# SET 1
# General Information

## Content




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# Introduction

An aging generation of nuclear power plants is going to be in operation in the coming 30 years in Europe. During the last 10 years some NPPs got unlimited or renewed operational licenses. It started with the oldest British reactors in Calder Hall (life time extension to 50 years) followed by Mühleberg and Beznau in Switzerland, which got an operational license until 2012 (40 years) and an unlimited operational license, respectively.

In comparison to the German "Atomkonsens", which is based on an operational time of 32 years of the German NPPs, operation through 40 and more years seems very long.

The NPP Dukovany in the Czech Republic has passed an extensive modernization program. In 2005 CEZ has announced that the NPP Dukovany will continue to operate until 2035 which will result in a life time of more than 50 years!

For Paks NPP in Hungary a licensing process (including an EIA procedure) is going on. Paks applies for a license to generate electricity another 30 years.

Other countries – e.g. Russia – allow their NPPs to succeed with operation without specific legal procedures.

The Nuclear Regulatory Commission in the USA has created a simplified generic licensing procedure for life extension of the aging US nuclear plants.

Regarding this development, this information package supports NGOs and administrative personal with technical expertise, case studies and also legal information concerning participation according to the ESPOO Convention and other possibilities for legal objection due to the law of nations.

Since this is the first part of the information package, it provides general information on the subject and the major points of criticism.

# What is PLEX?

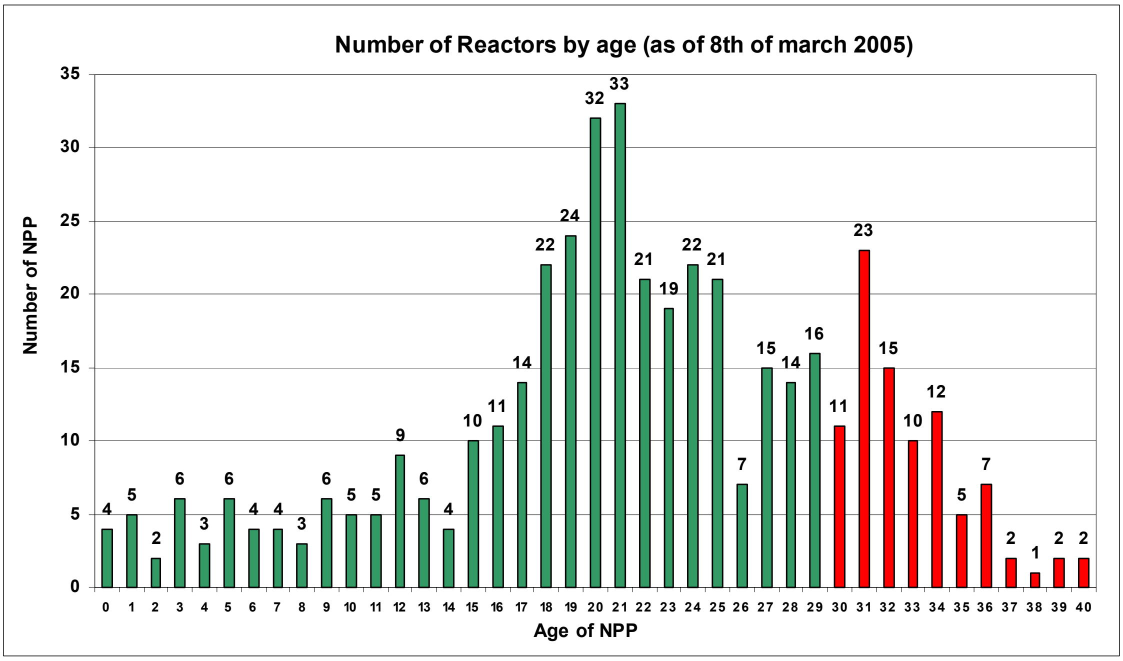
Plant Lifetime Extension (PLEX), Plant Life Management (PLIM) and Long-Term Operation (LTO) are different names for the same activity - extending the operation of old nuclear power plants beyond the time, it was assumed that NPPs could be used without major problems.

