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MACHINERY BREAKDOWN RISKS OF NUCLEAR POWER PLANTS

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CHAPTER 1 - INTRODUCTION

This paper presents an overview of the machinery breakdown aspects, provides data on nuclear energy context and describes the following issues.

The nuclear power has become an important energy source in many countries since its introduction four decades ago.
At the end of 2001, there were 438 operating nuclear power reactors. Together they provided about 16% of global electricity generation. The main nuclear countries are Japan, US, France, Germany, and some West Europe countries.

There are several different types of reactors but most about 79% of the nuclear power reactors in operation are water-cooled reactors. Advanced reactors designs are in stages of development.

At nuclear power plants worldwide, electrical and mechanical equipment does break down occasionally. Although these failures do not necessarily compromise nuclear safety, they can cause significant damage to equipment, leading to a considerable loss of generating revenue and causing sizeable insurance losses.
Additionally, machinery failures at power plants can cause major fire events.

More than 85% of world’s commercial nuclear reactors are insured by the nuclear insurance pools.
The largest part of the property insurance risk has its origin in the machinery breakdown events.
Since late 1989, there have been several major incidents due to machinery breakdown events which attracted attention around the world.

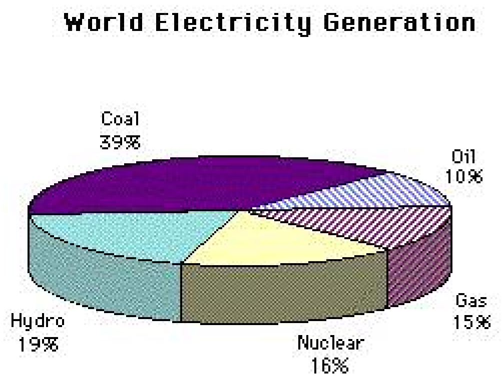
Machinery breakdown losses can be minimized through the development of quality operating, maintenance and training programmes. And the peculiarities of this industry have to be taken into account.

Nuclear power plants, like all industrial installations, are subject to ageing. The lifetime and decommissioning of nuclear power plants is a main issue for the near future and the consequences, in terms of operation insurance, have to be analysed.

CHAPTER 2 - NUCLEAR ENERGY IN ELECTRICITY GENERATION

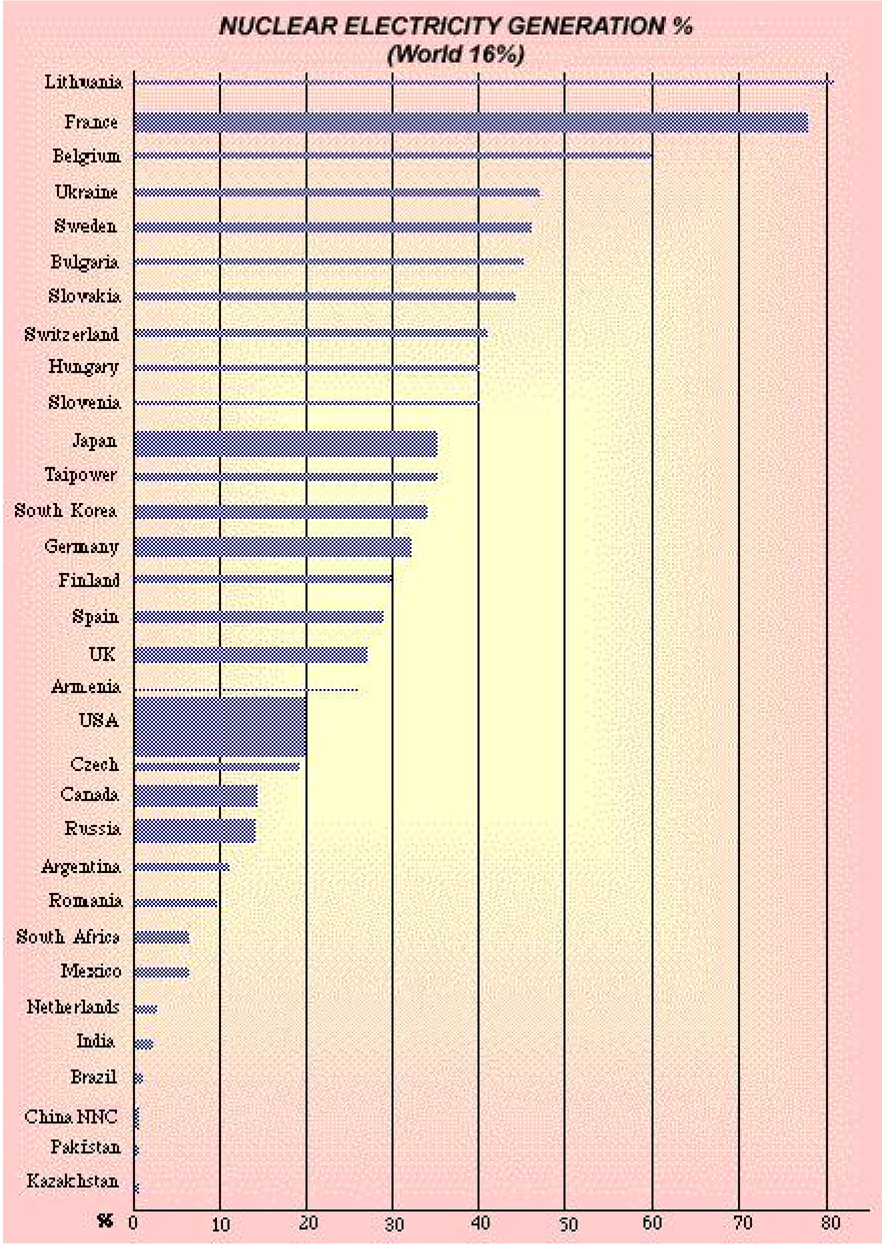
The nuclear power has become an important energy source in many countries since its introduction four decades ago.
The first commercial nuclear power stations started operation in the 1950s.

Over the past 50 years, nuclear power has become an important part of the energy mix in many countries. At the end of 2001, there were 438 operating nuclear power reactors. This was equal to 351 GW(e) of installed capacity. Together they provided about 16% of global electricity generation. Six new power reactors, with a total capacity of 3056 MW(e), were connected to their respective national electricity grids in 2000. Three of these were in India, while Brazil, Czech Republic and Pakistan each had one. One reactor was shut down – Chernobyl-3 in Ukraine.



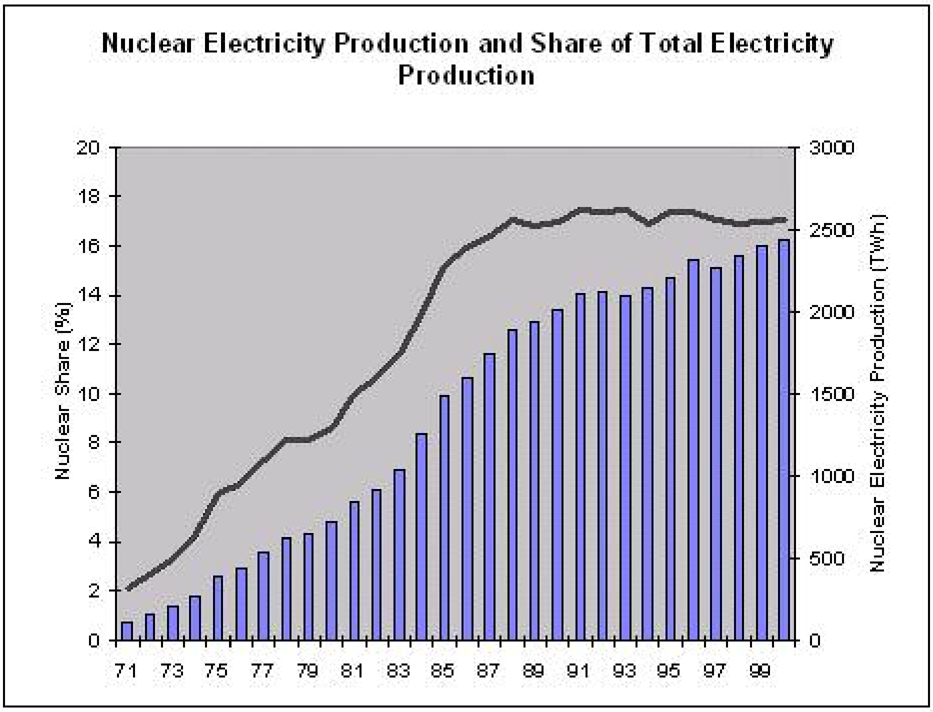
Canada is the world's leading supplier of uranium.

Over 30 countries are using nuclear power to produce electricity. In 2001, its share of total electricity generation ranged from 76 % in France to 1.4% in Brazil. The construction of 31 new power reactors, equivalent to 8.2% of existing capacity, continued in Argentina, China, the Czech Republic, the Islamic Republic of Iran, Japan, the Republic of Korea, the Russian Federation, Romania, Slovakia and Ukraine.



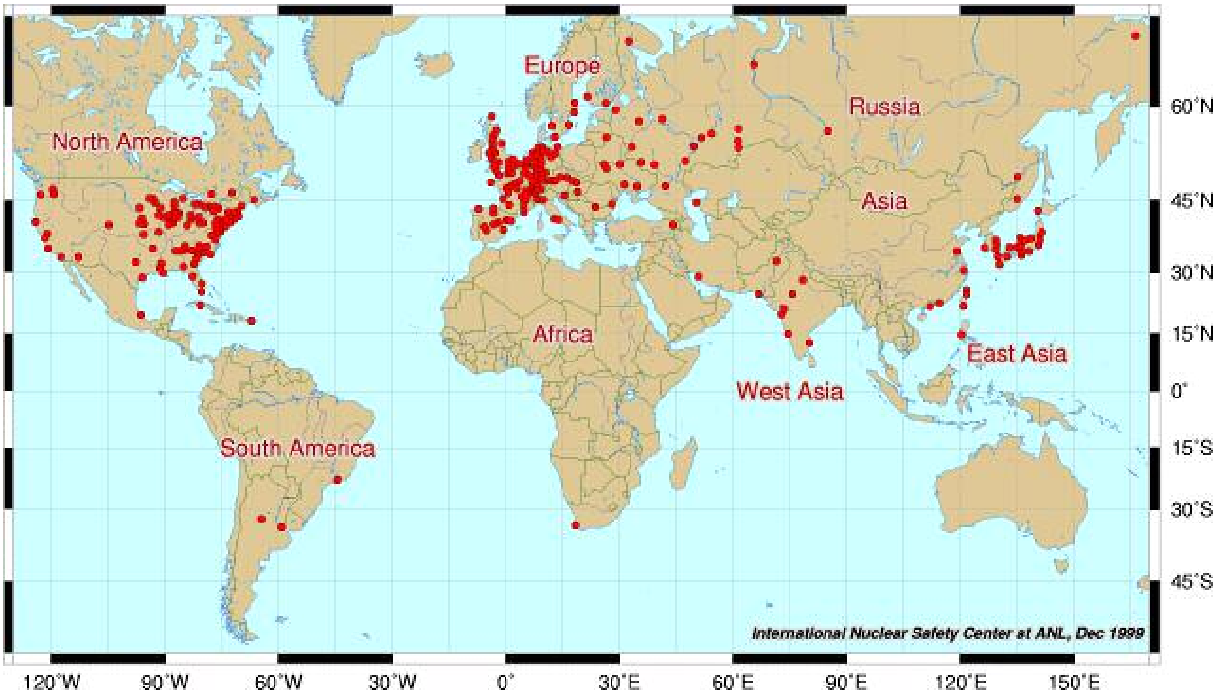
While a survey of global nuclear power plant construction plans indicates that, in constrast to Asia, no new plants are being built or have been ordered in North America and Western Europe, the economics of existing nuclear power plants showed improvement in 2001, particularly in North America.

