4 ANALYSIS AND ASSESSMENT OF OTHER PREDICTED SIGNIFICANT EFFECTS ASSOCIATED WITH OPERATION OF NUCLEAR POWER PLANTS

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4.1 Impacts at the Programme implementation stage

Due to the fact that a lot of place in the assessed Polish Nuclear Power Engineering Programme is devoted to the Programme implementation stage, potential impact associated with this stage was also examined. It aims at enabling construction of the first nuclear power plant in Poland, and the scheduled actions precede the construction itself by many years. Although the effects are not very significant in comparison to the construction and operation stage, they are however long-term and multi-aspect (they are to last until 2020), and their results will certainly have effect much longer. Also, their scope of impact will be greater than the one related to construction of the power plant itself (socio-economic aspect).

At the first stage of execution, the Programme assumes appointing proper units and creating legal framework to introduce nuclear power engineering in Poland. The actions will have far-reaching results, enabling development of a new branch of power engineering industry in Poland, and they will mainly be based on providing the conditions for safe application of nuclear power engineering (for humanity and environment).

Providing specialised staff is necessary for development of nuclear power engineering in Poland. The actions concerning investment in human capital, aiming at educating necessary Polish specialists in this field, are also planned in terms of the assessed Programme.

Furthermore, education of the entire society is planned by means of information and education campaigns.

4.2 Impacts at the construction stage

Impacts occurring at the nuclear power plant construction stage are identical to those usually related to construction of large-format facilities. In case of nuclear power plants, however, they are significant due to construction time, which is about 6-7 years. This chapter discusses in detail impacts on water and air, as being most significant. Other impacts are summarised in the summary table in chapter 0.

4.2.1 Impact on water

4.2.1.1 Construction stage

The greatest threat which may directly affect contamination of underground water and disturbance of water surface level will result from ground works at the investment site. This will be particularly important in the areas characterised by high and very high sensitivity to underground water pollution related to lack of rock insulation of aquiferous layer from the surface of the area. Hydrogeological analysis performed for potential nuclear power plant locations has shown very high diversity in the insulation level and depth of utility aquiferous layers. Impact of ground works on underground water may be particularly visible in the areas of shallow deposits of aquifers. Such a situation will necessitate intensive excavation pumping and thus creation of local cones of depression, which as a result may cause drainage of surface water reservoirs hydraulically related to underground water.

When examining probability of direct intervention in aquatic environment, three hydrogeological cases must be considered (Fig. 4.2.1):

- location of a nuclear power plant in the area where in the ground impermeable deposits are found (case 1) with thickness of at least several meters (e.g. moraine blocks made of clay) - guarantees protection against potential pollution of underground water,

- location of a nuclear power plant in the area where in the ground semi permeable deposits are found (case 3) with medium pollution permeation time enables taking relevant preventive actions in case of water pollution,

- location of a nuclear power plant in the area where in the ground permeable deposits are found (e.g. sandur plateaus made of sands and gravel) with short pollution permeation time (case 2) - the most unfavourable situation in case of pollution penetration in the ground; in short time, infiltration through the rocks and widespread aquifer contamination takes place, and in case of hydraulic connection with a main watercourse, contamination of further situated areas.

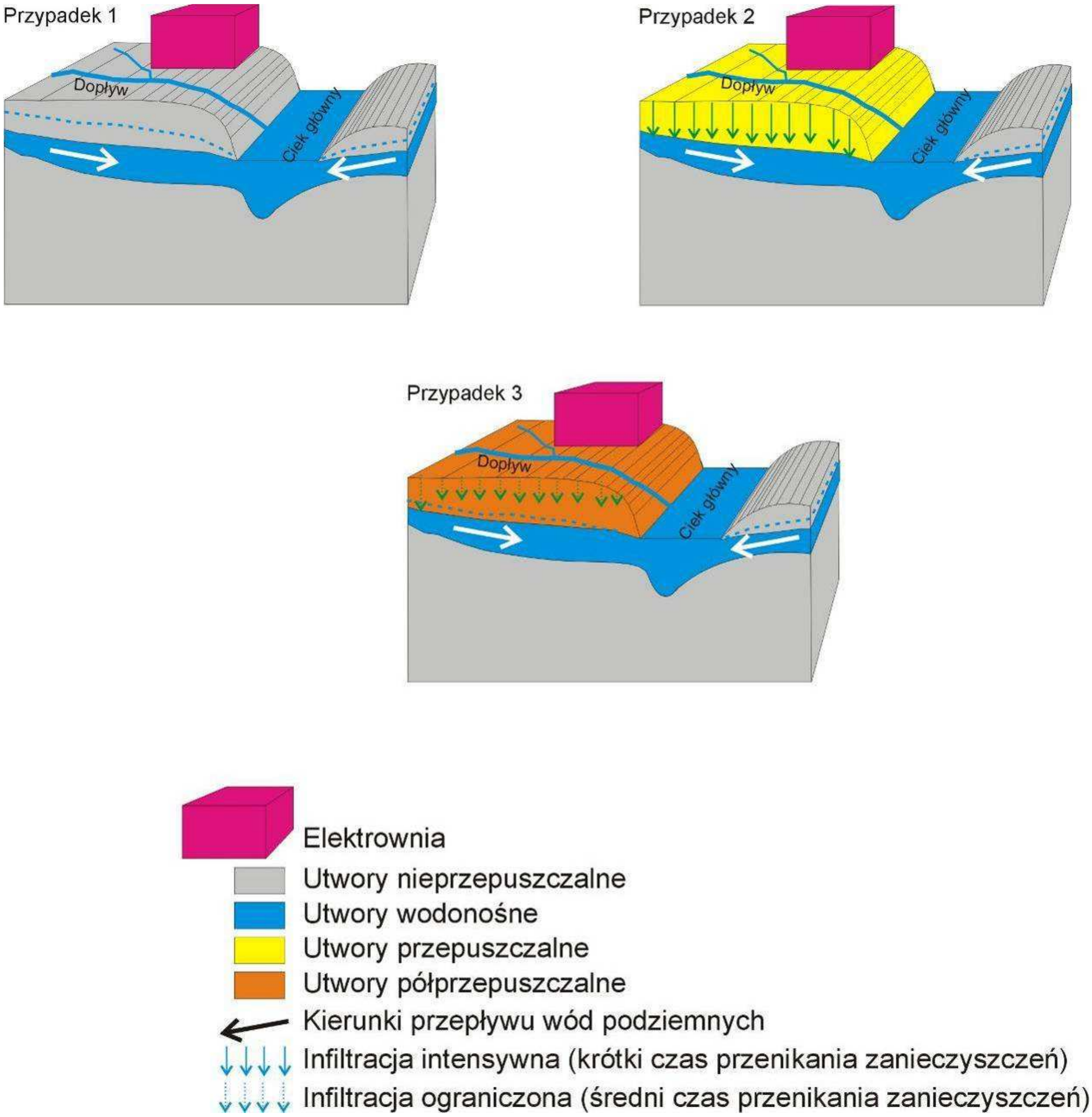


Fig. 4.2.1 Impact of potential pollution of underground water by a nuclear power plant depending on hydrogeological conditions.

[Przypadek – Case
Elektrownia – Power plant
Utwory nieprzepuszczalne – Impermeable formations
Utwory półprzepuszczalne – Semi-permeable formations

Kierunki przepływu wód podziemnych – Flow directions of groundwater
Infiltracja intensywna (krótki czas przenikania zanieczyszczeń) – Intense infiltration (short pollution penetration time)
Infiltracja ograniczona (średni czas przenikania zanieczyszczeń) – Limited infiltration (medium pollution penetration time)]

It may be assumed that the very basic safeguards during normal construction works will eliminate the risk of groundwater contamination with substances from the surface of the construction site. However, actual contamination hazard may occur in emergency situation related to uncontrolled leaks, e.g. oil derivatives and other compounds applied in construction. Therefore, provision of emergency water collection tanks and development of emergency procedures is a key element in the design and construction phase.