For existing nuclear power plants generally a commercial lifetime of 30 to 40 years was assumed, because of the weakening impact by neutron irradiation, high temperature and pressure to the components which have to contain the reactor core and the core cooling system. Of all these influences only neutron irradiation is specific to nuclear power plants, all other effects of material aging are well known at the chemical industry, gas, coal and other power plants as well as in the transport sector: broken wheels and axis endanger travellers in trains and cars; Pressure vessels are also a hazard in chemical plants.

Neutron irradiation is the specific contribution to hazard of using nuclear fission. Neutron irradiation leads to embrittlement of the pressure vessel steel and its welds. Because of increasing danger with operational time and energy produced, this effect has to be monitored carefully.

Many reactors have reached the age of 30 years and more will follow in the next years. The reality of operating NPPs proofed that after 30 years and in some cases even before this time serious problems with material degradation occurred:

- at the 900 MW series PWR in France all plants developed leakages at vessel head penetrations
- the first CANDU series reactors developed degradation of the pressure tubes,
- steam generators in many PWRs leaked because of corrosion, and most of them had to be changed
- RPVs in first generation VVER 440 reactors had to be thermally annealed because of excessive embrittlement




picture 2-1: operating time of NPP worldwide (IAEA PRIS 2005)

## Ageing Effects:

Ageing already occurs during the lifetime of a NPP as originally planned, over the years ageing mechanisms become increasingly important. Particularly with plant lifetime extension, ageing effects become a more and more important contribution to the overall plant risk.

The most important influences leading to ageing processes in a nuclear power plant are:

- Irradiation
- thermal and mechanical loads
- corrosive, abrasive and erosive processes;

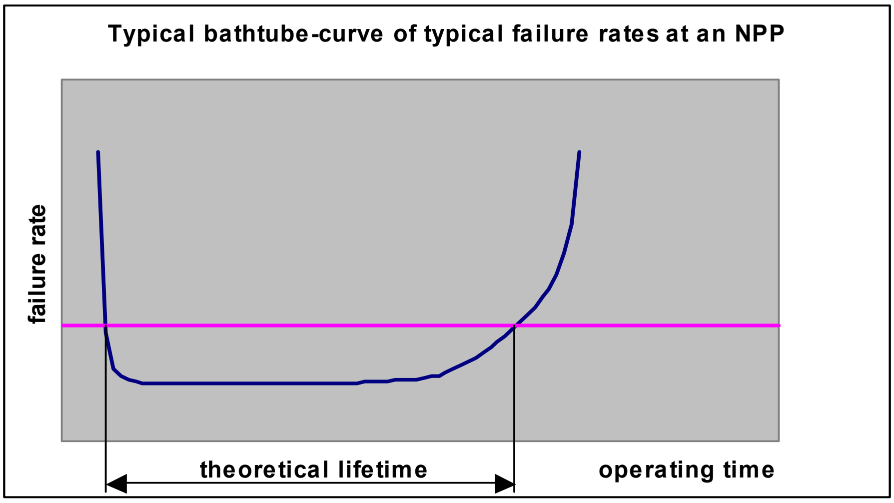
In many cases, **non-destructive examinations** permit to monitor crack development, changes of surfaces and wall thinning. But changes of mechanical properties frequently cannot be recognised by non-destructive examinations. Therefore it is difficult to get a reliable, conservative assessment of the actual state of materials. However, because of limited accessibility due to the layout of components and/or high radiation levels not all components can be examined one hundred percent. Therefore, it is necessary to rely on model calculations in order to determine the loads and their effects on materials. (GREENPEACE, 2005).

The consequences of ageing are on the one hand the increasing number of incidents (e. g. small leakage, cracks, short-circuits due to cable failure etc.) and on the other hand, the effects leading to gradual weakening of materials which could lead to catastrophic failures of components with subsequent severe radioactive releases.

Most notable among those is the embrittlement of the reactor pressure vessel, increasing the hazard of vessel bursting. Failure of the pressure vessel constitutes an accident beyond the design basis. Safety systems are not designed to cope with this emergency. Hence there is no chance that it can be controlled. Furthermore, pressure vessel failure can lead to immediate containment failure as well, for example through the pressure peak after vessel bursting, or by fragments of the ruptured vessel break through walls. Catastrophic radioactive releases might be the consequence. (GREENPEACE, 2005).

picture 2-2: Brunsbuettel ruptured tube (HIRSCH 2005)

In probabilistic risk assessment studies (PRAs), which are increasingly used as a tool by nuclear regulators, ageing is usually not taken into account. PRAs assume that equipment failure rates are taken from the low centre portion of the "bathtube curve". This leads to underestimation of the risk (LOCHBAUM, 2000). The "bathtube curve" shows that a high rate of incidents occur at the start-up of the NPP and after the planned lifetime.




picture 2-3: Typical bathtube-curve of typical failure rates at an NPP (HIRSCH 2005)

Since some ageing mechanisms are still not completely understood, a complete and satisfactory treatment of ageing effects in the framework of a PRA is not possible today and would require extensive further research.