Asia is the only region in the world where electricity generating capacity and specifically nuclear power is growing significantly
In East, South and SE Asia there are currently 94 nuclear power reactors in operation, 19 under construction and plans to build about a further 35.
The greatest growth in nuclear generation is expected in China, Japan, South Korea and India.



SOURCES:
ANSTO, data to March 2002
ENS NucNet background # 16/00
Nuclear Engineering International, February 2001

CHAPTER 3 – NUCLEAR POWER PLANTS IN THE WORLD



* * * *

	Nuclear Electricity Generation 2000		Reactors Operating Dec 2001		Reactors Construction Dec 2001		On order Or planned Dec 2001		Uranium Required 2001
	Billion kWh	%	No.	MWe	No.	MWe	No.	MWe	Tonnes U
Argentina	5.7	7.3	2	935	0	0	1	692	133
Armenia	1.8	33	1	376	0	0	0	0	68
Belgium	45	57	7	5728	0	0	0	0	68
Brazil	5.6	1.5	2	1855	0	0	0	0	1109
Bulgaria	18	45	6	3538	0	0	0	0	296
Canada	69	12	14	9998	6*	3598	0	0	618
Chinese									1343
China NNC	16	1.2	3	2167	8	6370	2	1800	572
Taiwan	37	24	6	4884	2	2600	0	0	966
Czech Republic	14	19	5	2560	1	912	0	0	519
Finland	21	32	4	2656	0	0	1	1000	553
France	395	76	59	63203	0	0	0	0	10159
Germany	160	31	19	21141	0	0	0	0	3712

Hungary	15	42	4	1755	0	0	0	0	425
India	14	3.1	14	2548	2	1000	4	2310	312
Iran	0	0	0	0	1	950	0	0	0
Japan	305	34	54	44301	3	3696	12	15858	7393
Korea DPR (north)	0	0	0	0	0	0	2	1900	0
Korea RO (South)	104	41	16	12970	4	3800	8	9200	2466
Lituania	8.4	74	2	2370	0	0	0	0	359
Mexico	7.9	3.9	2	1310	0	0	0	0	232
Netherlands	3.7	4.0	1	452	0	0	0	0	115
Pakistan	1.1	1.7	2	425	0	0	0	0	56
Romania	5.1	11	1	655	1	620	0	0	90
Russia	120	15	30	20793	3	2625	2	1900	3411
Slovak Rep	16	53	6	2472	2	840	0	0	528
Slovenia	4.5	3.7	1	679	0	0	0	0	131
South Africa	13	6.7	2	1842	0	0	0	0	363
Spain	59	28	9	7345	0	0	0	0	1613
Sweden	55	39	11	9460	0	0	0	0	1533
Switzerland	24	36	5	3170	0	0	0	0	599
Ukraine	72	47	13	11195	2	1900	0	0	1893
United Kingdom	78	22	33	12528	0	0	0	0	2588
USA	754	20	104	98105	0	0	0	0	20801
WORLD	**2447**	**16**	**438**	**353,42**	**35**	**28.91**	**32**	**34,66**	**64,956**
	Billion kWh	**%**	**No.**	**MWe**	**No.**	**MWe**	**No.**	**MWe**	**Tonnes U**

Sources :

Reactor data : ANSTO, based on information to 1 december 2001

- In Canada, construction data is for four laid-up Pickering A reactors expected to re-enter service by 2003, plus two Bruce A units very likely to do so later.
- IAEA – for electricity production.
- WNA : Global Nuclear Fuel Market (reference scenario) – for U
- Operating = Connected to the grid
- Building / Construction = first concrete poured
- Planned = Relatively firm plans
- TWh = Terawatt-hours (billion kilowatt-hours), MWe = Megawatt net (electrical as distinct from thermal), kWh = kilowatt-hour
- NB : 64,956 tU = 76,603 t U_3O_8

CHAPTER 4 – NUCLEAR REACTORS TECHNOLOGY

A nuclear reactor produces and controls the release of energy from splitting the atoms of certain elements. In a nuclear power reactor, the energy released is used as heat to make steam to generate electricity. The principles for using nuclear power to produce electricity are the same for most types of reactor. The energy released from continuous fission of the atoms of the fuel is harnessed as heat in either a gas or water, and is used to produce steam. The steam is used to drive the turbines which produce electricity (as in most fossil fuel plants).

There are several components common to most types of reactors :

Fuel : Usually pellets of uranium oxide (UO2) arranged in tubes to form fuel rods. The rods are arranged into fuel assemblies in the reactor core.

Moderator : This is material which slows down the neutrons released from fission so that they cause more fission. It may be water, heavy water, or graphite.

Control rods : These are made with neutron-absorbing material such as cadmium, hafnium or boron, and are inserted or withdrawn from the core to control the rate of reaction, or to halt it. (Secondary shutdown systems involve adding other neutron absorbers, usually as a fluid, to the system.)

Coolant : A liquid or gas circulating through the core so as to transfer the heat from it.

Pressure vessel or pressure tubes : Either a robust steel vessel containing the reactor core and moderator, or a series of tubes holding the fuel and conveying the coolant through the moderator.

Steam generator : Part of the cooling system where the heat from the reactor is used to make steam for the turbine.

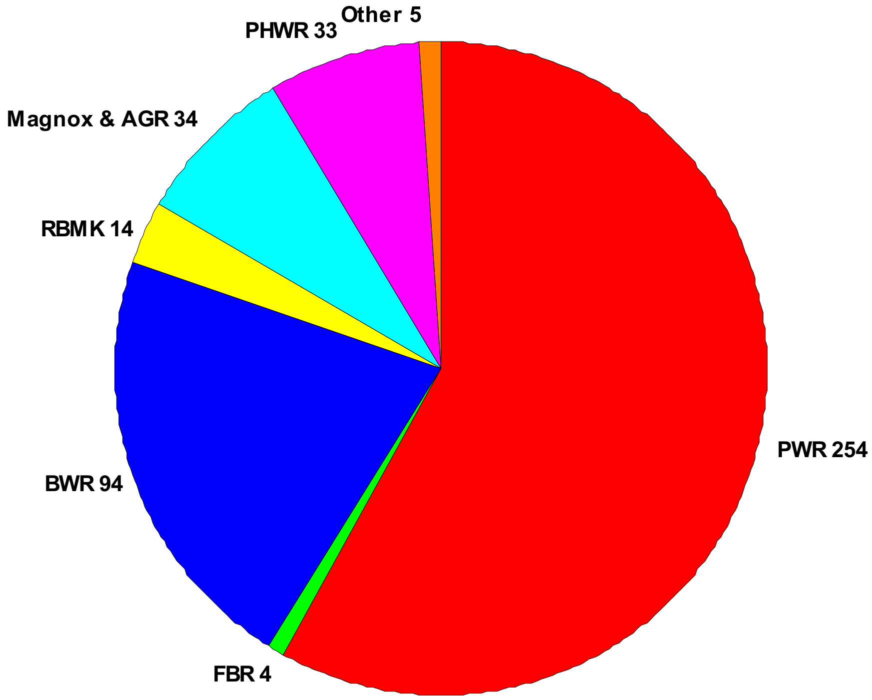
Containment : The structure around the reactor core which is designed to protect it from outside intrusion and to protect those outside from the effects of radiation or any malfunction inside. It is typically a metre-thick concrete and steel structure.

Most about « about 79% » of the nuclear power reactors in operation are water-cooled reactors. They are of two basic types : light-water reactors (LWRs) with ordinary water as moderator, and heavy-water reactors (HWRs). The LWRs are in turn subdivided into boiling and pressurized water reactors (BWRs and PWRs).

Typical examples of advanced HWRs under development

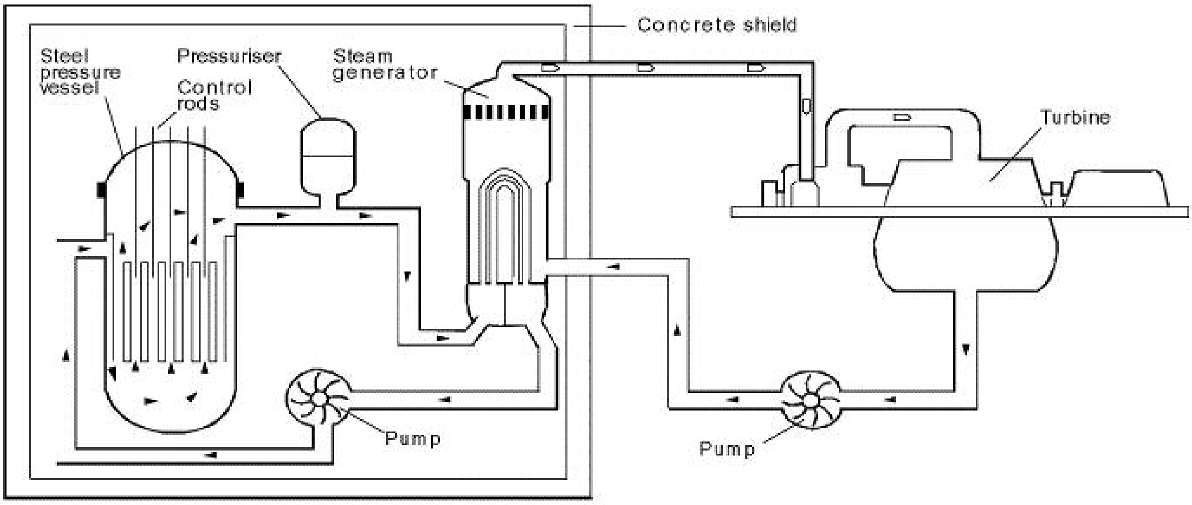
There are several different types of reactors as indicated in the following table.

Most nuclear electricity is generated using just two kinds of reactors which were developed in the 1950s and improved since.



