deposit.

The cell was removed from service, and routine efforts to remove the deposit by in-place chemical treatment were unsuccessful. The piping from which the high gamma was emanating was removed, and a large, moderated deposit was discovered in the 8-inch diameter pipe and accompanying compressor. Enrichment was greater than 97 percent.

The area was roped off, and following planning sessions, cadmium strips were inserted, and the material was removed and placed in always-safe containers. Approximately 25 pounds of U-235 were recovered.

38.2. Important consequences

38.3. Root causes

Vibrations in the normal operation abraded two adjacent pipes.

38.4. Lessons learned

The importance of using radiation readings to detect uranium deposits.

38.5. Action taken

- The inspection and separation of the thousands of instrument and hydraulic lines throughout the process.
- Additional training of supervisors and operators.

38.6. Source

"Safety-related events at US gaseous diffusion plants", Shoemaker, J.E., 1988.

39. Release of uranium hexafluoride

Type of facility	Enrichment
Name of facility	Oak Ridge gaseous diffusion plant
Location	Tennessee, USA
Incident date	1975 September 17

39.1. Description of the incident

The accident was the result of a UF_6 - hydrocarbon oil reaction. Oil was introduced into a cylinder by a faulty vacuum pump. When the hot, liquid UF_6 was poured into the cylinder, the resultant high pressure from the reaction caused the concave cylinder heads to bulge and crack. The name plate was thrown off with considerable force, and a small amount of UF_6 was released. It is estimated that less than two litres of oil were contained in the cylinder.

The estimated amount of energy released by the reaction was 233 kcal, resulting in an internal cylinder pressure in excess of 1200 psi.

39.2. Important consequences

39.3. Root causes

The use of a faulty vacuum pump to evacuate the product cylinder caused the hydrocarbon-based oil to enter the cylinder.

39.4. Lessons learned

The exclusion of oil filled vacuum pumps for evacuation of UF6 cylinders. The evacuation of cylinders must be accomplished with equipment such as air ejectors.

39.5. Action taken

Quality assurance plans were prepared for cylinder decontamination, evacuation, and valve installation.

39.6. Source

"Safety-related events at US gaseous diffusion plants", Shoemaker, J.E., 1988.

40. Release of uranium hexafluoride

Type of facility	Enrichment
Name of facility	Portsmouth Gaseous diffusion plant
Location	Ohio, USA
Incident date	1978 March 7

40.1. Description of the incident

While a 14-ton cylinder containing liquid UF_6 (natural uranium) was being moved from the cart onto the cylinder cradle, it fell 8-10 inches because of a troubled lifter.

The cylinder developed a crack of approximately 8 inches in length, through which approximately 6.5 tU of its contents was released.

40.2. Important consequences

No human damage was reported
Restoration work was finished in a few hours.

40.3. Root causes

- The cylinder lifter was faulty.
- Maintenance procedure for the lifter was improper, and workers had not been trained enough to be able to handle the cylinder properly.

40.4. Lessons learned

40.5. Action taken

- The lifter was replaced with an improved design version.
- Maintenance procedure for the lifter was reviewed and corrected where necessary.

40.6. Sources

(1) "Safety-related events at US gaseous diffusion plants" , Shoemaker, J.E., 1988.
(2) "Incidents assessment of fuel cycle facilities", Sato, H., Kanamori, M.

41. Release of solid uranium compound

Type of facility	Enrichment
Name of facility	Oak Ridge Gaseous diffusion plant
Location	Tennessee, USA
Incident date	1981 May 27

41.1. Description of the incident

As a result of an error on a drawing, a four-inch line to process was cut allowing a large inrush of atmospheric air to enter the process. This resulted in surging of the axial-flow compressors and failure of one of the compressors. Overheating of the compressor caused growth of the aluminum rotor relative to the steel shell, and metal-to-metal rubbing occurred. Friction resulted in localized elevated temperatures initiating a UF_6 - metal reaction.

The reaction continued and eventually spread to the cooling system which released refrigerant-114 to process, further contributing to the chemical reaction; and the resulting high pressure ruptured an expansion bellows in the cell, relieving the gases to atmosphere.