Sealing a large area by construction of a nuclear power plant and adjacent infrastructure may cause decreasing water surface, and thus local drainage of the area surface. On general level, it is difficult to determine whether location of a nuclear power plant may impact condition and quality of Main Underground Water Reservoirs. Determination of potential impact will only be possible at the moment of establishing specific location and performing a more detailed geological and hydrogeological study.

Regardless of geological construction, execution of piezometer network around the planned investment is necessary. Distribution and depth of piezometers should be planned at the stage of the investment environmental impact report in a specific location depending on local hydrogeological conditions. Water samples from piezometers will be taken before commencement of the construction in order to establish the existing background of underground water pollution. During investment execution and operation, samples should be taken regularly in order to detect potential substance leaks to aquiferous layers.

Generally however, during construction, temporary storage of chemicals should take place on hardened and sealed surfaces, and all construction actions should take into account ground and water protection against potential pollution. Therefore, besides unforeseen emergencies, the construction stage should not adversely affect the quality of underground water.

4.2.1.2 Test stage

A separate aspect in water impact analysis is the reactor commissioning stage with tests. It is related to potential emission of the following chemical compounds to the water: iron (Fe), phosphates (PO_4^{2-}), lithium hydroxide (LiOH), hydrazine (N_2H_4), boric acid (H_3BO_3), morpholine ($HNCH_2CH_2OCH_2CH_2$), sodium (Na), sulphates (SO_4^{2-}), bromoform ($CHBr_3$). Among the mentioned substances, the potential impact on water quality is displayed by boron compounds and iron. Boron is used in cooling cycles, and its leaks are related with first temperature increase tests in those cycles. Iron may also come from cooling cycles and production of demineralised water. The quantities of substance releases were specified in UK EPR report[149] on the basis of conducted tests. Maximum daily release values are 40 kg of iron and 1250 kg of boric acid. However, actual values depend on installed cooling systems and local water intake and discharge conditions, therefore they should be specified in detail for a specific investment location.

4.2.2 Impact on the air

4.2.2.1 Construction stage

4.2.2.1.1 Dustiness

Ground works, soil mass and construction materials transport, concrete production and loose material storage cause dust emission into atmosphere. However, there are effective methods of dust prevention, such as water sprinkling of roads and material processing areas (e.g. cutting, crushing), which should be planned prior to commencement of construction and consistently applied in its duration. Impact of dustiness may only be assessed at the stage of environmental assessment of power plant construction in its specific location, taking into account current air quality and assessing potential additional effect of dust emission resulting from the planned construction.

4.2.2.1.2 Exhaust emission from machines and vehicles

In relation to construction, transport of construction materials and workforce will take place, resulting in exhaust emission (containing, i.a., carbon monoxide, dust particles, hydrocarbons and nitrogen oxides). Impact of those emissions remains closely dependent on selection of investment location and charting transport routes to a construction site. At the preparation stage of the environmental impact report, distribution of pollutions should be examined in detail.

4.2.2.2 Test stage

A the test stage, first commissioning of the entire installation takes place, along with its first heating to high temperature, which in turn may cause releasing formaldehyde and carbon monoxide to the atmosphere. Quantities of these releases were specified in UK EPR report[149] based on identification of potential emission quantities and modelling distribution in the atmosphere of significant emissions. Assuming the most unfavourable scenario, the emission value was specified at 1230 g of formaldehyde (at release rate 0.0342 g/s) and 1152 g of carbon monoxide (at release rate 0.032 g/s). The report states that the emissions have no significant impact on air and do not have to be modelled in detail.

4.2.2.3 Impact on the ground surface

In construction of power facilities and related transmission infrastructure, impacts during construction will be mainly based on land take and changes in soil structure (thickening, removal of humus layer etc.) in direct vicinity of planned investments. Such impacts may occur also in temporary storage sites of construction materials and structural elements. Potential impacts also include soil contamination with petroleum derivatives, which may penetrate soil due to lack of tightness/failure of mechanical vehicles. However, such impacts only refer to the nearest neighbourhood of the investments and due to their scale they usually do not require recultivation activities. Other impacts with examples are presented in the first part of the table, in the section 5.3.

4.3 Impacts in conditions of normal operation of the nuclear power plant

The figure below (Fig. 4.3.1), illustrates impact of nuclear power plant in operation stage on individual elements. This Chapter discusses these impacts one by one, with the exception of radiological impacts – they have been discussed earlier in chapter 7).

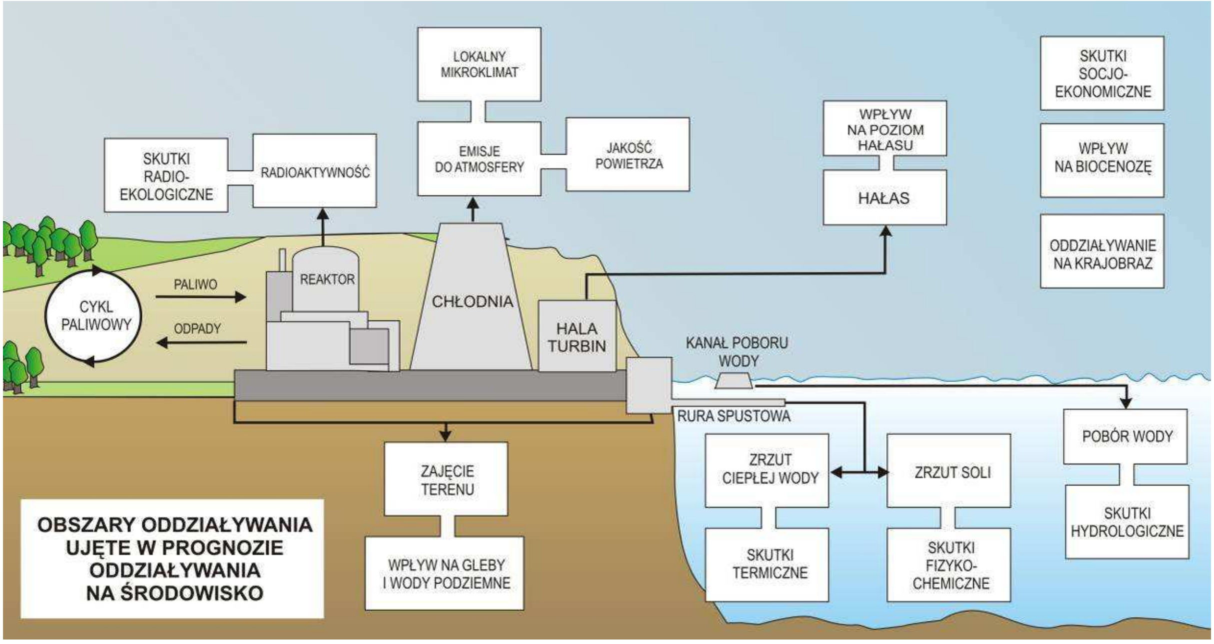


Fig. 4.3.1 Illustration of environmental nuclear power plant impact aspects and their mutual relations [own study based on [UK EPR: PCER, Chapter] [150]

[OBSZARY ODDZIAŁYWANIA UJĘTE W PROGNOZIE ODDZIAŁYWANIA NA ŚRODOWISKO – IMPACT AREAS INCLUDED IN THE ENVIRONMENTAL IMPACT FORECAST