GWe: capacity in thousands of megawatts.
Source : Nuclear Engineering International handbook 2000 updated, including Pickering A in Canada**.**

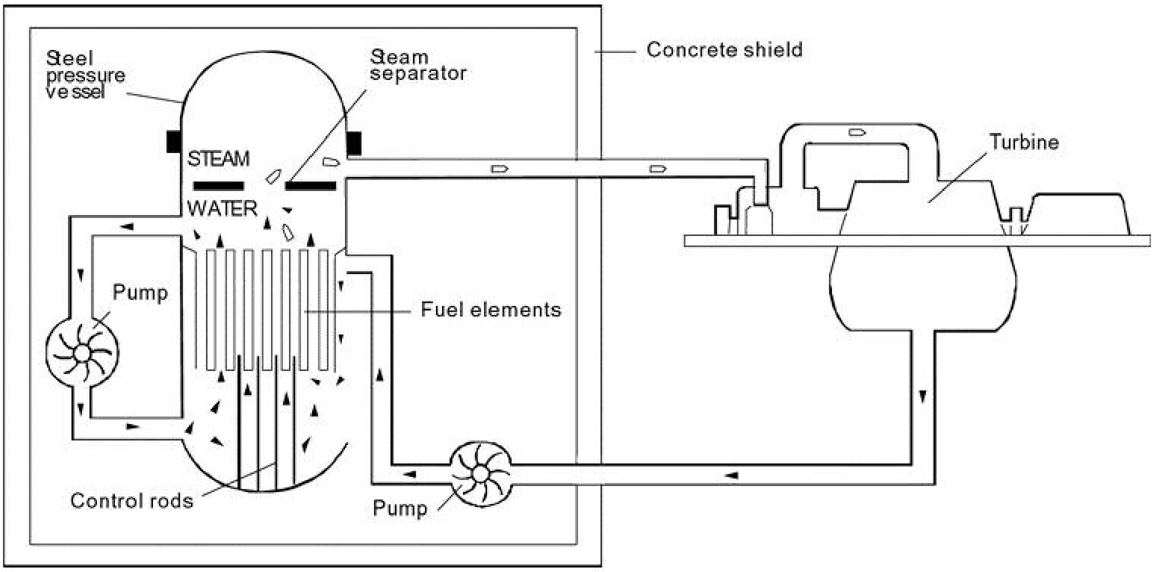
4 . 1 - PWR : Pressurised Water Reactor



Main countries : US, France, Japan, Russia,… with a total of 252 reactors equalling 235 Gwe.
Fuel : enriched UO2
Coolant : Water
Moderator : Water

This is the most common type, with over 250 in use for power generation and a further several hundred in naval propulsion. The design originated as a submarine power plant. It uses ordinary water as both coolant and moderator. The design is distinguished by having a primary cooling circuit which flows through the core of the reactor under very high pressure, and a secondary circuit in which steam is generated to drive the turbine.
A PWR has fuel assemblies of 200-300 rods each, arranged vertically in the core, and a large reactor would have about 150-250 fuel assemblies with 80-100 tonnes of uranium.
Water in the reactor core reaches about 325°C, hence it must be kept under about 150 times atmospheric pressure to prevent it boiling. Pressure is maintained by steam in a pressuriser (see diagram). In the primary cooling circuit the water is also the moderator, and if any of it turned to steam the fission reaction would slow down. This negative feedback effect is one of the safety features of the type. The secondary shutdown system involves adding boron to the primary circuit.
The secondary circuit is under less pressure and the water here boils in the heat exchangers which are thus steam generators. The steam drives the turbine to produce electricity, and is then condensed and returned to the heat exchangers in contact with the primary circuit.

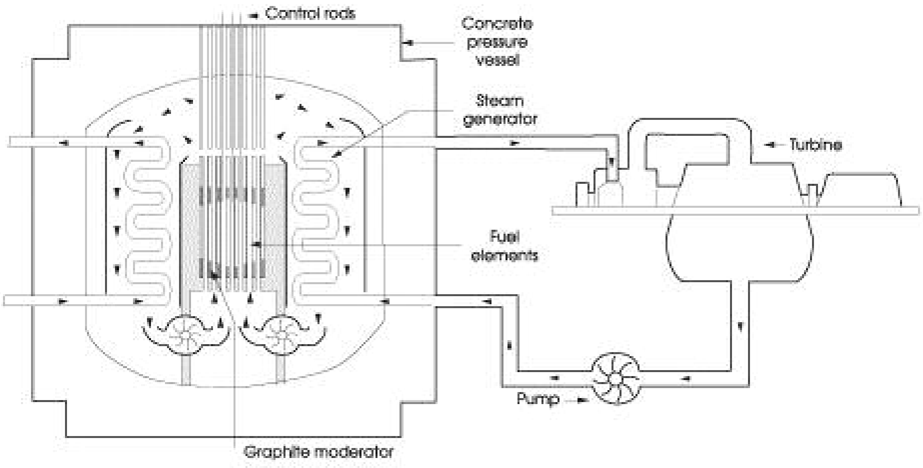
4 . 2 - BWR : Boiling Water Reactor



Main countries : US, Japan, Sweden,…with a total of 93 reactors equalling 83 Gwe.
Fuel : enriched UO2
Coolant : Water
Moderator : Water

This design has many similarities to the PWR, except that there is only a single circuit in which the water is at lower pressure (about 75 times atmospheric pressure) so that it boils in the core at about 285°C. The reactor is designed to operate with 12-15% of the water in the top part of the core as steam, and hence with less moderating effect and thus efficiency there.
The steam passes through drier plates (steam separators) above the core and then directly to the turbines, which are thus part of the reactor circuit. Since the water around the core of a reactor is always contaminated with traces of radionuclides, it means that the turbine must be shielded and radiological protection provided during maintenance. The cost of this tends to balance the savings due to the simpler design. Most of the radioactivity in the water is very short-lived*, so the turbine hall can be entered soon after the reactor is shut down.
* mostly N-16, with a 7 second half-life
A BWR fuel assembly comprises 90-100 fuel rods, and there are up to 750 assemblies in a reactor core, holding up to 140 tonnes of uranium. The secondary control system involves restricting water flow through the core so that steam in the top part means moderation is reduced.

4 . 3 - Magnox & AGR (Advanced Gas Reactor) : Gas – Cooled Reactor

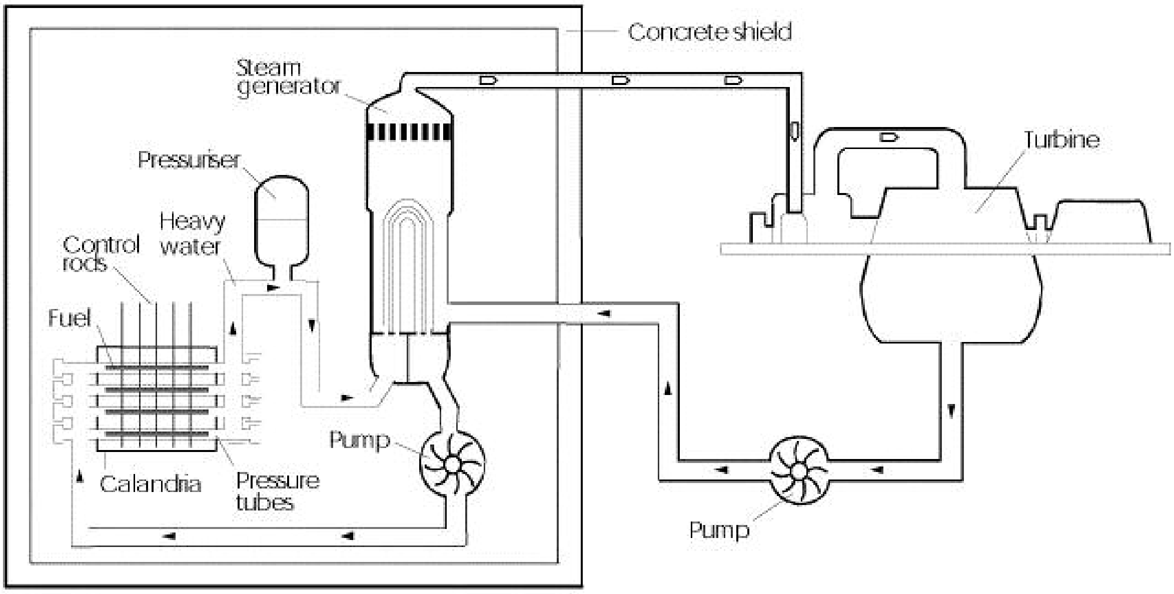


Main countries : UK with a total of 34 reactors equalling 13 Gwe.
Fuel : natural U (metal), enriched UO2
Coolant : CO2
Moderator : Graphite

These are the second generation of British gas-cooled reactors, using graphite moderator and carbon dioxide as coolant. The fuel is uranium oxide pellets, enriched to 2.5-3.5%, in stainless steel tubes. The carbon dioxide circulates through the core, reaching 650°C and then past steam generator tubes outside it, but still inside the concrete and steel pressure vessel. Control rods penetrate the moderator and a secondary shutdown system involves injecting nitrogen to the coolant.

The AGR was developed from the Magnox reactor, also graphite moderated and CO_2 cooled, and a number of these are still operating in UK. They use natural uranium fuel in metal form.