The UF_6 - metal reaction reduced the UF_6 to a solid uranium compound, and a significant amount of solid material was contained within the cell after the reaction was complete. The U-235 assay was approximately 3 percent. Sprinkler systems near the affected cell were removed from service to assure that no water was added to the reaction products. A specially-modified emergency fire truck containing boronated water was available but was not needed.

A detailed action plan was developed for removal of the solid deposit. Gamma measurements indicated no real problem, and the equipment was removed, and the deposit was placed into always-safe containers. Approximately 250 pounds of uranium were recovered from the solid deposits from the cell.

41.2. Important consequences

41.3. Root causes

An error on a drawing.

41.4. Lessons learned

41.5. Action taken

- Inspection and correction of compressor running clearances to allow for rotor growth under unusual circumstances.
- Additional instrumentation to monitor stage temperatures, vibration levels, motor loads, and process pressures.
- Additional training of emergency drills involving high temperature reactions within process equipment.

41.6. Source

"Safety-related events at US gaseous diffusion plants", Shoemaker, J.E., 1988.

42. Accidental release of UF_6

Type of facility	Conversion
Name of facility	Pierrelatte
Location	Pierrelatte, France
Incident date	1977 July 1

42.1. Description of the incident

A cylinder containing 8,827 kg of liquid UF_6 at around 95 C was resting on a berth, close to the ground next to the sampling building, its valve being at the lowest position. During handling, a mishap occurred and the valve, still connected to the sampling building via a flexible tubing, broke flush with the cylinder wall leaving an opening under one inch diameter.

The release of toxic materials took place over almost one hour. Using fire-fighting equipment, water and liquid carbon dioxide were sprinkled. A total of 7,106 kg of UF_6 was released to the atmosphere. The amount of uranium detected in the atmosphere was only a small fraction of the UF_6 vaporized. Hydrogen fluoride from UF_6 hydrolysis could be traced in an area extending 15 km downwind.

42.2. Important consequences

At the locations where the highest concentrations were detected, chemical dangers were small. As for the radioactive hazard associated with uranium deposited on the ground, a dose of 1.5 mSv to the kidneys could have been received at a distance of 600 m downwind from the source but this point lay within the controlled area of the plant site.

42.3. Root causes

42.4. Lessons learned

42.5. Action taken

42.6. Source

"The Safety of the Nuclear Fuel Cycle", OECD/NEA, 1992.

43. Accidental release of UF_6

Type of facility	Conversion
Name of facility	Sequoyah Fuels Corporation
Location	Gore, Oklahoma, USA
Incident date	1986 January 4

43.1. Description of the incident

A cylinder filled with UF_6 ruptured while it was being heated because of the expansion of UF_6 as it changed from the solid to the liquid phase.

The cylinder was not properly placed on the scales during its filling. This was due to the fact that the 14-ton cylinder being filled was longer than the 10-ton cylinder for which the equipment was originally designed. One wheel of the cart was off the platform and was resting on the floor. This caused erroneously low readings on the scale during filling. After the cart and cylinder were repositioned, the scale was unable to record the actual weight of the cylinder because the weight exceeded the dial indicator range. The operator attempted to evacuate the excess material by vacuum back into the cold traps.

The next operator concluded that the material was no longer being evacuated, presumably because the contents of the cylinder had cooled and solidified. The cylinder was moved to a steam chest for being heated.

Approximately two hours after heating began, the cylinder ruptured in the steam chest. The explosion damaged the steam chest enclosure. The escaping UF_6 rapidly reacted with moisture in the air to form uranyl fluoride and hydrofluoric acid. The resulting vapour cloud of these materials was carried southeast by a wind.

43.2. Important consequences

One worker died because he inhaled hydrogen fluoride fumes. Several other workers were injured by the fumes, but none seriously. Much of the facility complex and some off-site areas to the south were contaminated with hydrogen fluoride and a second reaction product, uranyl fluoride.