# Why PLEX?

Why are operators and energy enterprises interested in PLEX?

„ One of the major trends in the global energy and electricity sector is the privatisation of electric utilities and deregulation of electricity markets. The increasingly competitive environment has significant impact on nuclear power. .... Competition from fossil fuels has increased. New and more efficient coal and gas technologies with comparatively low initial capital costs and substantially faster construction time schedules are being introduced. Joint studies by the International Energy Agency (IEA) and the Nuclear Energy Agency (NEA) have shown that new nuclear plants in OECD countries can only be competitive with other base load electricity generation alternatives under certain conditions. ....It is difficult for new nuclear generation to compete with gas, combined cycle, or even with coal, in regions where coal is abundant and economical." (IAEA-TECDOC-1309)

As it is stated in the IAEA document for a profit oriented enterprise there is not much incentive to build a new NPP. It takes high capital investment, a long licensing process and a long construction period to realize it (e.g. 7 years planned for the EPR in Finland or up to 20 years in Japan). In addition to it there are several options to provide cheaper capacities for electricity generation in less time (gas, gas-combined-cycle, wind power, biomass...).

However, to generate electricity in an old NPP as long as possible, is profitable, because the investment has been recouped long ago. Therefore utilities prefer life extension to construction of a new NPP.

Frequently PLEX programs are carried out together with measures to increase the efficiency of electricity generation, known as 'power uprating'. Various measures contribute to this target: some concern only the turbine, others require changes in the reactor core and the operating cycle, leading to a higher burn up of the fuel.

**Both processes, plant life extension and power uprating contribute to a decrease of safety margins of NPPs. As a worldwide tendency this will result in higher risk for all of us.**

# Actual Projects

The regulation of plant lifetimes varies from country to country. Some have operating licenses with a fixed plant lifetime (e. g. US: 40 years, Hungary: 30 years) and others have open licenses with regular safety reviews (e. g. Czech Republic, France, Spain). However, a commercial lifetime of 30 to 40 years is generally assumed.

Life extensions are planned in many countries operating NPP for many of the existing NPP:

- In the United States, licensing for life extension from 40 to 60 years is now well under way. The first extensions were granted in spring 2000 (for Calvert Cliff and Oconee) and license renewal appears to be speeding up in the USA.
- In France, there are definite plans to extend the lifetime of the whole PWR fleet from 30 to 40 years. Lifetime extension will begin at the earliest, 900 MWe-series PWRs for which the 30th year-outage could become the springboard to life extension.

Life extensions are also planned in South Korea, Sweden (total operation of 60 years) and India.

For NPPs with Soviet-designed reactor types, PLEX is already planned:

- The operating lifetime of Paks NPP in Hungary (four units of second-generation VVER440-V213 reactors) shall to be increased from 30 to 50 years.
- The Ukrainian government recently has approved a comprehensive programme for life extension of the 13 nuclear units operating at four power plants.
- Life extension plans do not even stop for the most hazardous and obsolete Soviet reactor types, first-generation VVERs and RBMKs. For example, in Russia, operating lifetime of the two Kola VVER-440/V230s is to be extended by 15 years. Leningrad-1 RBMK reached its design lifetime at January 2004. After a "modernization program" which was completed in October, lifetime was extended by 15 years, despite protests from scientists working at the All-Russian R&D-Institute for Atomic Power Engineering. Life extension is also planned for the three other RBMK units of the Leningrad NPP.