4 . 4 - PHWR : Pressurised Havy Water Reactor « CANDU »

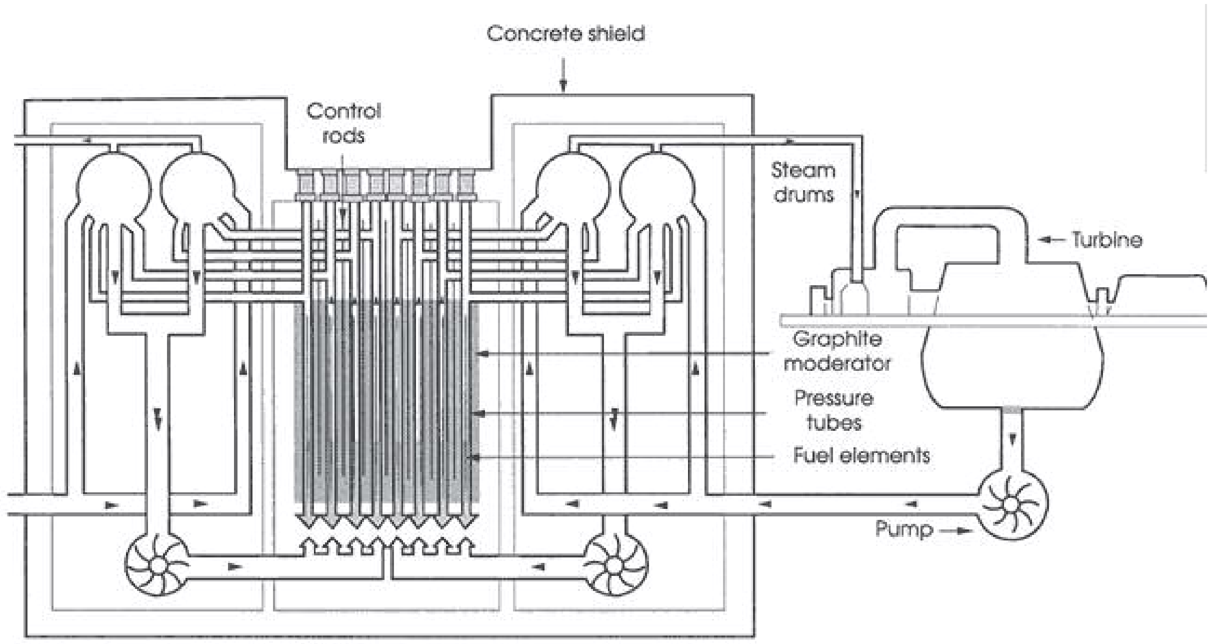


Main countries : CANADA with a total of 33 reactors equalling 18 Gwe.
Fuel : natural UO2
Coolant : heavy Water
Moderator : heavy Water

The CANDU reactor design has been developed since the 1950s in Canada. It uses natural uranium (0.7% U-235) oxide as fuel, hence needs a more efficient moderator, in this case heavy water (D_2O).**
** with the CANDU system, the moderator is enriched (ie water) rather than the fuel, - a cost trade-off.
The moderator is in a large tank called a calandria, penetrated by several hundred horizontal pressure tubes which form channels for the fuel, cooled by a flow of heavy water under high pressure in the primary cooling circuit, reaching 290°C. As in the PWR, the primary coolant generates steam in a secondary circuit to drive the turbines. The pressure tube design means that the reactor can be refuelled progressively without shutting down, by isolating individual pressure tubes from the cooling circuit.

A CANDU fuel assembly consists of a bundle of 37 half metre long fuel rods (ceramic fuel pellets in zircaloy tubes) plus a support structure, with 12 bundles lying end to end in a fuel channel. Control rods penetrate the calandria vertically, and a secondary shutdown system involves adding gadolinium to the moderator. The heavy water moderator circulating through the body of the calandria vessel also yields some heat (though this circuit is not shown on the diagram above).

4 . 5 - LWGR (RBMK) : Light Water Graphite Reactor



Main countries : RUSSIA (11) with a total of 14 reactors equalling 14 Gwe.
Fuel : enriched UO2
Coolant : Water
Moderator : graphite

There are 30 nuclear power units in commercial operation in Russia at present. The RBMK reactors in operation belong to three different design generations, built to comply with different generations of Soviet safety requirements.
The RBMK evolved from Soviet uranium-graphite reactors whose purpose was the production of plutonium.The first of these plutonium production reactors began operation in 1948. Today 15 RBMK power reactors are producing electricity in three States, the gross electricity power rating of all but two RBMKs is 1000 Mwe.
A channel-type RBMK –1000 reactor is a system with a graphite moderator, light-water coolant and uranium dioxide fuel.

It employs long (7 metre) vertical pressure tubes running through graphite moderator, and is cooled by water, which is allowed to boil in the core at 290°C, much as in a BWR. Fuel is low-enriched uranium oxide made up into fuel assemblies 3.5 metres long. With moderation largely due to the fixed graphite, excess boiling simply reduces the cooling and neutron absorbtion without inhibiting the fission reaction, and a positive feedback problem can arise.

4 . 6 - FBR : Fast Neutron Reactor

Main countries : Japan, France, Russia with a total of 4 equalling 1.3 Gwe.
Fuel : PuO2 and UO2
Coolant : liquid sodium
Moderator : none

Several countries have research and development programmes for improved Fast Breeder Reactors (FBR), which are a type of Fast Neutron Reactor. These use the uranium-238 in reactor fuel as well as the fissile U-235 isotope used in most reactors. About 20 liquid metal-cooled FBRs have already been operating, some since the 1950s, and some supply electricity commercially. About 290 reactor-years of operating experience have been accumulated.
Natural uranium contains about 0.7 % U-235 and 99.3 % U-238. In any reactor the U-238 component is turned into several isotopes of plutonium during its operation. Two of these, Pu-239 and Pu-241, then undergo fission in the same way as U-235 to produce heat. In a fast neutron reactor this process is optimised so that it can 'breed' fuel.
FBRs can utilise uranium about 60 times more efficiently than a normal reactor. They are however expensive to build and could only be justified economically if uranium prices were to rise to pre-1980 values, about four times the current market price.
For this reason research work on the 1450 MWe European FBR has almost ceased and the 1250 MWe French Superphenix FBR has been closed down. Research continues in India. Japan's Monju prototype commercial FBR was connected to the grid in August 1995, but was then shut down due to a sodium leak.
The Russian BN-600 fast breeder reactor has been supplying electricity to the grid since 1981 and has the best operating and production record of all Russia's nuclear power units. The BN-350 FBR operated in Kazakhstan for 27 years and about half of its output was used for water desalination. Russia plans to reconfigure the BN-600 to burn the plutonium from its military stockpiles, and construction has started on the first BN-800, a new larger FBR with improved features.
In the USA, GE was involved in designing a modular 150 MWe liquid metal-cooled inherently-safe reactor - PRISM. GE and Argonne have also been developing an advanced liquid-metal fast breeder reactor (ALMR) of over 1400 MWe, but both designs are still at an early stage and have been withdrawn from NRC review. No US fast neutron reactor has so far been larger than 66 MWe and none has supplied electricity commercially.

4 . 7 - Advanced reactors

More than a dozen advanced reactor designs are in various stages of development. Some are evolutionary from the PWR, BWR and CANDU designs above, some are more radical departures. The former include the Advanced Boiling Water Reactor, two of which are now operating with others under construction. The best-known radical new design is the Pebble Bed Modular Reactor, using helium as coolant, at a very high temperature, to drive a turbine directly.

CHAPTER 5 - MACHINERY BREAKDOWN INSURANCE DATA

More than 85% of the world's commercial nuclear reactors are insured by the nuclear insurance pools, which are comprised of members from all western and most east Asian countries and in recent years has expanded to include newly formed nuclear insurance pools in central and eastern Europe.

At nuclear power plants worldwide, electrical and mechanical equipment does break down occasionally. Although these failures do not necessarily compromise nuclear safety, they can cause significant damage to equipment, leading to a considerable loss of generating revenue and causing sizeable insurance losses.

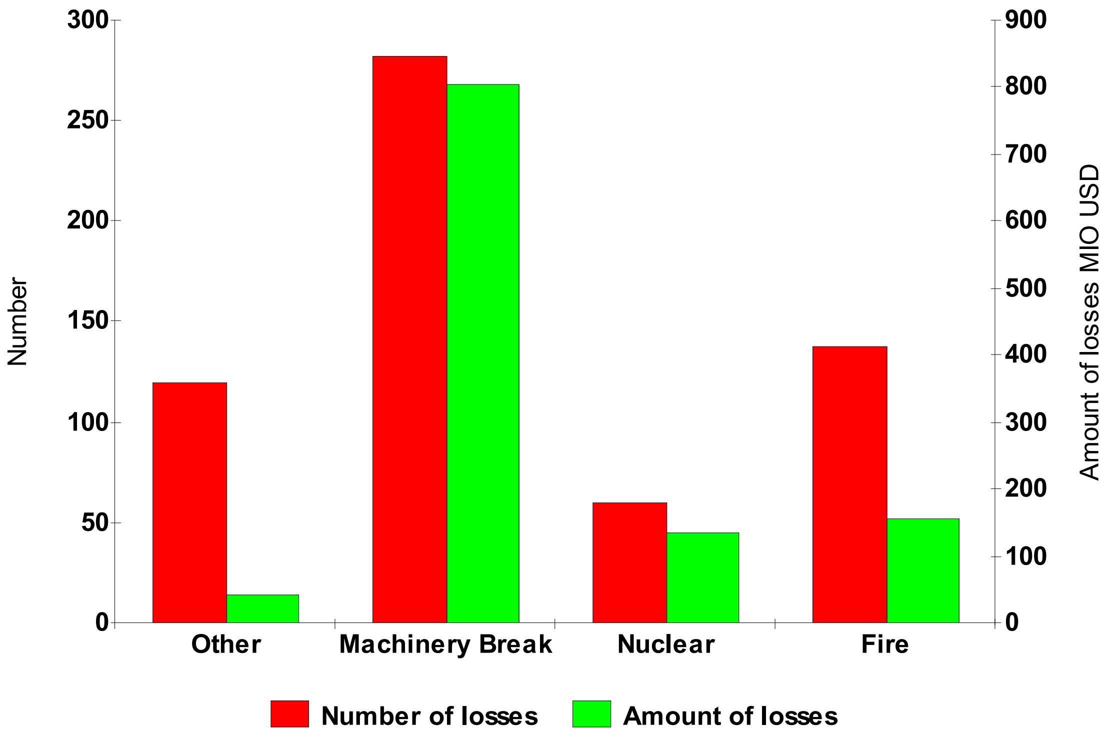
This paper addresses Machinery Breakdown insurance, which normally covers mechanical and electrical failures. Machinery breakdown events include : turbine and electrical generator failures ; catastrophic failures of steam, condensate and feedwater piping, foreign material damage in primary and secondary systems affecting both electrical and mechanical systems, and catastrophic failures of transformers, load distribution centres and switchyard equipment.
Additionally, machinery failures at power plants can cause major fire events.

The largest part of the property insurance risk has an origin from machinery breakdown events.

5 . 1 - Cause of insurance Loss (1996 – 2000)

A review of more than 600 property insurance losses that occurred in both nuclear and non-nuclear (balance-of-plant). The following figure shows the distribution of paid losses with respect to each peril type. Excluded are business interruption losses which are insurance losses resulting from the loss of revenue due to the inability of the damaged facility to generate electricity.

Figure 1.