Cykl paliwowy – Fuel cycle
Paliwo – Fuel
Odpady – Waste
Reaktor – Reactor
Radioaktywność – Radioactivity
Skutki radio-ekologiczne – Radiological and environmental effects
Chłodnia – Cooling tower
Emisje do atmosfery - Emissions to atmosphere
Lokalny mikroklimat – Local microclimate
Jakość powietrza – Air quality
Zajęcie terenu – Land take
Wpływ na gleby i wody podziemne – Impact on soils and groundwater
Hala turbin – Turbine room
Hałas – Noise
Wpływ na poziom hałasu – Impact on noise level
Skutki socjoekonomiczne – Socio-economic effects
Wpływ na biocenozę – Impact on biocoenosis
Oddziaływanie na krajobraz – Impact on landscape
Kanał poboru wody – Water intake channel
Rura spustowa – Discharge pipe
Zrzut ciepłej wody – Warm water discharge
Skutki termiczne – Thermal effects
Zrzut soli – Salt discharge
Skutki fizyko-chemiczne – Physicochemical effects
Pobór wody – Water intake
Skutki hydrologiczne – Hydrological effects]

4.3.1 Impacts related to the fuel cycle

Fig. 4.3.2 schematically presents simplified fuel cycle of a nuclear power reactor, including three basic elements:

„Preliminary part" of the fuel cycle *(„front-end")*, consisting of:

- uranium output and uranium concentration production in form of "yellow cake" – containing 70-90% triuranium octoxide U_3O_8;
- chemical conversion to uranium hexafluoride (in gaseous form) U_3O_8, → UF_6;
- uranium enrichment with isotope U235 (to ca. 4%);
- nuclear fuel production: conversion to uranium dioxide (in powder form) UF_6 → UO_2, production of fuel pellets (powder sintering UO_2 and forming pellets), assembly of fuel elements and sets.

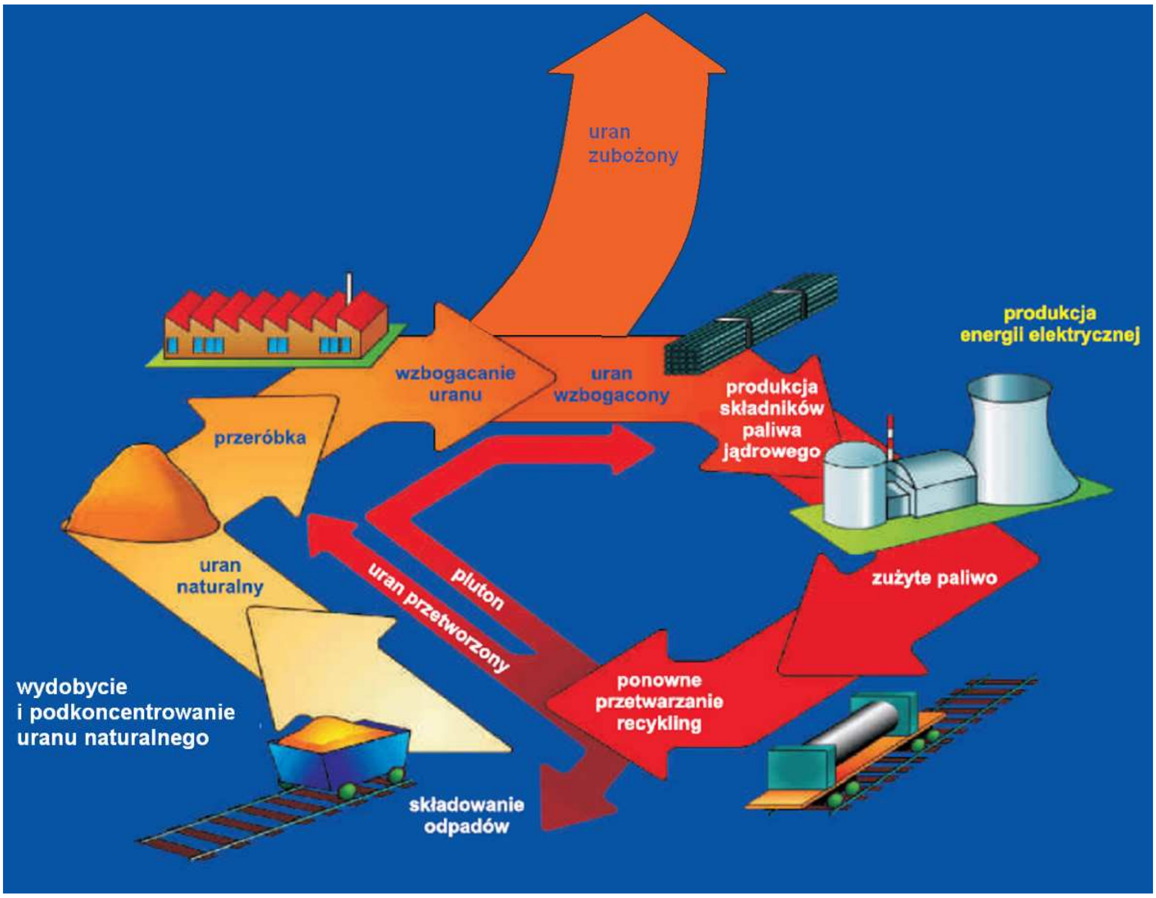


Fig. 4.3.2 Fuel cycle of nuclear power reactor [EDF][151]**.**

[Wydobycie i podkoncetrowanie uranu naturalnego – Extraction and sub-concentration of natural uranium
Uran naturalny – Natural uranium
Składowanie odpadów – Waste storage
Przeróbka - Processing
Wzbogacanie uranu – Uranium enrichment
Uran wzbogacony – Enriched uranium
Uran zubożony – Depleted uranium
Produkcja składników paliwa jądrowego – Production of nuclear fuel components
Zużyte paliwo – Spent fuel
Ponowne przetwarzanie, recycling – Reprocessing, recycling
Produkcja energii elektrycznej _ Electricity production
Pluton – Plutonium

Uran przetworzony – Reprocessed uranium]

Middle part of the cycle: fuel combustion in the power reactor when producing electricity, involving, among others, the following issues:

- long-term optimising planning of nuclear fuel demand - on the basis of electricity production plans;
- commissions, transport and storage of fresh fuel on the plant premises;
- planning fuel campaigns with optimisation of core loading for individual campaigns *(in-core fuel management)*;
- fuel reloading, fuel campaign supervision and temporary storage of burnt nuclear fuel on the plant premises.

„Final part" of the fuel cycle *(„back-end")*, consisting of:

- transport of burnt fuel to a processing plant or deep geological waste dump,
- processing the burnt fuel with recycling of recovered uranium (directed to chemical conversion and enrichment) and plutonium (used in uranium-plutonium MOX fuel production after mixing with depleted uranium - being a waste product of enrichment process);
- rendering harmless and storage of the high-activity radioactive waste from burn fuel processing process.

This chapter briefly characterises the middle part of the fuel cycle: fuel combustion in the reactor - also including nuclear fuel supply, fresh fuel transport and storage on the plant premises, and temporary storage on the plant premises and disposal of burnt fuel.