43.3. Root causes

- The cylinder was overfilled because it was not placed fully on the scales. Plant facilities were not designed to accommodate 14-ton cylinders, and associated equipment was not designed to prevent improper positioning of cylinders on the scales.
- The time required for filling the cylinder was long enough to allow partial solidification of the UF_6 which inhibited product removal from the cylinder.
- The precise weight of the cylinder was not readily determinable after it was overfilled.
- Employees violated company procedures when they heated an overfilled cylinder. Workers, including line-management personnel, had not been trained in regard to company procedures. Procedural controls such as checklists or approval points were not an integral part of plant operations.
- Equipment for monitoring or automatically venting cylinders was not provided for by the plant design.

In summary, the factors can be aggregated into the following causes of the accident:

1. The physical equipment and facilities used for filling and weighing UF_6 cylinders were inappropriate for safe use with 14-ton cylinders.

2. The training of workers in operating procedures, and ensuring the implementation of the procedures, was not carried out effectively.

43.4. Lessons learned

43.5. Action taken

43.6. Source

Report to Congress on abnormal occurrences, Vol. 9, No. 1 1986.

44. Accidental release of UF_6

Type of facility	Conversion
Name of facility	Comurhex's Pierrelatte conversion plant
Location	Pierrelatte, France
Incident date	1987 April 12

44.1. Description of the incident

The leak of UF_6 from a 48Y cylinder occurred when technicians tried to block a valve on the container whose bolt had split, causing the valve to lose leaktightness. Although there were 5.5 metric tons U of UF_6 in the cylinder before the leak, measurements indicated that around 700 grams U, of natural uranium had escaped into the atmosphere from the cylinder filling shop in which the leak occurred.

44.2. Important consequences

Seven employees were slightly injured. Six of them had suffered burns on hands and feet from the CO_2 foam and limestone used to neutralize the UF_6-oxygen reaction within the filling cell; the seventh suffered glass cuts on his hand. The electronic scale mechanism for weighing the cylinder was corroded and some components had to be replaced.

44.3. Root causes

44.4. Lessons learned

44.5. Action taken

44.6. Source

Nuclear Fuel, April 20, 1987.

45. Seepage of uranium-contaminated water

Type of facility	Conversion
Name of facility	Sequoyah Fuels Corporation (SFC)
Location	Gore, Oklahoma, USA
Incident date	1990 August 22

45.1. Description of the incident

Uranium-contaminated water was discovered seeping into an excavation near the solvent extraction building. The uranium concentration in the seepage ranged up to 8 grams per litre, which was substantially above SFC's environmental action level of 0.000225 grams per litre for uranium in water.

45.2. Important consequences

Because evidence indicated that the contaminated water did not migrate offsite or reach the water table, there was no impact on public health and safety.

45.3. Root causes

45.4. Lessons learned

45.5. Action taken

45.6. Source

Report to Congress on Abnormal Occurrences, NUREG-0090, Vol.13, No. 3.

46. Release of nitrogen dioxide gas

Type of facility	Conversion
Name of facility	Sequoyah Fuels
Location	Gore, Oklahoma, USA
Incident date	1992 November 17

46.1. Description of the incident

In the facility, digesters are used to dissolve "uranium concentrate" to produce feed materials for the solvent extraction system. About 1,225 kg of nitrogen dioxide gas was released in the digester area of the main process building. The duration of the release was about 20 minutes.

The release of several nitrogen oxide gases, the bulk of which was nitrogen dioxide gas, resulted from an uncontrolled chemical reaction that occurred when nitric acid was placed in what was supposed to be an empty digester. The digester actually contained about 3,992 kg of uranium concentrate. Uranium concentrate had been inadvertently added to the digester due to operator error in operating the screw conveyor and a faulty isolation valve which was stuck in the open position. The resultant uncontrolled reaction overwhelmed the off-gas handling system and forced the nitrogen oxide gases out of the digester into the main process building.

46.2. Important consequences

The nitrogen oxide gas escaped the main building and was carried by a southeasterly wind toward Gore, Oklahoma, which is located about 4.83 km northwest of the plant. Residents of Gore did not report a visible cloud nor did they report eye or respiratory irritations. All air sampling performed in the town showed negative results. However, several workers and members of the public who were near the facility at the time of the release, reported signs and symptoms characteristic of exposure to nitrogen dioxide gas.