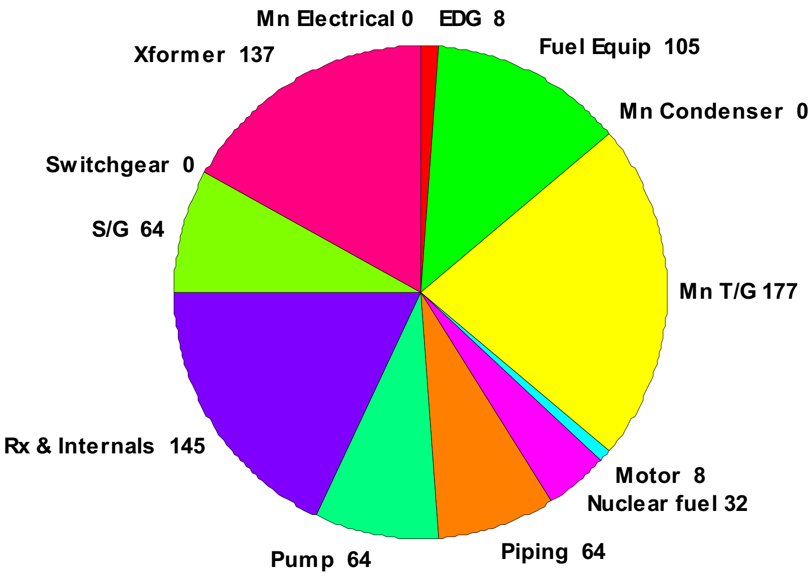


As illustrated above, Machinery Breakdown insurance losses constitute the vast majority of insurance losses. Machinery Breakdown losses account for 47 percent of the total number of the nuclear insurance loss history and represent the most costly losses.

The results of a more detailed analysis of the machinery breakdown loss history reveals that the largest nuclear insurance risk (loss frequency x monetary damages) involves Main Turbines, Main Generators, Reactors and Internals, Transformers and Pumps.

5 . 2 - <u>Machinery Breakdown Losses by Component (1966 – 2000)</u>

MB Loss Amount (MioUSD) (Figure 2).



Main primary and secondary system condition

Reactor vessels

In normal operation, the vessel gradually deteriorates as the neutron radiation from the reactor's fissile core slowly embrittles the vessel metal opposite the fuel. This embrittlement makes the vessel particularly sensitive to pressurized thermal shocks or to sudden pressure surges when cold. The presence of a crack would then be potentially damaging.

Sub-coating defects

In order to prevent the risks of corrosion, the carbon steel components of the primary system are coated with one or more layers of stainless steel, or nickel based alloy (inconel). Potential defects are then created in the base metal, just under deposited metal coat and are known as sub-coating defects (examples, vessel nozzles, steam generator tube sheets,…).

Steam generator tubes

The steam generators are the heat exchangers which transfer energy between the water of the primary system and that in the secondary system and are equipped with thousands of small-diameter, thin-wall (about 1 mm) tubes subjected to extremely harsh thermal and mechanical conditions. These tubes degrade in service mainly due to stress corrosion cracking of the tube inner or outer skin. Other deterioration such as wear, deformation and vibration continue to affect the tubes, regardless of the material used to make them.

Alloy-600 zones

Stress corrosion cracks were discovered in alloy 600 (inconel) parts. This material , which chiefly consists of nickel, chronium and iron, is used to coat certain large ferritic carbon stell components of the primary system to prevent corrosion.

Defects were observed on certain instrumentation nozzles, which have been replaced by parts made of alloy 690, a material of similar composition but which is far less prone to stress corrosion, according to currently available data.
The same type of damage was brought to light on the vessel closure head adapters, which are short tubes for insertion of the control clusters and thermocouples and the closure heads were replaced by new components with adapters made of alloy 690.

Primary pump thermal barriers

The primary pump thermal barrier consists of a flange, a coil containing cold water and an outer casing. It prevents overheating of the pump shaft transmitting the motor movement.
Cracks on the thermal barriers due to thermal fatigue can cause failures.

Check-valves

Problems of blockage of the check-valves.

Control cluster movement anomalies

Major malfunctions in the control clusters have been detected in recent years.Under the effect of repeated mechanical loadings, a small 5 mm diameter screw broke inside the mechanism controlling cluster movement, triggering uncontrolled movements (partial drop or insufficient travel during operation), followed by seizing of the clusters.

Core baffle assembly screw deterioration on some reactors

Inside the reactor vessel, baffle plates hold the fuel elements in place. This baffle assembly, secured to the cylindrical casing of the vessel, comprises vertical steel plates, plus horizontal stiffeners to which the plates are attached by screws. These screws are affected by the cracking.

Primary Circuit

Components, systems and support weldments failures can include unacceptable indications that need to be repaired, leaks or structural failures that result in unanticipated plant shutdown, or catastrophic ruptures that result in plant damage (all weldments and heat affected zones associated with vessels, piping, pumps, valves, heat exchangers, steam separators or generators, core support structures and internals forming part of or connected to the primary cooling circuit), pressure vessel supports and attachment welds,…

Secondary circuit

Excessive thermal shock due to uncontrolled admission of heating steam to the tube bundle.
Erosion/corrosion and cracking of heaters tubes, impingement baffle, tube bundle headers, pass partitions, vessel internal structures, inlet/outlet nozzles.
Integrity of heater tubes and tube-to-tubesheet welds.
The turbine should be tripped by condensate conductivity exceeding a prescribed level.

Main Turbine and support systems

Lubrication failure : loss of lubrication

Thrust Bearing failure : changes in position of the thrust bearing collar relative to the casing. These changes indicate thrust bearing wear, overloading, failure or other conditions causing the rotor to move relative to the casing. Rotor movement relative to stationary components of the machine can result in rubbing damage.

Differential expansion : Axial interference between rotating and stationary components during periods when temperature differences between rotor and casing are at the maximum (startup, load transients, shutdown,..).

Blade and Rotor Failure : Blade and rotor failures are generally due to design deficiencies and/or corrosive attack. Blade failures due to design deficiencies stem from situations where steam flow causes blades to vibrate at a frequency close to a resonance for the blade, resulting in fatigue failure. Corrosive attack on blades or rotors is of lesser concern because of the chemistry and material controls associated with the steam, condensate and feedwater systems. Blade damage may also result from thrust or journal bearing problems that allow the turbine rotor to move axially or radially causing contact of rotating and stationary components.

High turbine exhaust pressure and temperature : The turbine should be unloaded if the exhaust pressure exceeds manufacturer's operating limits. An automatic turbine trip should be actuated if the exhaust pressure reaches limits that present dangerous operating conditions for the low pressure blades,resulting from a loss of or degraded condenser vacuum.

Stall/Flutter : main turbine stall/flutter is an unsteady flow condition in which the elastic deformation of a blade couples with its aerodynamic loading to produce a sustained nonsynchronous (not associated with the rotational frequency of the rotor) blade vibration (destructive mode under operating conditions of high condenser back pressure).

High Eccentricity : eccentricity occurs when rotors are slightly bent due to extended periods of standstill or non-uniform temperature distribution when turning gear operation has been interrupted. Normally such eccentricity is reduced to acceptable levels but the turbine should not be rolled on steam when values are outside prescribed limits, since bent rotors can result in high vibrations and consequential damage when passing the first critical speed.
High vibration : high vibration may be an indication of a significant problem.

Torsional vibration : torsional vibration can occur where minor electrical grid disturbances cause phase unbalances and unbalanced currents in generators, which ultimately results in double frequency load pulsations on the turbine-generator rotor system. If the natural frequency and vibration mode of the turbine blades is near this double frequency, a sharp resonance resulting in large torsional displacement and high stresses can occur, leading to blade failures.

Turbine water induction : water induction to the turbine can result in severe blade damage, distortion of turbine shells, bending of turbine rotors and surface cracks on high temperature components.

Large pumps (high monetary value pumps or pumps with nuclear safety significance)

- primary heat transport pumps, reactor/steam generator feedwater pumps, main condenser cooling water pumps (main circulating water pumps), heater drain transport pumps, condensate transfer pumps, nuclear safety related pumps,…

Operating hazards can be : cavitation, wear of impeller sealing rings, bearing wear, gland leakage or mechanical seal leakage, shaft bending or warping, impeller wear or damage.

Most premature pump shutdowns are related to seal and bearing failures. Seal failure is usually caused by : incorrect installation, overheating (loss of cooling or flushing water,..), change of state of pumped fluid (from a liquid to a vapor). Bearing failure may be caused by : incorrect installation, loss of lubricant, excessive lubrication (too much grease or oil), overheating (loss of secondary cooling, vibration, misalignment, radial thrust, axial thrust,..)

Safety devices for overpressure protection (safety valves, relief valves, rupture disk devices,..)

Reaction damage due to inadequately supported discharge pipes, valve body deformation, blockage of discharge pipes by water, ice or debris, build-up of foreign deposits on valves, corrosive attack on the seating surfaces of the valves, valve drainage pipes or orifices blocked, unauthorized lift pressure or blowdown setting adjustment, build-up of vessel content deposits on disks, corrosion of disk causing rupture below designed pressure setting, fatigue or creep, causing rupture below designed pressure setting.

Main electrical generator and support systems

Electrical Hazards : most generator electrical hazards (transients and faults) cause sudden increases in stator currents, with subsequent excessive temperature. Also common to these hazards are severe mechanical shocks caused by increased mechanical (magnetic) forces that could cause damage to end turns, blocking, winding insulation and possible shocks to the turbine-generator coupling and shaft.

Stator overheating : stator overheating is caused by overload, cooling system failure, or short-circuiting. Overheating will deteriorate insulation and lead to faulting.

Stator Ground faults : stator ground faults are caused by the deterioration of stator winding insulation, either by ageing, overheating or mechanical deterioration, such as insulation migration or stator bar vibration.

Stator phase-to-phase faults : faults between any two phases in the winding can result in extensive damage to the winding and stator. These faults are usually caused by mechanical damage to insulation, similar to that causing ground faults, or by vibration at the end windings.

Loss of field : loss of excitation causes rotor overheating unless the generator load breakers are opened quickly. The degree of heating is a function of the initial load, the manner in which the field is lost and overspeed (generator operation as an induction motor). Armature current increases as terminal voltage decreases, this is accompanied by high rotor currents. High rotor currents cause high temperatures particularly across the wedges and retaining rings. Overheating of the end portions of the stator core may also result (low excitation).

Unbalanced Armature Current : Unbalanced armature current produces negative sequence currents in the stator and induces circulating currents on the surface of the rotor and in the rotor wedges. The current's magnitude depends on the degree of imbalance and armature currents. Localized heating is produced at the wedge joints, retaining ring fits and rotor surfaces.

Synchronization errors : synchronization errors occur when the generator is out-of-phase with the system. These cause high torques in the stator and can lead to extensive mechanical damage, depending on the degree of phase error. Generator design standards do not generally require that a machine be able to withstand the currents and mechanical forces created during incorrect phasing or synchronizing.

Mechanical hazards

Retaining rings : retaining rings are highly stressed components that are subject to loosening at operating speed or to fracturing due to stress corrosion cracking, which may lead to failure. Water leakage can cause stress corrosion and needs to be prevented through inspection of fittings, maintenance of differential pressures between hydrogen and cooling systems and moisture elimination. Every effort should be made to prevent exposure of 18Mn-5Cr retaining rings to moisture.

Cooling fan fractures : Cooling fan fractures can be caused by resonant vibration. Inspection for blade and attachment degradation or discontinuities should be done during periodic inspection.