4.3.1.1 Options of securing the raw material for uranium concentrate production

The analyses below are based on materials from the report ***„Assessment of possibility of uranium mineralisation in Poland on the basis of the results of geological and search works"*** prepared by the interdisciplinary team of specialists, composed of: A. Solecki, W. Śliwiński, I. Wojciechowska, D. Tchorz-Trzeciakiewicz, P. Syryczyński, M. Sadowska, B. Makowski. The basis of the report was agreement no. 330/2009/Wn-07/FG-sm-tx/D of 28th January 2009, concluded between Minister of Environment, National Fund for Environmental Protection and Water Management and WS Atkins – Polska Sp. z o.o. Also a part of materials by A. Solecki, were used, not included in the final report version. The report, completed in April 2010, in the final corrected version was accepted in October 2010. Therefore, some data were updated on the basis of sources published in the second half of 2010.

The fundamental fact which must be taken into account when considering fuel supply of nuclear power plants planned in Poland is uranium demand, which in 60 years may reach 72.240 Mg of natural uranium[152], which equals 85.191 Mg U_3O_8 being the main component of "yellow cake", the basic trade form of concentrate of this raw material.

The second fact is price of metallic uranium, which in the last decade fluctuated between: 18.45 $/kg U at the end of 2000 to 354 $/kg U in June 2007. In December 2010 the price was 134 $/kg U [153].

Purchase of metallic uranium, necessary to provide fuel for the planned nuclear power plants at a price 134$/kg means expenditure of 9.7 billion $. It should be emphasised that this is an initial phase of fuel cycle, consisting of: uranium output and uranium concentrate production in form of "yellow cake", containing 70-90% of triuranium octoxide U308. Further stages usually require an expensive enrichment procedure in order to increase 235U isotope content in nuclear fuel. The enrichment takes place in plants with expensive equipment, the construction of which requires international community supervision due to the threat of nuclear weapon production. At the assumed scale of development of nuclear power engineering in Poland and lack of significant natural uranium resources, building such plants does not seem to be economically justified. With large-scale fuel production, currently taking place in global power engineering, costs of uranium enrichment and fuel production are low. In total, fuel costs including all phases of fuel cycle amount to approximately 10-15% of the entire electricity cost.

Assuming that future documentation of uranium resources in Poland sufficient for profitable operation would be possible, we may obtain complete independence from import of uranium, since fuel cycle services are offered by various countries and do not pose any obstacles in developing nuclear power engineering. In the discussed case (which currently is hypothetical), future development of domestic nuclear power industry could be based on reactors using natural (non-enriched) uranium. Currently, such reactors do not meet European standards and are not considered for Poland.

4.3.1.1.1 Options of obtaining uranium from domestic deposits

During developing the report by Solecki's team (2010), balancing criteria were used from 2008 presented in Table 4.3.1.

Table 4.3.1 Balancing criteria from 2008

Parameter	Unit	Marginal value
Maximum depth of deposit documentation	m	1000
Minimum content of U_3O_8 in the sample outlining the bed	% U_3O_8	0,03 (0,01)*
Minimum mean content of U_3O_8 in the bed profile with barren interlayers	% U_3O_8	0,03 (0,01)*
Minimal bed abundance (U_3O_8)	kg U_3O_8/m^2	1,2 (0,8)*
* in brackets parameters for extra-balance resources		

Until the preparation of the above mentioned report, the most up-to-date published diagnosis of status and prospects in terms of searching for uranium deposits in Poland was presented by Nieć [154]. Comparison of the diagnosis conclusions with report results was presented in Table 4.3.2.

Table 4.3.2 Status and prospects of search for uranium deposits in Poland according to Nieć (2009) and Solecki et al. (2010)

Deposit	The most optimistic variant (Nieć 2009)		REMARKS resulting from the team report (Solecki et al. 2010)
	Resources estimated (t)	Content ppm U_3O_8	
Rajsk	1444	295	From the resources documented in 1976, 470 Mg meet the balancing criteria from 2008 (according to checking calculations performed in terms of this study ca. 450 Mg). One may take into account double increase in resources upon examining the area adjacent from SE. At large depth of deposition (544 m) and low resources, only pit mining remains, requiring developing new technologies
Podlaskie depression			Among the prospective resources documented in 1977, none meets balancing criteria from 2008
Grzmiąca	789	637	776 Mg of resources meet balancing criteria
Okrzeszyn	935	590-1180	Content of U_3O_8 meets the criteria, but since the strata

Deposit	The most optimistic variant (Nieć 2009)		REMARKS resulting from the team report (Solecki et al. 2010)
			are very thin (0.1-0.2 m) , the richness does not meet the balancing criteria, option of pit mining or surface mining of "highwall mining" type may be considered, performed from the surface or from shallow dip headings.
Radków Wambierzyce	217	118-354	Too low content and richness
Radoniów	131		Irregular and very diverse deposits
Podgórze	81		Irregular and very diverse deposits

The presented summary indicates, that currently a bit more than 450 tonnes of uranium in Rajsk deposit and 776 tonnes of uranium in Grzmiąca deposit may be deemed documented. Those resources are so small that potential mine construction is not profitable.

The currently known uranium deposits and mineralisations occur in the area of the following Polish geological units:

- Precambrian platform (podlaskie sink hole - Ordovician dictyonemic shales and Peribaltic Syneclise - Lower Triassic sandstone);
- Lower Silesian block (Sudety - both Variscan subsoil and Post-Variscan platform);
- Horst of Świętokrzyskie Mountains and lower San (Świętokrzyskie Mountains - tectonic zones within the block and cap);
- Śląsko morawska structure (Zagłębie Górnośląskie-Upper Carboniferous series);
- Palaeozoic platform (Foresudetic monocline - Lower Triassic sandstone);
- Carpathian Mountains - Oligocene menilite shales.

Podlaskie synecline-Ordovician dictyonemic shales

In the series of Ordovician dioctynemic shales from the resources documented [155] in 1976, only 470.683 Mg U_3O_8 meet the balancing criteria from 2008. According to the checking calculations performed in scope of the report by Solecki's team (2010), it is only 450.316 Mg U_3O_8. One may take into account potential double increase in resources upon examining the area adjacent from the south to Rajsk 1 hole.

At large depth of deposition (544 m) and low resources, only pit mining remains, requiring developing new technologies. Despite relatively high average uranium content in the entire series of shales, especially its black variation, the deposit quality is determined by secondary mineralisation processes, probably related to the tectonic zone. Therefore, prospective resources documented in 1977 [155] should be deemed not meeting current criteria, although in this area there are certain chances of finding secondary enrichment zones.

The significant global resources of rock with similar uranium content, being revealed on the surface (phosphorites from Morocco and USA, dictyonemic shales from Estonia) make it difficult to expect future economic conditions suitable for uranium mining from the Podlasie shales, except for secondary enrichment zones. One may hold certain hopes in case of combining the search and extraction works on uranium ores with works concerning shale gas. Upon completion of gas extraction, application of pit method should be considered, combined with combustion (or microbiological oxidation) and gasification of organic substance and leaching the residues in order to mine uranium. However, this is the issue of long-term works on development of new technologies.

Lower Triassic sandstone of Peribaltic Syneclise

In Lower Triassic sandstone of Peribaltic syneclise, uranium ore resources have not been documented so far. The obtained results create prospects of documenting the resources meeting balancing criteria from 2008. However, it is necessary to examine hydrogeological conditions, critical for underground leaching process. Lithological conditions of deposition are unfavourable and require serious modification of existing technologies.

Lower Silesian block (Sudety - Variscan subsoil and Post-Variscan platform);

Among the deposits documented in the past, only Grzmiąca deposit has the resources amounting to 810 tonnes of metallic uranium in three strata. The current criterion of U_3O_8 content is met by all sections taken to calculate resources. The richness criterion is met by most sections.