Source: Rosenergoatom 2005, GREENPEACE 2005, nucleonics week, NEA 2000, NEA 2002

# Risks and Problems related to PLEX

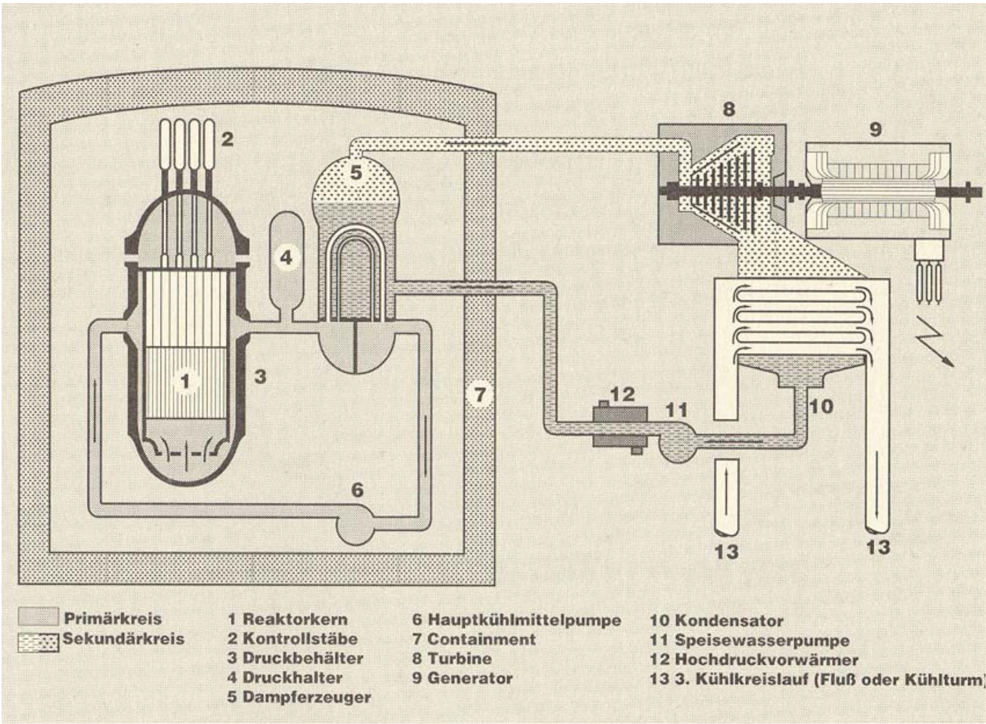
In any industrial plant, material properties are deteriorating during operation due to the loads the components are subjected to. The International Atomic Energy Agency (IAEA) defines ageing as a continuous time-dependent loss of quality of materials, caused by the operating conditions (IAEA, 1990).

Of particular importance, and potential safety significance, is the ageing of the reactor pressure vessel, the steam generators, as well as of the containment system.

Pressure vessels are used not only in NPPs; they can contain a multitude of things, including air, water, chemicals, nitrogen, and fuel. They are used in paper and pulp, energy, food and beverage, and chemical industries.

Pressure vessels also frequently control temperature as well as pressure. This is especially important when they hold more volatile substances. Signals on the outside can be read that will show what the internal pressure and temperature is. If the substance inside is potentially dangerous, alarms, pressure release valves, and other safety-measures have to be built-in to the pressure vessel.

Rupture of a pressure vessel presents a hazard for every kind of pressure vessel, not only would the vessel be damaged but injury could result due to shrapnel and dangerous chemicals. Because they are containing substances at greater than normal pressures, upkeep and maintenance of the vessels is very important.




picture 5-4: scheme of PWR: 1-core, 2-control rods, 3-reactor pressure vessel, 4-pressurizer, 5-steam generator, 6-main cooling pump, 7-containment, 8-turbine, 9-generator, 10-condensor, 11-main feed water pump, 12-reheater, 13-third cooling circuit (WENISCH, 1991)

## Reactor Pressure Vessel (RPV) - the heart of the NPP

The reactor pressure vessel is a thick-walled cylindrical steel vessel enclosing the reactor core in a nuclear power plant. The vessel is made of special fine-grained low alloy ferritic steel, well suited for welding and with a high toughness while showing low porosity under neutron irradiation. The inside is lined with austenitic steel cladding to protect against corrosion.