End windings : bracing or supports can be loosened and weakened by generator vibration and forces caused by system faults. This weakening can cause insulation wear, leading to more severe faults.

Hydrogen seals : incorrect operation of the Hydrogen Seal Oil System or inadequate maintenance can result in excessive hydrogen leakage or ingress of oil into the operating generator. Oil ingress into the generator can result in the need to rewind the stator due to excessive bar vibration. The generator should be removed from service if hydrogen leakage exceeds the manufacturer’s recommendations.

Stator winding leaks : stator winding leaks have occurred in liquid cooled generators resulting in water penetration of the stator bar groundwall insulation. Excessive hydrogen flow in the stator cooling water system should be detected. The generator should be removed from service if hydrogen leakage exceeds manufacturer’s recommendations.

Damage from Foreign material : foreign material will likely be introduced into the generator during internal inspections. Operating the generator with this foreign material present will damage the stator core, windings, end windings and rotor.

Electrical Transformers (oil-filled)

There is no recognized single indicator to accurately predict transformer failure.
Static electrification of oil, power backfeeding, geomagnetically induced currents, overexcitation, lightning, surge, …can cause a transformer failure.

Switchyard and Electrical Equipment

Failure of power transmission equipment may be significant from both an economic and a safety standpoint. Reliable and redundant power supplies to nuclear safety systems must be provided at all times. Protection against voltage variations, frequency variation, voltage or current harmonics, and short-circuit currents ,… are fault-protected by the action of mechanical and electrical devices and normally triggered into action by relays. Relay response under distorted conditions may result in negative effects and create disturbances and damages.

Damages to electrical equipment are caused by abnormally high voltage surges ; the most severe over-voltages are caused by lightning and switching surges.

Large Motors and Emergency generators

Synchronization of the generator out-of-phase can cause major damage to the generator.
Recent industry experience has indicated that most motor breakdowns result from :
- Bearing-related failures 44%
- Stator-related failures 26%
- Rotor-related failures 8%

Other industry data bases show that mechanical failures occur twice as frequently as electrical failures.

Emergency Prime Movers

The emergency power system provides an independent supply of power to ensure the availability and operability of safety systems. The emergency power system includes an electrical generator driven by a prime mover, usually a diesel engine or gas turbine. Normally this entire system is subject to close regulatory scrutiny.
Significant machinery breakdown damage may occur as a result of any of the following :

- Synchronization out of phase
- Loss of lubrification or cooling
- Water leakage into cylinder(s)
- Overspeed
- Uneven thermal expansion
- Local overheating
- Stall flutter
- Foreign material ingestion
- Poor quality fuel

Mechanical equipment supports

The supports under large items-steam generators and primary pumps-as well as certain primary, secondary and ancillary system components, are secured to the civil works by steel rods passing through the concrete slab, called tie-rods. These tie-rods are pre-stressed, in other words they are tensioned at erection. Inadequate pre-stressing or rupture of the tie-rods can lead to situations in which the supports no longer perform their function, which could compromise the performance of the equipment in an accident situation.
Loss of pre-stressing and anchor tie-rod breaks have already been observed on secondary and ancillary system supports.

Anomalies were observed on the anti-seismic tie-rods on the vessel closure heads. These tie-rods are designed to provide firm, zero-play clamping of the anti-seismic ring or the anti-missile slab, in order to limit the movements of the control rod drive mechanism. These tie-rods are adjusted at reactor commissioning and are not covered by any preventive maintenance programme.
Some inspections revealed tie-rod adjustment anomalies leading to a degree of play when the reactor is in operation, as well as loosening of the lock-nuts, further compromising the adjustment. The risks associated with this type of anomaly could be loss of one or more tie-rods in the event of an earthquake. The potential consequences of this would be seizing of a number of control clusters and the appearance of primary breaks in the control rod drive mechanism housings or casings.

Safety role of human and organizational factors

A substantial proportion of nuclear safety actions concern the equipment and how to improve its reliability and progress continues to be made in these areas. However, the correct functioning of the installations, to a very large extent, depends on the quality of the work done by the personnel. It is therefore essential to look closely at the « human factor », given that is a broad field encompassing individual and collective behavior as well as organization and management.

5 . 3 - Fire Losses and Machinery Breakdown

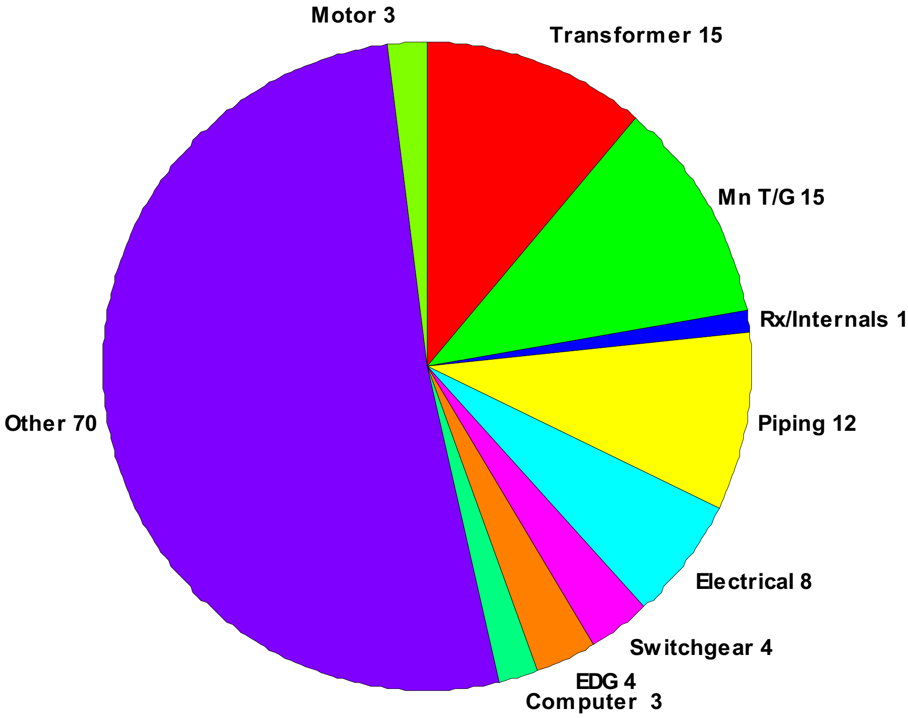
As illustrated in the previous figure 1-page19, fire losses account for 23 percent of the total number of the nuclear insurance loss history.

Moreover, many fires are the result of mechanical (Machinery Breakdown) failures of large equipment, such as main turbines and main generators. There are five major events which were the result of mechanical failures of this equipment.

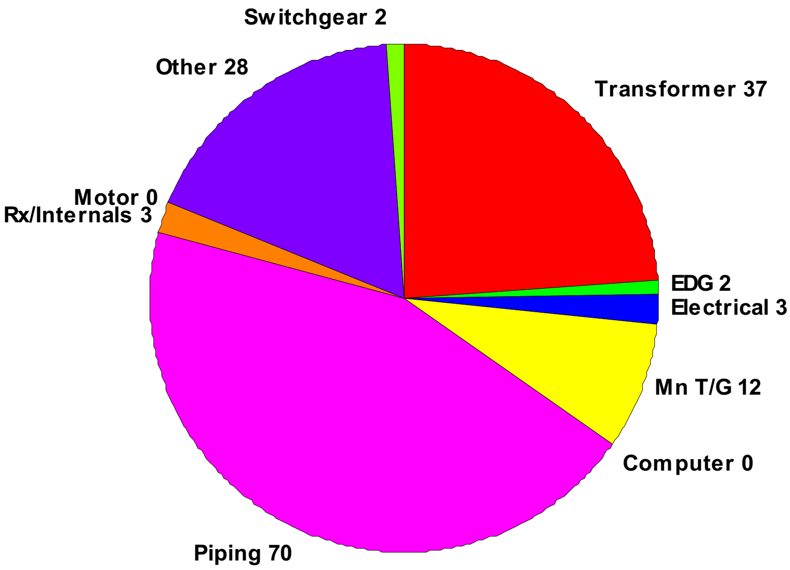
The largest number of losses was associated with components located in areas outside the plant although the average loss in this category is relatively small. Losses in the « other » category include such things as security, outside warehouses, material handling components, water treatment and meteorological equipment. The greatest monetary impact is associated with fires that damaged piping and transformers, with an average loss of approximately USD 5 million and USD 2 million respectively. Individually, losses associated with transformers and oil fires are the most expensive.

Fire losses by component (1966 – 2000) :

Number of Losses (Figure 3)



Aggregate Loss Amount (mioUSD) (Figure 4)



The largest number of losses involves the turbine building. The highest average losses are associated with the turbine building and switchyards. The average turbine building loss totalled approximately US $3 million.
The most costly individual losses occurred in the Main Turbine and Main Generator/Generator Support Systems, with the average loss totalling over US $5 million for each.

5 . 4 - Losses and the Plant Age

The following figure shows a representation of plants by age and provides the percent of total insurance losses for each group. The vast majority of losses occur early in plant life. The average plant age at time of fire loss is approximately 6 years.

Nuclear power plants, like all industrial installations, are subject to ageing. This can affect civil engineering structures (buildings, anchors, supports), mechanical equipment, process control equipment (electrical equipment, instrumentation and control systems, actuators, etc.) and modify the installation's safety. Ageing determines equipment life and two families of equipment are considered :
-non-replaceable equipment – the vessel and the containment building, which are consequently subjected to specific studies and supervision. For this equipment, the design-related and supervisory provisions are essential, even if for the containment buildings, and maybe one day for the vessels, a number of repair processes are conceivable and must be developed.
-replaceable equipment, which is all the remaining equipment. For these components, the operator feels that the notion of lifetime does not apply, since the equipment can be replaced. Aside from application of scheduled maintenance, the ageing strategy in this case consists in anticipating and where necessary implementing repair and replacement operations.

5 . 5 - Reporting nuclear incidents

The International Nuclear Event Scale (INES) was developed by the IAEA and OECD in 1990 to communicate and standardise the reporting of nuclear incidents or accidents to the public. The scale runs from a zero event with no safety significance to 7 for a "major accident" such as Chernobyl. Three Mile Island rated 5, as an "accident with off-site risks", and a level 4 "accident mainly in installation" occurred in France in 1980, with little drama. Another accident provisionally rated at level 4 occurred in a fuel processing plant in Japan in September 1999. See table.