In the opinion of the report's authors (Solecki et al. 2010) good deposit recognition status and favourable geological conditions predispose Grzmiąca deposit for potential exploitation with underground leaching method. [156] [157] The following support it:

a) occurrence of mineralisations in porous and permeable detritic sediments;

b) presence of moderately regular silty formations isolating uranium layers from barren formations;

c) frequent location of neighbouring uranium strata within one clastic bank.

With Okrzeszyn deposit, the content of U_3O_8 meets the balancing criteria, but since the strata are very thin (from 0.1 to 0.2 m), richness is unsatisfactory. The following constitute additional impediment with potential deposit exploitation: multi-layer character of the deposit, unresolved method of uranium recovery from carbon and probably necessity of repeating a part or majority of geological works on this deposit. Pit mining or underground open pit mining of "highwall mining" type may be potentially considered, performed from the surface or shallow dip-headings.

Uranium mineralisations of Radków-Wambierzyce region are characterised with much too low content of U_3O_8. The deposits in the area of Variscan mass of Sudety Mountains are mostly fully depleted, and resources remaining in Radoniów are small and difficult to mine due to high deposit variability.

Option of discovering new deposits is related to examining tectonic zones and their intersection (especially related to albitisation processes).[154] The analysis (Solecki et al. 2010) indicates the possibility of relation of mineralisation of the Sudety Mountains Variscan mass rather with tectonic zones than with grantoids, which may result in new search strategies in the Fore-Sudetic block and Fore-Sudetic monocline.

There are certain hard to specify options of finding deposits associated with the secondary infiltration enrichment zones in permocarbonic and Cretaceous sediments.

Horst of Świętokrzyskie Mountains and lower San

Uranium ores were mined as accompanying mineral during pyrite exploitation in Staszic mine. Lack of detailed information on the remaining resources. Świętokrzyskie Mountains should be treated as a region enabling positive assessment of options of finding mineralised tectonic zones in the substrate of Palaeozoic platform cap on Fore-Sudetic Monocline.

Palaeozoic platform (Fore-Sudetic Monocline - Lower Triassic sandstone);

Uranium concentrations in zechstein formations do not meet current balancing criteria. It is a fact that even with uranium content of several dozen ppm, at the current scale of copper ore mining, according to simple mathematical operations astounding quantities of uranium may be obtained, but those quantities have no significance when costs of potential uranium recovery are taken into account.

The uranium ore resources have not been so far documented in Lower Triassic sandstone of Fore-Sudetic Monocline, despite some interesting local anomalies in the area of Nowa Sól. Lithological conditions of mineralisation deposition are unfavourable and require serious modification of existing technologies.

Śląsko-morawska structure (mineralisation in Carboniferous coal of Górnośląskie Zagłębie Węglowe)

Lack of documented resources in Carboniferous coal of Górnośląskie Zagłębie Węglowe. They have never been mined. There are certain prospects of finding richer, mineralised sections in leap zones of peripheral sections of Zagłębie Górnośląskie and perhaps Lubelskie. The global experience of uranium exploitation from coal up to date is not optimistic.

Carpathian Mountains

In Carpathian Mountains, uranium mineralisations are related to the series of Oligocene menilite shales. Probably, a part of menilite series from Bezmiechowa region meets current balancing criteria.

Taking into account thickness of uranium shales, falling between 2-5 m, with average content of U_3O_8 238 ppm for volume density 2 Mg/m^3, one may except capacity from 0.95 to 2.4 kg U_3O_8 /m^3. Exploitation of those rocks was considered in the 1990s for the purpose of obtaining shale oil and even then, the enterprise was barely profitable. In Synowódzkie region (presently Verkhnye Synyovydne, Ukraine) even before World War II „Wspólnota Interesów Górniczo-Hutniczych w Katowicach" made an attempt at industrial menilite shales exploitation for the purpose of shale oil production, later continued by the Ukrainians. In current economic conditions, combined uranium and shale oil recovery should be considered, including the pit mining method, combined with burning organic substances, gas generation and leaching the residues in order to mine uranium.

To sum up, it must be stated that resources of uranium currently available in Poland are scarce, and many years of exploration and prospecting works will be required to find new uranium deposits (if any). Therefore, the only solution seems to be importing nuclear fuel.

4.3.1.1.2 Options of obtaining uranium from import

In the World War II period and right after, uranium became a strategic raw material, due to works on nuclear weapon. Until the 1960s, economic issues were secondary in terms of uranium production. After creating a basic nuclear arsenal, rapid decrease in uranium production down to 30 thousand tonnes per year took place, which completely secured not only the military demand, but also nuclear power engineering.

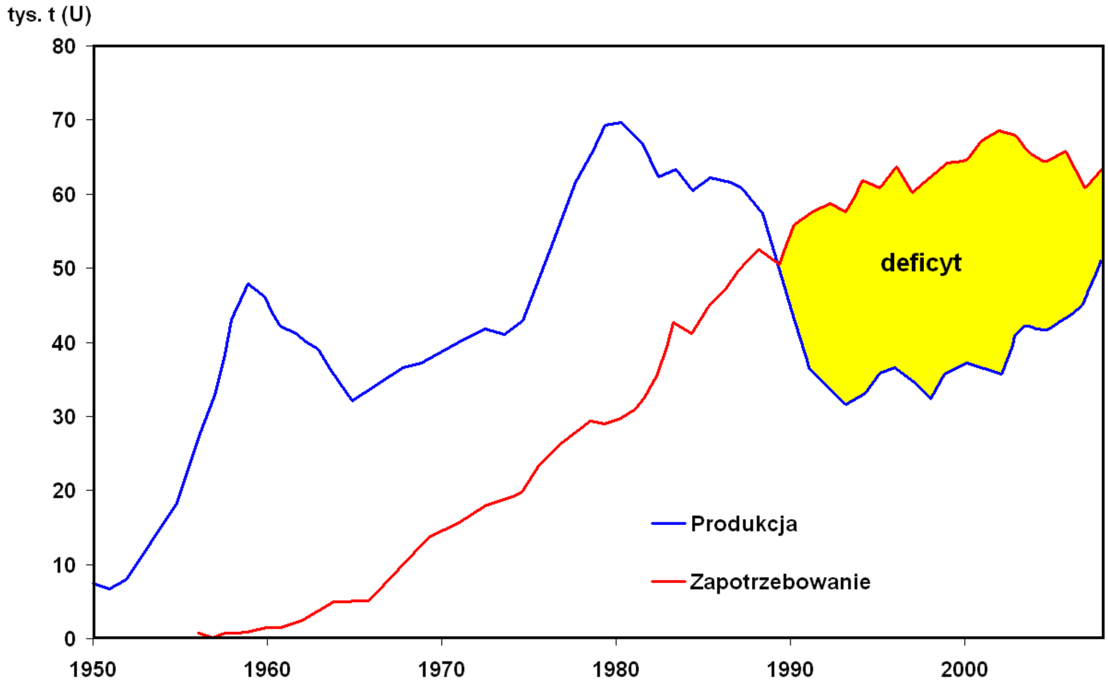


Fig. 4.3.3 Global uranium demand and production in 1950-2006 based on the data of WEC 2010

[Deficyt – Deficit
Produkcja – Production
Zapotrzebowanie – Demand
Tys. t – Thousand tonnes]