46.3. Root causes

46.4. Lessons learned

46.5. Action taken

46.6. Source

Report to Congress on Abnormal Occurrences, NUREG-0090, Vol.16, No.1.

47. Contamination

Type of facility	Fuel fabrication
Name of facility	Nukem
Location	Hanau, Germany
Incident date	1987 February 27

47.1. Description of the incident

Detection of americium in one worker's stools indicated that he had ingested a trace amount of plutonium. Examination of 67 other employees revealed radiation doses in 14 workers of between 0.002 Bq and 0.068 Bq. The Pu problem arose while the employees were handling a 4.3-gram batch of ostensibly pure UO_2 which in fact contained 0.2 g Pu.

47.2. Important consequences

47.3. Root causes

47.4. Lessons learned

47.5. Action taken

47.6. Source

Nuclear Fuel, March 23, 1987.

48. Release of uranium powder

Type of facility	Fuel fabrication
Name of facility	Assea Atom
Location	Vasteras, Sweden
Incident date	1989 January 11

48.1. Description of the incident

The incident started in the reduction furnace, when a valve in the pneumatic filter-cleaning system malfunctioned; the resulting pressure increase opened the relief valve. The relief valve failed to reset properly, while the furnace gas supply did not stop. This resulted, over a one-hour period, in about 200 kg of 3 per cent enriched uranium following the fumes from the furnace to the scrubber system and subsequently to the storage tanks.

Triggered by the sludge-level alarm, the storage tank was emptied three times normally within a period of four hours. After the last emptying the alarm signal was not deactivated which led to the solution being flushed onto the floor one hour later.

48.2. Important consequences

48.3. Root causes

Plant item malfunctioning was mainly due to quality assurance failures.

48.4. Lessons learned

- Quality assurance requires special care and consideration when applied to safety;
- A well-trained operator of the Quality Assurance Programme for Safety is essential for the effective and smooth operation of compliance assurance.

48.5. Action taken

48.6. Source

"The Safety of the Nuclear Fuel Cycle", OECD/NEA, 1992.

49. Explosion

Type of facility	Fuel fabrication
Name of facility	Siemens uranium fuel element fabrication
Location	Hanau, Germany
Incident date	1990 December 12

49.1. Description of the incident

An explosion occurred in a scrubber at the fuel fabrication plant for uranium fuel elements in Hanau. The spray scrubber for off-gas cleaning was part of the installation for uranium recycling and treatment of liquid waste streams.

The scrubber treated the off-gas of several systems; nitrous gases from dissolvers, ammonia, organic carbon and fluoride from furnaces, ammonia from storage and precipitation tanks. In the scrubber pool there was an ammonium nitrate solution with parts of ammonium nitrate, fluoride and organic compounds.

Due to a failure of the liquid level control, the ammonium nitrate concentration in the scrubber liquid increased because of evaporation of the water into the off-gas. Probably the formation of slurry, or crystallization, occurred in consequence. Obviously the explosion was initiated by the hot-running loop pump. The rapid thermal decomposition of ammonium nitrate destroyed the pump and struck back to the sump of the scrubber where an explosion also took place and the remaining scrubber pool liquid was thrown upwards.

49.2. Important consequences

The lower part of the scrubber column built of steel was ripped and demolished, the bottom was thrown down and the upper part built of polyvinyl chloride was broken into many pieces; also bolts and flanges were torn. The housing of the loop pump was smashed into small missiles. The adjacent storage tanks, pipings and switch cabinets were deformed by the pressure wave. Some storage tanks were penetrated by missiles and also the roof of the hall got some small holes.

No radiation or emission of radioactivity to the environment occurred. Two workers were injured, one of them severely.