The International Nuclear Event Scale

For prompt communication of safety significance

Level, Descriptor	Off-Site Impact	On-Site Impact	Defence-in-Depth Degradation	Examples
7 Major Accident	*Major Release:* Widespread health and environmental effects			Chernobyl, Ukraine, 1986
6 Serious Accident	*Significant Release:* Full implementation of local emergency plans			-
5 Accident with Off-Site Risks	*Limited Release:* Partial implementation of local emergency plans	Severe core damage		Windscale, UK, 1957 (military). Three Mile Island, USA, 1979.
4 Accident Mainly in Installation either of:	*Minor Release:* Public exposure of the order of prescribed limits	Partial core damage. Acute health effects to workers		Saint-Laurent, France, 1980 (fuel rupture in reactor). Tokai-mura, Japan, Sept 1999.
3 Serious Incident any of:	*Very Small Release:* Public exposure at a fraction of prescribed limits	Major contamination, Overexposure of workers	Near Accident. Loss of Defence-in-Depth provisions	Vandellos, Spain, 1989 (turbine fire, no radioactive contamination) Mihama-2, Japan, S/G tube rupture event
2 Incident	nil	nil	Incidents with potential safety consequences	
1 Anomaly	nil	nil	Deviations from authorised functional domains	

0 Below Scale	nil	nil	No safety significance	

Source: International Atomic Energy Agency

General Background on Fires in Turbine Buildings due to Machinery breakdown failures.

Turbine buildings are a source of major fires in all electrical power generation stations. Since late 1989, there have been several major fires which attracted attention around the world, for example :

1989 Vandellos –1, Spain

Stress corrosion resulted in ejection of high pressure turbine blades, high vibration and lube oil pipe failures. Fires below turbine deck and flooding of both turbine and reactor building. Station decommissioned.

1991 Salem-2, USA

Turbine overspeed, turbine blades penetrated casing. Hydrogen and lube oil fires. Approximately six months outage.

1991 Chernobyl-2,Ukraine

Electrical fault resulted in failure of retaining rings and excitation windings. Hydrogen seal oil fires. Building roof collapsed onto main and auxiliary feedwater pumps. Unit not restarted.

1993 Narora-1, India

Fatigue failure of low pressure turbine blades, high vibration. Hydrogen seal oil fires. Outage more than one year.

1993 Fermi-2, USA

Fatigue failure of turbine blades which penetrated casing,high vibration. Hydrogen and lube oil fires plus local flooding. Outage approximately one year.

The insurance experience has shown that major fire losses are generally preceded by mechanical breakdown of the turbine (e.g., blade failure) or generator (e.g., retaining ring failure), or electrical breakdown of the main generator (e.g., winding ground fault). Generally a turbine failure causes excessive vibration and rotor axial and radial displacement. Postulating a turbine over speed event and mechanical failure of the turbine, a fire involving either the generator cooling gas and bearing lube oil is likely to occur… Oil is the major fire hazard in the turbine building…

CHAPTER 6 - MACHINERY BREAKDOWN AND PREVENTION

6 .1 - Organization and Management

Machinery breakdown losses can be minimized through the development of quality operating, maintenance and training programmes. These programmes establish policy for the proper operation and maintenance of structures, systems and machinery, and the qualification and training of personnel.

The plant organization should be described in organizational charts, functional descriptions and position descriptions.

The maintenance organization should include a « As Low As Reasonably Achievable » (ALARA) coordination

The interface of maintenance with related functional groups should be defined.

Engineers should be assigned responsibility for all aspects of specific plant systems and components.

1.1. Maintenance Administration

The maintenance programmes should incorporate a maintenance management system.

A master file of all machinery requiring maintenance should be developed and maintained.

Procedural controls should be established for maintenance activities. A formal process to develop, classify, review, approve, maintain, modify and distribute maintenance procedures should be established.

Maintenance, test, operational and inspection data should be routinely analyzed for the evaluation of system performance and the identification of trends. The result of the analyses should be used to continuously improve the maintenance programme and machinery performance.

1.2. Maintenance Activity Control

A process should be developed to control maintenance activities. The process should be defined by procedures that cover the following elements.

ALARA and industrial safety planning for maintenance activities should be conducted.

Manufacturers’ and contractors’ maintenance activities should be subject to the same administrative, procedural and activity controls as plant maintenance activities.

1.3. Training and Qualification

Plant management and staff should possess the skills, knowledge and abilities commensurate with their individual and collective responsibilities.

A training programme should be established to develop and maintain a qualified, trained and skilled staff.

Job descriptions for each type and level of position should establish requirements for training, qualification and experience needed.

A formal training programme for plant and contractor personnel should include classroom and on-the-job training in plant design, systems and administrative controls as applicable to the job description.

The Training Programme should be periodically evaluated to determine effectiveness.

Training facilities should be sufficient to support training programmes. Consideration should be given to training on plant equipment mock-ups where possible.

The training programme should ensure that radiation training is provided to all plant staff and contractors who will enter into controlled areas to ensure that they will follow recognized ALARA principles and practices.

To independently perform the duties of technician/maintenance person, an individual should possess experience in their Programme speciality, knowledge of the significance and potential impact of their tasks on plant operations and a demonstrated ability to perform assigned tasks.

1.4. ALARA (As low as Reasonable Achievable)

Maintenance in radiation controlled areas should satisfy all regulatory requirements contributing to the ALARA programme**.**

The radiation exposure to personnel should be monitored, recorded, available for review and should not exceed regulatory prescribed values.

To reduce radiation exposures, the use of remote surveillance and inspection equipment, including closed circuit television (CCTV) and video recording techniques, should be evaluated.

1.5. *Chemistry* Programme

The role of the plant's chemistry programme should be to:

- Minimize the degradation rate of structural materials
- Reduce the probability of corrosion by controlling key chemical and biological parameters
- Minimize deposition of corrosion products on heat transfer surfaces

1.6. Foreign Materials Exclusion (FME)

Entry of foreign material into plant systems and components is a significant factor contributing to machinery breakdown losses. FME related losses have produced major damage to equipment. Plant recovery can be extremely complicated and expensive because of the extraordinary measures that may need to be employed. Insured losses have frequently resulted from maintenance activities during or at the end of planned
outages.

1.7 Material Handling

A comprehensive material handling control programme should apply to all material handling operations, including those conducted by contractors.

1.8 Quality Assurance Programme

The Quality Assurance (QA) programme should contain requirements for how work that may affect equipment operation, maintenance and performance is to be managed, performed and assessed. The programme should include organizational structure, functional responsibilities and levels of authority.

6.2 - Maintenance

Maintenance programmes generally consist of corrective and preventive maintenance activities and equipment performance monitoring. The plant's work request authorization programme should ensure repairs are identified, prioritized and planned, and that parts are available for repair. Maintenance records for components should be maintained to allow for retrieval and trending of component performance. Even the best nuclear power plant will experience component failures and the effects of human performance events. To prevent recurrence of failures, plant maintenance programmes should have an event reporting process supported by a root cause analysis methodology.

2.1 Corrective Maintenance

Corrective maintenance activities include rework, repair or replacement of equipment or components that have failed or are not performing their intended function. A corrective maintenance programme responds to equipment malfunction or failures that require corrective actions. Equipment failure should be documented and reviewed, and corrective actions should be identified.

2.2 Preventive Maintenance (PM)

Preventive maintenance activities are planned, periodic maintenance actions undertaken to maintain equipment within design operating conditions. These actions can be recommended by manufacturers of the equipment/components, based on historic reliability data and corrective maintenance trends. The following elements of a PM programme should be included:

- Manufacturers' recommendations should be accurately reflected in maintenance
- procedures.

- Deviations from these recommendations should be documented and technically sound.
- Manufacturers' reports on equipment failures and/or servicing should be reviewed.
- Corrective maintenance experience should be reflected in the programme.
- All protective devices, instruments and controllers should be periodically calibrated and tested.

If the results of PM activities reveal deficiencies, these should be analyzed and corrected before the equipment is returned to service.

2.3 Root Cause Analysis

The root cause of an adverse condition, if eliminated, would prevent its recurrence. Root causes are identified by a formal Root Cause Analysis conducted to determine significant conditions including deteriorating programmatic, human performance, systematic and hardware trends.

1 All causes of significant machinery breakdowns should be identified by Root Cause Analysis.
2 The results of the Root Cause Analysis should be formally factored into maintenance programme improvements to identify the causes of repetitive maintenance and appropriate corrective actions.

2.4. Equipment Performance Monitoring (EPM)

Equipment performance monitoring activities are used to measure and diagnose equipment conditions and component degradations. State-of-the-art diagnostic equipment can offer advantages to plant management in optimizing their maintenance programmes. Where appropriate, EPM can be used to extend or eliminate time-based maintenance intervals.

1 Equipment performance monitoring priorities should be established.
2. The effectiveness of the Equipment Performance Monitoring Programme should be periodically evaluated.

<u>2.4.1. Vibration Monitoring</u>

Vibration monitoring is an element of the EPM programme used to identify problems of balance, alignment or bearing condition in plant rotating equipment.

<u>2.4.2. Lubricant Analysis</u>

The physical condition of lubricants and the equipment they serve should be assessed by a lubricant analysis programme.

<u>2.4.3. Thermography</u>

Thermography is a measurement of differential infrared radiation patterns to detect changes in equipment condition. It is performed during operation.

2.4.4. Motor Operated Valve Testing

The motor operated valve testing programme is used to measure and analyze key motor-operator parameters such as running current, voltage, stem thrust, limit and torque switch set points, and valve stroke times to identify degrading conditions.

2.4.5 Non-destructive Examination (NDE)

A wide variety of non-destructive test methods are used at nuclear power plants. These guidelines do not describe every method nor provide prescriptive requirements beyond using trained and qualified staff, reviewed and approved procedures, functional certification and calibration of examination equipment.

2.4.6 Erosion/Corrosion Monitoring

A programme should be established to identify and monitor high energy piping and critical equipment susceptible to erosion/corrosion.

2.5. Surveillance Test Programme *(Safety Related Systems)*

For safety related systems, a surveillance test programme that meets the requirements of the operating license should be implemented by plant controlled and approved procedures.

2.6. Routine Surveillance Testing (Non-Safety Related Systems)

Routine surveillance testing typically includes the testing of automatic pump starts, automatic pressure and flow regulators and other necessary automatic features designed into non-safety related systems.
Testing should include verification of the automatic actuation set points and alarms.

2.7. Post-Maintenance Testing

Post-maintenance testing confirms the operability of a component or system and may establish a new performance baseline. Responsibility for test requirements, scheduling and acceptance criteria should be assigned. During unit outages, system configuration may not support such testing, resulting in a backlog of post-maintenance tests to be completed prior to the return to service of systems. A post-maintenance test coordinator should be assigned to determine test requirements, schedule testing and to establish acceptance criteria for each test based on the maintenance performed and operability requirements.

2.8. Spare Parts/Material Control

Optimum stock level for spare parts should be maintained. Minimum quantities of individual spare parts should be defined and prompt reordering should be done when this threshold is reached. The limits should be reviewed periodically and adjusted on the basis of experience, outage planning, cost and lead time. A strategic spares programme should be in place to mitigate against prolonged shutdown of the plant.
Examples of strategic spares are: turbine and generator components and selected large pumps, motors and transformers.