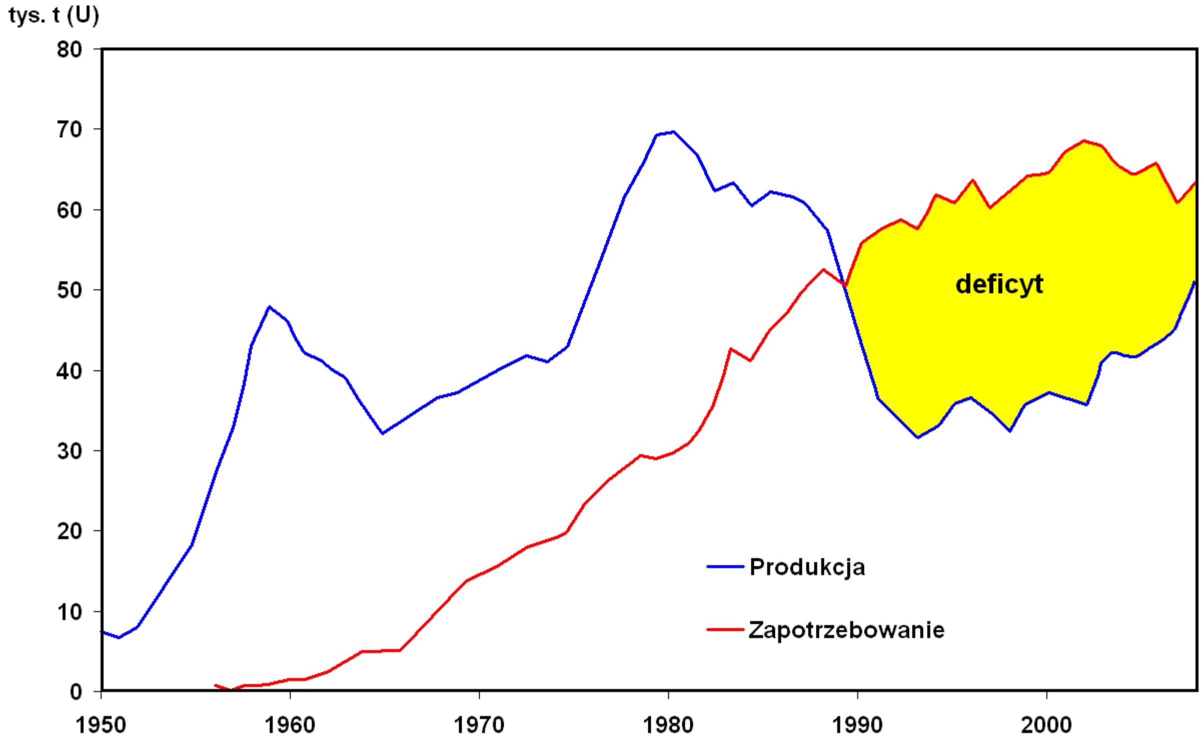


Fig. 4.3.4 Global uranium demand and production in 1950-2006 based on the data of WEC 2010

Increase in petroleum prices in the 1970s caused rapid development of nuclear power engineering, and consequently demand for uranium. Subsequent decrease in petroleum prices and Chernobyl failure affected the decrease in interest in nuclear power engineering development, which had its effect on development of mining industry. In 1995-2005 global uranium production dropped to 30-40 thousand Mg, which meant a deficit in the market for this raw material.

Since 1990 the deficit (several tens of thousands of tonnes) was covered from secondary sources, among others from recycling of Soviet warheads and recycling of fuel and processing the accumulated dumps, which kept uranium prices on relatively low level. Price of uranium reached its record low of 18.45 $/kg at the end of 2000. From 2001, increase in price occurred, additionally stimulated by failures in mines exploiting Olympic Dam and McArthur River deposits. Price increase caused increased interest of extractive industry and increase in production to the level of 52 thousand Mg in 2006. In June 2007 the prices reached their record high: 354 $/kg. Since then in 18 months prices dropped to 138$/kg[158] and stabilised. As it was mentioned previously, price of uranium in December 2010 was 134 $/kg. Currently, forecasts for nuclear power engineering and uranium mining indicate increase in demand to the level of 94 or even 122 thousand Mg/year in 2030.[158]

Currently, the indentified worldwide resources of uranium extracted at a price lower than $130/kg amount to 5.5 million tonnes[169]. Known resources of uranium ore extracted at about $130-260/kgU amount to 0.9 million tonnes. The resulting 6.4 million tonnes of uranium ore will satisfy the demand (at the current level of production) for more than 100 years. With the introduction of breeder reactors and fuel recycling technologies that considerably increase the energy efficiency of nuclear fuel, the same resources will suffice for several thousand years (at the current level of electricity production).

Other, conventional uranium resources, possible to document in commonly exploited deposit types, are estimated at approximately 10 million Mg. Additionally, the size of resources possible to obtain from phosphorites (at a cost of 60-100$/kg) and black shales is estimated at 10-22 million Mg of uranium. In the 1990s, until the decrease in raw material prices, recovery of this element from phosphorites was started in the USA, Belgium and Kazakhstan. With significant increase in prices (above 210-260 $/kg) it also becomes profitable to obtain uranium from sea water, where ca. 4 billion Mg of this stock is dispersed.[159] [160] As it can be seen, prices of uranium in long-term perspective should not increase, since with their increase it becomes profitable to extract huge resources from new types of deposits (phosphorites, black shales, sea water).

Existence of unconventional resources raises doubts concerning the sense of searching for uranium deposits in Poland. At the same time, we cannot forget about hundreds of thousands of tonnes of phosphorites processed in our country. Uranium contained in phosphorites is mostly found in phosphates obtained in production, where it forms an unwanted component. It seems appropriate to undertake works on recovering uranium from the same source as with significant import scale (458.92 thousand Mg[161]) it could lead to obtaining approximately 50 tonnes of U per year, with simultaneous positive ecological effect.

4.3.1.2 Environmental effects of preliminary hazard related to securing raw material for production of uranium concentrate

Mining related to extraction and processing of uranium ores until the stage of obtaining "yellow cake" is associated with significant environmental impact. This impact depends on the type of deposit, parameters of the surrounding area, and the adopted mining technology.

As the processing of uranium ore involves a chemical separation of this element, it may lead to migration of radioactive isotopes deposited in uranium ore during millions of years.

Among those isotopes, the highest environmental migration ability is displayed by radium Ra-226 and radon Rn-222, the radioactive progeny of which are, among others: bismuth Bi-214 (main emitter of gamma radiation in the series of uranium U-238 decay) and highly radiotoxic polonium Po-210.

Migration of these isotopes may be reduced by using the optimum extraction and processing technologies. In terms of the extraction process itself, extraction with underground headings may be considered as the least burdensome. The ore is then transported to a processing plant, and environmental changes in the mine area do not vary from those occurring with any other type of mineral extracted in underground mines. The mine drainage and ventilation system may release increased concentrations of radium and radon to the atmosphere, but taking into account uranium ores in regions with naturally increased content of uranium and its derivatives, this phenomenon should not significantly increase the natural radiation level in mining areas.

A more significant problem is mechanical and chemical ore processing. Waste from this process is made up of radioactive isotopes, accumulated in the ore for millions of years, as a result of uranium decay. The best solution is waste deposition in special dumps, rendering the isotope migration difficult. We must note that these activities will not lead to any increase in the amount of radioactive elements in the lithosphere, and the only risk is related to their relocation or easier migration to water and air. A properly designed radioactive waste depository (using mining pits whenever possible) will ensure permanent neutralisation of natural radioactive isotopes in a manner that is not much different from their original state. It must be emphasised that migration of radium, radon, and other products of uranium decay is a natural process, and radium and radon waters are commonly found in the lithosphere and sometimes used for medical purposes.

In case of surface mining, environmental impact of the mining process itself is more significant, but the increase is related with the nature of this sort of mining, causing significant changes in the landscape, regardless of the type of mineral.