49.3. Root causes

49.4. Lessons learned

- The off-gas of the dissolvers and the calcining furnaces or other liquid waste treatment systems will be cleaned in separated scrubbers;
- The scrubber has to be operated in a way that the formation of ammonium nitrate can be neglected.
- The liquid level control in the scrubbers has to be improved so that undetected concentration cannot occur;
- The pump control of systems with ammonium nitrate solution has to guarantee that no "dead-heated" pumps could cause local concentration increases.

49.5. Action taken

49.6. Source

"The Safety of the Nuclear Fuel Cycle", OECD/NEA, 1992.

50. Inhalation of plutonium

Type of facility	Fuel fabrication
Name of facility	Siemens MOX plant
Location	Hanau, Germany
Incident date	1991 June 18

50.1. Description of the incident

Routine measurements of four workers were taken as required by radiation protection regulations after they had removed from a safe and transported on a cart a canister containing 3.3 kg of MOX powder. The powder, which contained 27% PuO_2, was in a double-sealed foil package.

Measurements indicated that three of the workers had been contaminated. After the incident, a four-centimeter-long rip was found along the seam of the foil container holding the MOX powder.

50.2. Important consequences

Three workers were contaminated by MOX powder.

50.3. Root causes

A four-centimeter-long rip along the seam of the foil container.

50.4. Lessons learned

50.5. Action taken

50.6. Source

Nuclear Fuel, June 24, 1991.

51. Potential criticality

Type of facility	Fuel fabrication
Name of facility	GE fuel & component manufacturing facility
Location	Wilmington, North Carolina, USA
Incident date	1991 May 29

51.1. Description of the incident

Higher than expected amounts of uranium were identified in a process tank of the waste treatment system, posing a potential criticality safety problem. The amount was approximately 2300 parts per million or 150 kg total uranium (about four percent enriched in uranium-235). The administrative criticality safety limit for transferring uranium into the process tank vessel (an unfavorable geometry tank) was 150 parts per million.

Sparging (mixing) was initiated in this tank to minimize the criticality potential by preventing an accumulation of material in the bottom of the tank. Later, uranium recovery operation began to remove uranium from this tank via a centrifuge linked to the tank.

51.2. Important consequences

51.3. Causes

- There was a pervasive attitude that a nuclear criticality was not a credible accident scenario.
- Management did not provide effective guidance and oversight of activities to ensure that operations were conducted in a safe manner.
- There was a production-minded orientation within the organization that was not sufficiently tempered by a "safety first" attitude.

51.4. Lessons learned

- System walkdowns and verifying that documentation matched current plant configuration;
- Revising procedures;
- Retraining of operators;
- Revamping sampling to ensure adequacy for measurement of uranium.

51.5. Action taken

51.6. Source

Report to Congress on Abnormal Occurrences, NUREG-0090, Vol.14, No.2.

52. Contamination around a machine and to workers

Type of facility	MOX fuel fabrication
Name of facility	FBFC International
Location	Dessel, Antwerpen, Belgium
Incident date	1992 November 23

52.1. Description of the incident

A fuel assembly bench consists of a bench to support the skeleton, a magazine filled with cleaned rods and an automatic pulling machine. The pulling machine first sends pincers through the skeleton. The pincers grab the fuel rod bottom end then pull the rods into the skeleton.

To avoid damaging the skeleton with the pincers, protective caps are placed on the pincers before they enter the skeleton. They are removed automatically when the pincers are through.

When pulling the first row of rods into the assembly, one rod was missed by its pincers. The automatic sequence was not interrupted, so the cap removing mechanism began to move to take its position for the next row of rods, hitting the rod remaining half way in the skeleton. The fuel rod, with approximately 4.5% Pu, was broken and the grinding dust was blown up by the fuel rod internal helium pressurisation.

52.2. Important consequences

The dust was carried away with the ventilation air current and spread around inside the building. Seven operators had only very slight external contamination, which disappeared after they showered; the eighth technician, who was close to the machine, had significant internal contamination. However the cumulated radiation dose was well under the legal yearly limit of 50 mSv.

The broken rod was removed and stored in a leak-tight container. There was no contamination of the external environment, since the fuel assembly workshop is completely closed.