For a typical 1,300 MWe pressurized water reactor, the pressure vessel is about 12 m high, the inner diameter is 5 m, and the wall of the cylindrical shell is about 250 mm thick. The overall weight amounts to approx. 530 t without internals. The vessel is designed for a pressure of 17,5 MPa (175 bar) and a temperature of 350°C.
[http://www.euronuclear.org/info/encyclopedia/r/reactor-pressure-vessel.htm]

The most important ageing effect on the RPV in a nuclear power plant is embrittlement. Embrittlement leads to the reduction of toughness of the materials and thus to a higher risk of vessel failure.

Materials close to the reactor core, i.e. walls and welds of the RPV, are exposed to neutron irradiation. Neutron irradiation induces a shift of the ductile-to-brittle-transition temperature to higher values - meaning that the material is still in a brittle state, and hence more prone to brittle failure under increasingly higher temperatures.

Impurities like copper and phosphorus are known to increase embrittlement, as well as nickel and manganese. Reactor pressure vessel embrittlement increases the hazard of vessel bursting - particularly in case of the injection of emergency core cooling water during an incident, which leads to cooling of the vessel wall (so-called thermo-shock). The rupture of the pressure vessel constitutes a beyond design base accident for all light water reactors. Furthermore, pressure vessel failure can lead to immediate containment failure as well, for example through the pressure peak after vessel bursting. A core melt accident with high and early radioactive releases would be the consequence. [UBA 2005]

In order to control this hazard, the following must be available, in accordance with internationally recognized standards:

- Reliable data on the original state of the pressure vessel, and the composition of the materials (base material and welds).
- A surveillance programme, with representative samples, providing reliable data on the progression of embrittlement to be expected.
- A database on the embrittlement properties of the materials used in the vessel that is sufficient for describing the dependence of material properties on temperature.
- A reliable, state-of-the-art system of in-service-inspection (in particular, ultrasound tests), regularly used for testing all the relevant parts of the vessel for small cracks.
- Fracture mechanics analyses for all potentially relevant sequences, taking into account appropriate crack sizes, shapes and locations, to determine the critical ductile-to-brittle-transition temperature. This critical temperature is a most decisive parameter – if it is reached by vessel materials, brittle failure cannot be excluded in case of a DBA.
- Definition of an appropriate safety margin between the critical temperature as determined by analyses, and the maximum ductile-to-brittle-transition temperature that the materials concerned are permitted to reach. [UBA 2005]

A measure to reduce the neutron flux on the vessel is to protect the walls by absorbing material in the outer fuel assemblies, but this reduces the capacity. (Loviisa, Finland)

In order to reduce the embrittlement effects some operators undertake the reactor vessels an annealing procedure. (Bohunice/ CR, Loviisa /FI)

Also other types of material degradation can occur in the reactor pressure vessel, the vessel head, core internals and shroud, nozzles and bolts: cracks develop in welds and in vessel head penetrations, corrosion and erosion lead to damages at various parts of the vessel and the core internals. [UBA 2005]

## Steam Generator (SG)

The function of the steam generator is to transfer the heat from the reactor cooling system to a separate cooling system: the secondary cooling (or feed water) system.

The SG is a big vessel where water from the secondary circuit is heated by several thousand small tubes. Through these tubes water from the reactor core is pumped. The water in the core cooling system is under high pressure, and thus prevented from boiling. Only in the secondary cooling system steam is building up, which is needed to drive the turbine.

Most popular are vertical steam generators: generally they have a feed water ring supply header on the outer edge of the steam generator. The water is directed downward and flows along a wrapper sheet then is directed upwards to flow along the steam generator heating tubes where the water temperature increases until boiling occurs so that the water converts into steam. In the upper part of the steam generator is a moisture separator region which forces the steam-water mixture through channels which allow only steam to pass. A vane arrangement in these steam generators also force a swirling action that enhances the steam-water separation.

The water supplied to the steam generators must be very pure, free of particles, and chemicals. In the boiling environment of the steam generator these chemicals can concentrate resulting in undesired corrosion.

Russian reactors are equipped with horizontal steam generators.

Corrosive and erosive damage in steam generators has occurred repeatedly world wide, as well as wall thinning. Steam generator ageing is particularly hazardous since it weakens the separating border between primary and secondary circuit. A leakage between the two circuits implies a loss of coolant which is bypassing the containment. Hence, the cooling water lost is not available for the emergency core cooling system.

Furthermore, there is a direct pathway for releases into the atmosphere, potentially leading to large source terms.