2.9. Measuring and Test Equipment

- Measuring and test equipment should be periodically calibrated as required by plant procedures.
- Measuring and test equipment should be stored according to manufacturer's recommendations.
- Control and calibration of measurement and test equipment should be specifically assigned and controlled by procedures.

6.3 - **Necessary Future Improvements**

Prevention in nuclear plants cannot be limited only to general considerations presented here above.
The specificities of this industry have to be taken into account : transparency , internationalisation and standardization.
The nuclear industry is developing norwithstanding strong anti-nuclear lobbying. To compete against arguments of these opposed groups, nuclear industry must show absolute transparency. Each time this industry will try to hide incidents, media consequences could be dramatic if those incidents should have been revealed a posterior.

A peculiarity of nuclear plants is the low number of types of technology in place. It should allow interesting and profitable exchanges of information between operators.

As part of the nuclear industry's response to the accidents at Three Mile Island (TMI) in 1979 and at Chernobyl in 1986, programmes to evaluate and encourage improvements in the operational safety performance of nuclear power plants were initiated. In the United States, the Institute of Nuclear Power Operations (INPO) was founded by nuclear utilities. It performs periodic operational safety evaluations of all nuclear power plants in the USA. INPO also provides a number of other services to help US and volunteer international utilities improve their safety performance.

On a broader international scale, the IAEA initiated the Operational Safety Review Team (OSART) programme for voluntary reviews of operational safety performance at power plants worldwide. The IAEA also initiated other voluntary programmes such as those on the Assessment of Safety Significant Events (ASSET), Assessment of Safety Culture in Organizations (ASCOT), and the Incident Reporting System (IRS) to assist nuclear plant operators in evaluating and strengthening their safety performance.

In September 1994, IAEA Member States began the process of ratifying a new Convention on Nuclear Safety. This convention will establish, for the first time, internationally agreed obligations for ensuring the safety of nuclear power plants and the commitment of the signatory States to meeting them. Under the Convention, Member States with nuclear power plants will report periodically to their peers on the measures taken to meet their obligations.
Although the exact nature of the reports to be made under the Convention has yet to be determined, Member States will need to determine, in some way, the degree to which the performance of their own nuclear power plant programme is in accordance with the obligations of the Convention. Operational safety performance reviews performed by independent organizations such as the IAEA could provide information for this purpose, but the substantial outside resources they require limit their availability.

Many utilities have chosen to use self-assessment processes to help their management obtain current information about safety performance. Regulatory authorities are increasingly recognizing and using self-assessments to judge nuclear power plant safety performance. Experience has shown that when organizations objectively assess their own performance, understanding of the need for improvements and the motivation to achieve them is significantly enhanced. Such self-assessments might also contribute substantially to the periodic reports required by the Convention.

Prevention in nuclear plants should be very reactive. International organizations should be able to collect all types of incidents and should adress to all operators a lot of recommandations.

- Manufacturers are in the centre of this process. Thanks to their frequent relations and visit to plants, they can improve their prevention guidelines, the design of the future equipment.
- Insurers, pools or mutuals, should write an annual report with concrete propositions of loss prevention measures. Unfortunately this loss experience is not enough developed right now.

CHAPTER 7 – LIFETIME AND DECOMMISSIONING

7 . 1 - Lifetime of Nuclear Power Plant

According to IAEA(International Atomic Energy Agency) survey, number of Reactors in operation worldwide at the end of 2001 is 438 and distribution of numbers by age is shown as (fig-1).

Assuming that lifetime of Nuclear Power Plant is originally designed as up to 40 years, number of reactors whose lifetime exceed 40 years by the end of 2000 is 7, and 27 by the end of 2010.

Most nuclear power plants originally had a nominal design lifetime of up to 40 years, but engineering assessments of many plants over the last decade has established that many can operate longer. In the USA the first few reactors have been granted licence renewals which extends their operating lives from the original 40 out to 60 years, and operators of some 80 more are expected to apply for similar extensions. In Japan, plant lifetimes up to 70 years are envisaged.

When the oldest commercial nuclear power stations in the world, Calder Hall and Chapelcross in the UK, were built in the 1950s they were very conservatively engineered, though it was assumed that they would have a useful lifetime of only 20-25 years. They are now authorised to operate for 50 years, and most other Magnox plants are licensed for 40-year lifetimes.

Sweden's oldest reactor which started up in 1971, has been fully rebuilt at a cost equivalent to 8% of a replacement unit, and all Sweden's reactors are maintained so that a further 20 years of life is in prospect.

The Russian government in 2000 extended the operating lives of the country's 12 oldest reactors from their original 30 years, and recently the extension was quantified as 15 years.

The technical and economic feasibility of replacing major reactor components, such as steam generators in PWRs and pressure tubes in CANDU heavy water reactors, has been demonstrated. The possibilities of component replacement and licence renewals extending the lifetimes of existing plants are very attractive to utilities, especially in view of the public acceptance difficulties involved in constructing replacement nuclear capacity.

On the other hand, economic, regulatory and political considerations have led to the premature closure of some power reactors, particularly in the United States, where reactor numbers have fallen from 110 to 104.

Decommissioning of Nuclear Power Plants

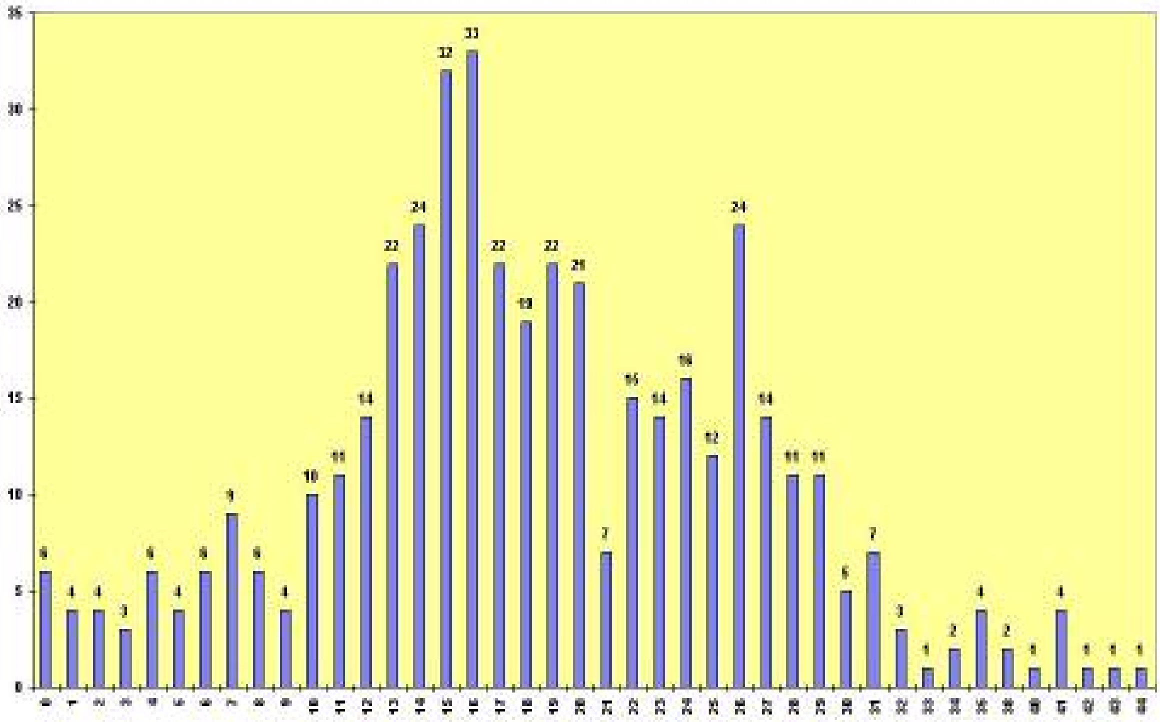


Figure.1

7 . 2 - <u>Decommissioning of Nuclear Power Plants</u>

Decommissioning: What's Involved?

After a nuclear power plant is permanently shut down, it must be decommissioned. This entails two steps: removal and disposal of all radioactive components and materials, and cleanup of any radioactivity that may remain in the buildings and on the site.

In the first step, the company that operates the plant either decontaminates or removes all contaminated equipment and materials. It also places the used nuclear fuel in storage until its final disposal. These materials and equipment account for more than 99 percent of the plant's radioactivity. Their removal lowers the level of radiation and thus reduces the exposure of workers during subsequent decommissioning operations.

In the second step, the utility deals with the small amount of radioactivity remaining in the plant, which must be reduced to harmless levels through a cleanup phase□□decontamination.

In the decontamination, workers remove surface radioactive material that has accumulated inside pipes and heat exchangers or on floors and walls, and was not decontaminated during normal plant operations because of inaccessibility or operational considerations. They are aided in decontamination activities by the records that plants are required to keep during operation. Workers use chemical, physical, electrical and ultrasonic processes to decontaminate equipment and surfaces. The removed radioactive material is concentrated and collected for disposal at a low-level radioactive waste disposal site. Concentration cuts the volume of low-level radioactive waste, thus reducing the expense of disposal.

CHAPTER 8 - CONCLUSION

As a specialized branch of the worldwide insurance industry, nuclear insurance pools have underwritten property damage protection for nuclear facilities. Several different kinds of nuclear insurance coverage are offered by nuclear insurers and machinery breakdown insurance, which covers mechanical and electrical failures, is a part of these.

The review of the losses reveals that the largest part of the insurance risk has an origin in the machinery breakdown events and concerns turbine and electrical generator failures,catastrophic failures of steam , piping, transformers,….Additionally, machinery failures can cause major fire events.

To minimize insurance losses, insurance companies analyse loss information, develop loss prevention guidelines, ..and plant operators' response to inspection recommendations is quite positive and reflective of the insureds' commitment to accomodate insurance risk perpective.

Studies suggest that nuclear energy will enjoy a significant share of total energy production through 2100 in most scenarios. According to the usual forecasts, the new century will consume three times more energy than the world has consumed since it began, and fossil fuel reserves will run out.
Despite the weight of these arguments, the nuclear industry has to persuade public opinion and investors to launch new projects. Perfect operation of existing reactors and transparency by operators in their business activities are essential.

So, what can be the future and new challenges of nuclear industry ? ?

A suggestion is to reinforce the competitive edge of nuclear industry in the context of increasing globalization, standardization of reactors with international standardization of safety rules, universally accepted solutions for end-of-cycle and waste disposal issues,…..

The insurance companies have to be present in this industry, as they are already involved in traditional energy industry, has to follow the evolution of this industry and develop risk assessment, prevention aspects, and statistics.
A positive point is the experience of insurance companies concerning the globalization of other sectors like oil and gas and the consequences in term of risks.
As they have been able to do it in other sectors like oil and gas, they should be able to share with the nuclear industry their experience.

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