52.3. Root causes

52.4. Lessons learned

The design of ventilation systems was reviewed. The air was formerly impulsed towards the assembly area (not contaminated in normal operation), then directed to the pelleting area along with the cascade of air depressions, before extraction and absolute filtration, so small but measurable quantities of Pu were found in the pellet and fuel rod areas.

52.5. Action taken

The fuel rod testing and skeleton area is separated from the uranium area; the assembly area and assembly storage room form new separated compartments, equipped with absolute filters. The extraction systems are located more closely to the potential aerosol sources.

The machines were also equipped with additional electronic and mechanical safety devices. Training sessions, including all safety aspects, have been organized for the workforce.

52.6. Source

"Some concrete safety aspects of the fuel manufacturing at FBFC International", P. Van Denhove, 1993.

53. Potential criticality

Type of facility	Fuel fabrication
Name of facility	B&W Naval fuel plant
Location	Lynchburg, Virginia, USA
Incident date	1994 June 29

53.1. Description of the incident

Workers in a scrap recovery area dissolved the contents of six bottles holding, they thought, 121 grams of U-235. After processing, they found the system held 649 grams of U-235, far above the 350-gram safety limit set for the unit. The problem arose because the six plastic bottles holding the material were not labeled properly. A "drum counter" used to measure the amount of radioactive material in the bottles recorded an inaccurate measurement.

53.2. Important consequences

53.3. Root causes

53.4. Lessons learned

53.5. Action taken

53.6. Source

Nuclear Fuel, July 18, 1994.

54. Fire

Type of facility	Fuel fabrication
Name of facility	B&W Naval fuel plant
Location	Lynchburg, Virginia, USA
Incident date	1994 July 7

54.1. Description of the incident

Fire broke out in a metallurgical lab where two maintenance workers were repairing a saw. Pyrophoric zirconium chips and enriched uranium caught fire, with radioactive dust falling on six workers. The fire was put out quickly. One of the workers received a first degree burn on his arm; he was treated and went back to work. The workers and the laboratory were decontaminated.

54.2. Important consequences

54.3. Root causes

54.4. Lessons learned

54.5. Action taken

54.6. Source

Nuclear Fuel, July 18, 1994.

55. High-dose irradiation of off-site residents by iodine released in the 1940s

Type of facility	Reprocessing
Name of facility	Hanford Nuclear Reservation
Location	Hanford, Washington, USA
Incident date	1944 through 1947

55.1. Description of the incident

It was reported in July 1990 that a large amount of iodine, 400 000 Ci in I-131 had been released over a period from 1944 to 1947 from the Hanford Nuclear Reservation then in the initial stage of commercial operation, exposing local residents to radiation.

Investigations into this incident are under way with the support of the US Department of Energy under a 5-year program called "Hanford Environment Dose Reconstruction Project". The above is an interim finding.

By comparison, 7 300 000 Ci of I-131 was released in the Chernobyl accident and 20 000 Ci in the well-known graphite gas-cooled reactor accident at Sellafield.

55.2. Important consequences

According to the report, for the wartime to postwar period of 3 years, 5% of 270 000 residents living around the Hanford site, or 13,500 persons, had absorbed more doses than 33 rad in the thyroid gland and that 1,200 infants had been irradiated with doses ranging from 15 to 650 rad. While it is possible that some of these infants were exposed to the highest 2,900 rad of radiation, the report says that there are many uncertainties with respect to the high-dose area.

These doses are considered to be worth health effect investigation, which is now under way by other groups.

55.3. Causes

In those days, insufficient information and knowledge was available about radiation control, which led to the heavy release of I-131.

55.4. Lessons learned

55.5. Action taken

In 1963, the release of I-131 at Hanford was noticeably reduced to 0.38 Ci per day. The Hanford Reprocessing Plant was shut down in 1972 and resumed operation at the end of 1983. The 1987 and 1988 releases of I-131 were reported as 0.002 Ci and 0.004 Ci, respectively. These data imply that proper control and management can reduce the release of I-131 to a non-hazardous extent.

55.6. Source

"Incidents assessment of fuel cycle facilities", Sato, H., Kanamori, M.