In case of application of underground leaching method (ISL) with acidic or alkaline solutions pumped through drill holes, most environmental changes are localised in rock medium, at the depth from several tens to several hundreds of meters. This extraction method requires natural hydrogeological insulation around the mineralised bed. Therefore, risk of contamination of adjacent water-bearing layers is small. With such a method, a part of chemical process takes place in natural rock medium and only uranium recovery from the leaching solution takes place in a processing plant. Some amounts of radium, radon and other undesirable elements pass into the solution, but in favourable geological conditions, the process may be limited.

Uranium mining and pre-processing takes place in areas where the quantities of radioactive elements are naturally higher, and their negative impact on the environment should not be exaggerated. For instance, average uranium content in granite is 3-10 grams per tonne, which means that in the area of one hectare, in ten-meter layer of this rock, there are 600-2000 kg of uranium and the entire set of accumulated decay products. In case of natural phosphorite occurrences, average uranium content is ca, 100 grams per tonne, which in turn means that uranium content in 10-meter layer in one hectare area reaches 20 tonnes. In case of phosphorites commonly processed into chemical fertilizers, uranium recovery would be a process improving environment.

The isotope enrichment process taking place after the "yellow cake" stage is a source of significant amount of depleted uranium, often treated as waste. This uranium is not different in terms of its radioactivity from natural uranium. Due to high density, it is sometimes used as cores of armour piercing shells and weights in industry. Coloured uranium salts are used for colouring ceramic products gold. With common introduction of breeder reactors, this uranium may be used as nuclear fuel.

4.3.1.3 Fuel campaigns and cycle of the reactor

A 3rd generation reactor of nuclear power unit with electric power of ca. 1000 MW_e uses less than **20 tonnes** of nuclear fuel per year - i.e. one train car per year. For comparison purposes: in a boiler of thermal power station unit with the same power, fuelled with hard coal, at least ca. 3 million tonnes of coal must be combusted per year (daily average ca. 160 cars)

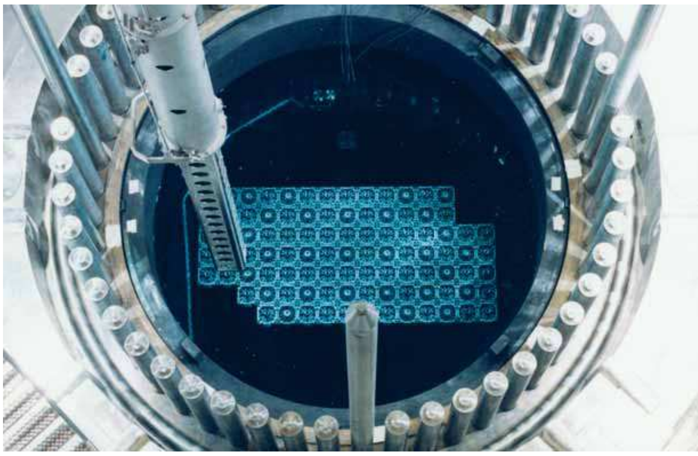


Fig. 4.3.5 Reloading nuclear fuel [AREVA: U.S. EPR Nuclear Plant]

In nuclear tank reactors - like light-water reactors, which will probably be erected in Poland - nuclear fuel is reloaded **periodically**, with the reactor *off-line*, after cooling the reactor, dismounting the tank lid and structures inside the tank above the reactor core, and then flooding the upper part of reactor shaft with water. Fuel reloading is performed with a special reloading machine, under a several-meter water layer, forming a shield against radiation. During fuel reloading, typically taking several days to one month, current overhaul of the nuclear unit is simultaneously performed. The period of fuel combustion in the reactor during operation between fuel reloading is called **fuel campaign**.

III and III+ generation reactors were designed to enable flexible planning of fuel campaigns, lasting from 12 to 24 months[162] and obtaining mean burn-up of nuclear fuel unloaded from the reactor at the level of ca. 60 MW·d/kgU. Depending on enrichment, nuclear fuel remains in the reactor from 3 to 5 years. During this time, most of the fissile U-235 is subject to "burn-up" (however, there still remains ca. 1%), and from nuclear transformations of U-238 and U-235 transuranic element isotopes are created, of which plutonium is particularly significant (fissile isotopes Pu-239 and Pu-241). At the end of a fuel campaign, ca. 35% of energy is created from fissions of plutonium isotopes, and their content in the fuel reaches ca. 1%. Other transuranic elements are also created, significant from the perspective of processing burnt-up fuel and disposal of radioactive waste, the so-called rare actinides (isotopes of neptunium, americium and curium)[163], as they are long-lived radioactive isotopes. The fission creates isotopes, mostly radioactive, called "fission products" (specific "ash" from fuel burn-up), some of the isotopes have long radioactive decay period (long-lived fission products)[164].

During reloading - depending on strategies of nuclear fuel management – $^1/_3$ or $^1/_4$ of the most burnt-up fuel sets (assemblies) are reloaded, which were in the reactor core for 3 subsequent campaigns. Other assemblies are properly relocated in order to obtain core arrangement providing meeting various physical (neutron-physical characteristics) and thermal and flow restrictions - resulting from safety requirements, and at the same time to generate the quantity of electric power planned for the period of a given fuel campaign (at the lowest possible fuel cost). **The most typical** for III and III+ generation reactors are **18-month campaigns**, where during reloading $^1/_3$ of the (most burnt-up) fuel assemblies are replaced with fresh fuel, and the remaining $^{2}/_{3}$ of the assemblies are rearranged. Presently, core loadings are designed with low neutron leakage *(low-leakage core)* – see Fig. 4.3.6.

The advantage of such core configurations - characterised with high gradient of radial power distribution - is possibility of obtaining higher fuel burn-up and simultaneously reducing neutron radiation of the structural elements of the reactor (pressure tank and certain structures inside the tank)[165]. However, a significant safety restriction is relatively high power density in the middle reactor core zones.

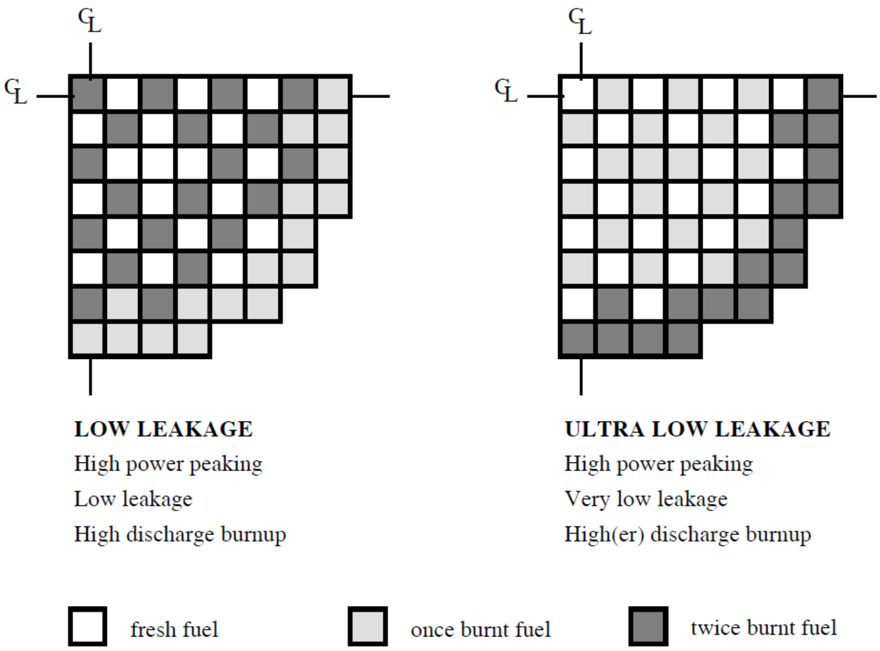


Fig. 4.3.6. Diagrams of reactor core configuration with low neutron leakage (configuration of ¼ of the core was presented)