These problems have led to comprehensive ageing management activities. Increasingly, they include exchanges of the whole components.

Concerning the aging effects it is important to note that it is more complex to change a vertical SG than a horizontal one. (E.g. Paks NPP wants to prevent the exchange of the SG because it would be a too expensive measure).

## The Containment

The containment is a large steel building, usually with a hemispherical dome. Containments are often not visible since they are usually surrounded by a steel or concrete building that provides additional boundaries and aesthetically pleasing designs.

The containment houses the reactor, reactor cooling system including the SG, the pressurizer and the coolant pumps.

The containment is one of the barriers in a nuclear power plant that make it difficult for radioactive substances to escape into the environment. It surrounds the nuclear part of the plant and is designed so that in case of serious malfunctions it collects the exiting steam without failing itself. The containment of a typical pressurized water reactor is e.g. a steel ball with a diameter of approx. 50 m and a wall thickness of 30 mm. It includes rapidly closing valves in the piping leading out of the containment and personal and material locks. The case is enclosed by an up to 2 m thick reinforced concrete dome to protect against external impacts. The inner wall of the dome is lined with a gas-tight steel skin. Negative pressure exists in the annular gap between containment and steel skin. The radioactive substances exiting the containment during normal operation enter the negative pressure zone and reach the vent stack via filters. During an incident, the air from the negative pressure zone is pumped back into the containment. [http://www.euronuclear.org/info/encyclopedia/containment.htm]

Containments have fans or chillers for cooling during normal conditions and in case of an accident.

Below the containment basement, sumps are located, that can be used during accident conditions. The sumps can be routed to cooling systems so that the fluid may be circulated and cooled. A grating system is installed over the containment sump to prevent materials from being sucked into the cooling system.

The concrete parts of the containment are subjected to thermo mechanical loads, but also to effects of the weather, chemical attacks and partly also to high radiation doses. Corrosive damage of steel reinforcements are difficult to inspect. Hence reductions in strength may occur unnoticed. The damage mechanisms to concrete through corrosive processes similar to high radiation doses are still largely unknown. It is particularly difficult to quantify the uncertainties of the models that were developed. (NAUS, 1996).

## Ageing management

Measures to monitor and control ageing processes are known as ageing management. Ageing management includes programmes with accelerated samples, in-service-inspections, monitoring of thermal and mechanical loads, safety reviews and also the precautionary maintenance or even exchange of components, if feasible. Furthermore, it includes optimizing of operational procedures in order to reduce loads.

| Counter measures | Costs |
|---|---|
| Exchange of components: In case of obvious shortcomings, leakages developing and other problems that directly influence the power plant operation is the exchange of the appropriate component. Even large components like steam generators and reactor pressure vessel heads can be exchanged. But there is a wide consensus among plant operators that in principle, all components crucial for safety in PWRs or BWRs can be replaced except two: The reactor pressure vessel (RPV), and the containment structure. | high |
| Annealing: In some plants thermal annealing of the RPV was carried out, in order to reduce embrittlement effects in the walls and welds. | high |
| Reduction of loads: To avoid thermal shock emergency cooling water can be preheated. To reduce neutron irradiation and hence the progress of embrittlement, neutron fluency in the vessel wall can be reduced by putting dummy elements or highly burnt-up fuel elements in outer core positions. This measures are primarily applied to the reactor pressure vessel. | moderate |
| Intensify inspections and plant monitoring: The measures of the intensification of plant monitoring and/or more frequent examinations, coupled with appropriate maintenance both rely on the optimistic assumption that cracks and other damage and degradation will be detected before they lead to catastrophic failure. | low |

table 5-1: Counter measures against ageing of components and systems

# Glossary

| | | | |
|---|---|---|---|
| CEZ | Czech electricity utility | PLIM | Plant Life Management |
| IAEA | International Atomic Energy Agency | PRA | Probabilistic Risk Assessment |
| IEA | International Energy Agency | PWR | Pressurized Water Reactor |
| LTO | Long Term Operation | RPV | Reactor Pressure Vessel |
| NEA | Nuclear Energy Agency / OECD | SG | Steam Generator |
| NPP | Nuclear Power Plant | VVER | Russian type of PWR |
| PLEX | Plant life Extension | | |

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