56. Explosion

Type of facility	Waste storage
Name of facility	Weapons Material Production Facility
Location	Kyshtym, Southern Urals, Russia
Incident date	1957 September 29

56.1. Description of the incident

A chemical explosion took place in a high-level radioactive waste storage tank, one of 16 steel tanks of about 300 m^3. This waste had been treated for removal of caesium and iodine. The storage tanks were contained in a block of concrete vaults that provided a space around each tank; this space was filled with cooling water. This cooling arrangement was somewhat primitive, consisting as it did of merely periodically changing the water surrounding the tanks.

When a leak occurred in one of the pipes carrying radioactive liquid, the cooling water around one of the tanks was contaminated and was pumped out but not replaced. The contents of the tank - about 70-80 tonnes of liquid containing around 20 MCi of waste - became overheated and largely evaporated, leaving explosive residues of sodium nitrate and acetate salts. These residues reached a temperature of 350°C and , at 4:20 p.m. on September 29, exploded, with an estimated force equivalent to 70-100 tonnes of TNT.

In the tank concerned, strontium-90 in equilibrium with yttrium-90 comprised 5.4% of the waste activity. Because caesium-137 had been selectively removed from the waste, it accounted for only 0.036% of the activity. The amounts of plutonium and iodine present were described as "negligible". The balance of the activity came from short-lived isotopes (isotopic composition of the waste was; Ce-144 + Pr-144 - 66%, Zr-95 + Nb-95 - 24.9, Sr-90 + Y-90 - 5.4%, Ru-106 - 3.7%, Cs-137 - 0.036%).

56.2. Important consequences

Two adjacent tanks were damaged. Most of the 20 MCi was deposited in the immediate vicinity of the tank, but an estimated 2 MCi was ejected up to 1000 m into the atmosphere (compared to 50 MCi during the Chernobyl accident). The radioactive plume extended over a distance of 105 km, but fortuitously was confined to a narrow width of only 8-9 km.

Within the first 7-10 days after the accident, about 600 people were evacuated from nearby settlements, where maximum densities of strontium-90 were in the range of 10-100 Ci/km^2. Over the following 18 months, further evacuations were carried out, eventually totaling 10,180 people. Maximum average exposure doses preceding evacuation reached 17 rem in external exposure and 52 rem in effective dose equivalent.

The region with a Sr-90 contamination density in excess of 2 Ci/km^2 was 1,120 km^2. By deep ploughing (about 50 cm), the radioactivity level at the surface was gradually reduced to lower levels.

Extensive health studies were carried out among the evacuated populations, as well as on other populations from the surrounding regions and a control population from another region. No statistically significant differences have been observed for any of the groups.

56.3. Causes

Deficiency of temperature control in the waste storage tank and possibility for interruption of the cooling of the tank.

56.4. Lessons learned

56.5. Action taken

The waste storage farm was redesigned and measures were taken to guarantee effective control of the parameters. Soon after the event technology was improved to avoid accumulation and storage of the explosive wastes.

56.6. Sources

(1) "Report on a radiological accident in the southern Urals on 29 September 1957", IAEA-INFCIRC/368, 28 July 1989.
(2) "More details presented on 1957 Urals accident", Nuclear News, Jan. 1990.

INES scale: Level 6

57. Fire danger

Type of facility	Spent fuel storage
Name of facility	Dry storage of MAGNOX fuel
Location	Wylfa, North Wales, United Kingdom
Incident date	1990 through 1991

57.1. Description of the incident

In summer 1990, only a fraction of the 21,000 elements of MAGNOX fuel were found to corrode. If water penetrates the cladding of the element, it can react with the metallic uranium fuel. One of the corrosion products is uranium hydride, which can ignite spontaneously in air. If enough uranium hydride burns, it can ignite the metallic uranium and release the highly radioactive fission products held in the uranium bar.

57.2. Important consequences

Surveillance confirms that the affected elements are all dry, stable and safe. The fire risk is therefore minimal; even if it occurred, the design of the store, which is kept at lower than atmospheric pressure with a full filter system, ensures that there would be no external risk.

57.3. Root causes

57.4. Lessons learned

57.5. Action taken

57.6. Source

"Fire danger at North Wales nuclear store", New Scientist, 2 and 16 March, 1991.

58. Thermal-chemical explosion

Type of facility	Isotope production plant
Name of facility	Pu-238 production facility
Location	Mayak, Russia
Incident date	1993 July 17

58.1. Description of the incident

The facility was used for Pu-238 recovery and purification. The column was installed in canyon with stainless steel lining. The column itself had a water cooling jacket, total volume of the column was 28 litres.

Before the event Pu-238 was sorbed on the ion-exchange resin from nitric acid solution. After the sorption process was finished the Pu-238 contained resin was flushed and the column was prepared for Pu stripping.

Due to the partial loss of solution from the column, the upper part of the resin drained and thus lacked the cooling. Selfheating of the resin because of the Pu-238 radioactive decay caused thermal decomposition of the resin, a gas generation and the column over pressure.

The rupture of the upper part of the column resulted in Pu contamination of the canyon and spilling of a burnt resin.

58.2. Important consequences

It was estimated that through the off-gas cleaning system 0.192 mCi of Pu-238 was released outside the building (about 0.01% of permissible year release). No worker contamination or injury occurred.

58.3. Root causes

After some changes were made in the design of the installation before the event, no changes were made in the process documentation. The necessary interlocking of the valves was not changed. An additional cause of the event could be connected with Pu-238 over-concentration in the upper part of the column.

58.4. Lessons learned

58.5. Action taken

All the ion exchange processes were examined and corrections were made. The design of the ion exchange column was improved and a new column was installed. An additional off-gas cleaning system was installed.

58.6. Sources

GLOSSARY

Magnox	A reactor or fuel used in the reactor (A thermal reactor named after the magnesium alloy in which the uranium metal fuel is contained. The moderator is graphite and the coolant is carbon dioxide gas).
MOX powder	Mixed powder of uranium oxide and plutonium oxide, which is blended, sintered and fabricated for the fuel used in light-water cooled reactors.
Purex process	**P**lutonium-**ur**anium reduction **ex**traction. One of the reprocessing processes which uses a mixture of tributyl phosphate and a hydrocarbon diluent to extract uranyl nitrate and plutonium nitrate from an aqueous solution containing nitric acid.
raffinate	The waste stream remaining after the extraction of valuable materials from solution in the milling, refining and reprocessing operations.
solvent extraction	A method to purify natural uranium, and to separate fissionable material and fission products in spent fuel, by making use of their differing solubilities in solvents which do not remain in a mixture with each other.

ABBREVIATIONS

INES	International Nuclear Event Scale
IRS	Incident Reporting System
TBP	tributyl phosphate, which is used as a solvent in the refining and reprocessing operations

CONTRIBUTORS TO DRAFTING AND REVIEW

Kanamori, M. — Safety Division,
Power Reactor & Nuclear Fuel Development Corporation,
9-13, Akasaka 1-chome, Minato-ku,
Tokyo 107,
Japan

Kudryavtsev, E. — Main Nuclear Chemical Department,
Ministry of Atomic Energy of the Russian Federation,
Staromeonetny per. 26,
RUS-109180 Moscow,
Russian Federation

Orita, Y. *(Scientific Secretary)* — Division of Nuclear Fuel Cycle and Waste Management,
International Atomic Energy Agency,
Wagramerstrasse 5, P.O. Box 100,
A-1400 Vienna, Austria

Roberts, D. — HM Nuclear Installations Inspectorate,
Rose Court,
2 Southwark Bridge,
London SE1 9HS,
United Kingdom

Sato, H. — Nuclear Materials Regulation Division,
Nuclear Safety Bureau,
Science & Technology Agency,
Kasumigaseki 2-2-1,
Chiyodaku, Tokyo,
Japan

Takamatsu, M. *(Scientific Secretary)* — Division of Nuclear Fuel Cycle and Waste Management,
International Atomic Energy Agency,
Wagramerstrasse 5, P.O. Box 100,
A-1400 Vienna, Austria