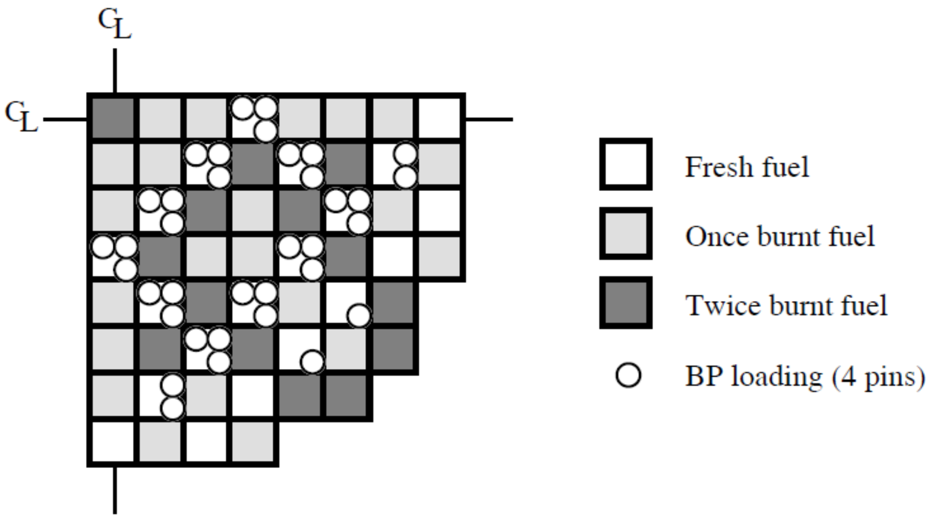


Fig. 4.3.7 Model core loading with BP – burnable poisons

Recently, in order to compensate high reactivity excess in power reactors[166] in the beginning of fuel campaign, the so-called "burnable poisons" were introduced - materials absorbing neutrons (usually gadolinium in form of Gd_2O_3) contained in fresh fuel assemblies (from several to several dozens of rods containing burnable poisons per fuel assembly). In the duration of the campaign, as a result of neutron absorption, the "poisons" are gradually burnt-up - i.e. their negative reactivity effect decreases. Due to application of burnable poisons, the highest local thermal loads (power density) in the core may also be decreased, (see Fig. 4.3.7).

4.3.1.4 Nuclear fuel management

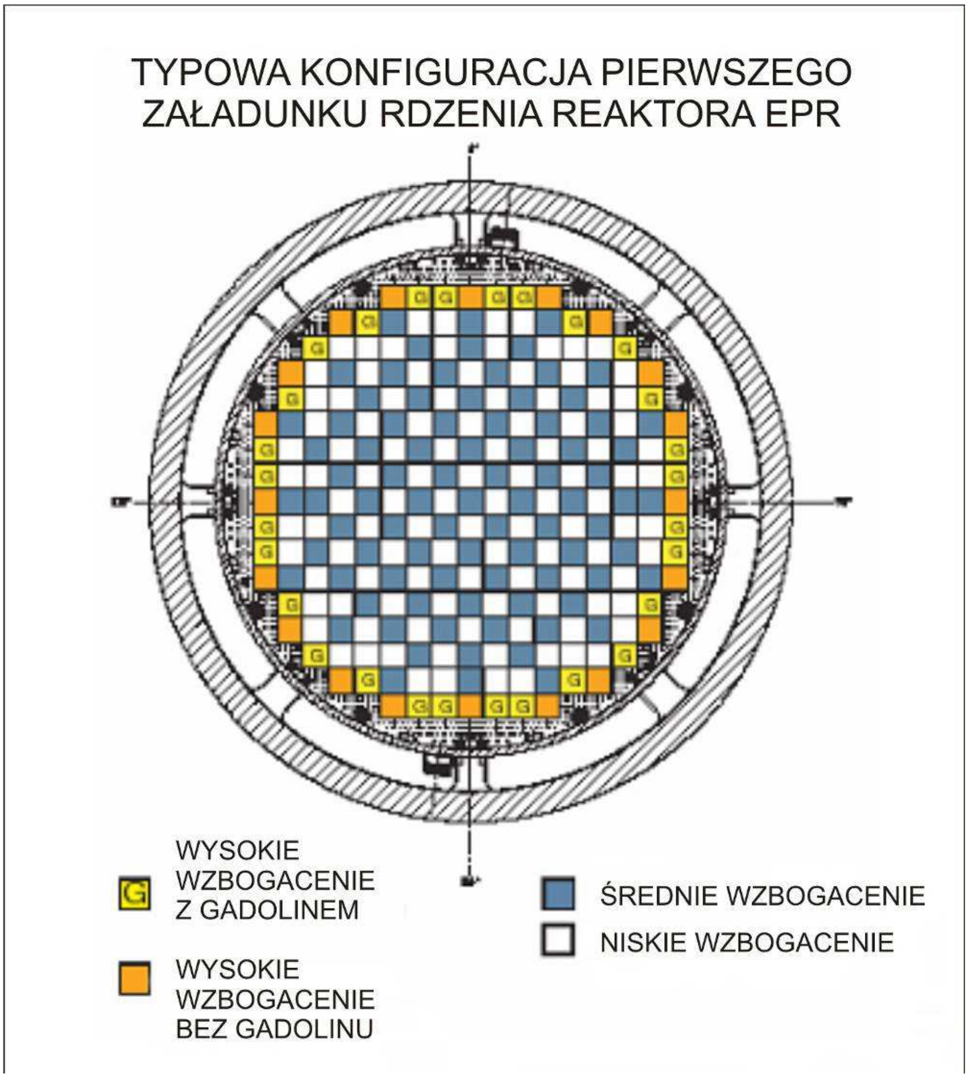


Fig. 4.3.8 Typical configuration of first charging of the EPR reactor core (24 fuel assemblies) [AREVA]

[TYPOWA KONFIGURACJA PIERWSZEGO ZAŁADUNKU RDZENIA REAKTORA EPR – TYPICAL CONFIGURATION OF FIRST CHARGING OF THE EPR CORE
Wysokie wzbogacenie z gadolinem – High enrichment with gadolinium
Wysokie wzbogacenie bez gadolinu – High enrichment without gadolinium
Średnie wzbogacenie – Medium enrichment
Niskie wzbogacenie – Low enrichment]

Economically optimal designing subsequent fuel campaigns (minimising fuel costs for specific amount of energy planned for generation), meeting all **requirements and physical , thermal and flow and material constraints** is a very complicated and hard to solve mathematical issue. As a result of optimisation calculations, a number of necessary fresh fuel assemblies of individual types is specified (enrichment, content of burnable poisons, MOX fuel), as well as core configuration for a specific fuel campaign (places of charging fresh fuel assemblies and manner of rearrangement of partially burnt-up assemblies).

The reactor core contains several hundred fuel assemblies of various enrichment and burn-up, distributed in a regular grid of cells - square in Western reactors or hexagonal - in Russian reactors (whereas identical-enrichment assemblies may be burnt-up to a different extent, depending on their locations in the core during campaigns).

Due to core symmetry, calculations are made for the section - in Western reactors: 90° (a fourth of the core), in Russian reactors: 60° (1/6 of the core). Still, the number of possible permutations of fuel assembly locations is huge (may even reach 10^{100}). Thus, it is a difficult discrete optimisation issue, requiring application of special advanced algorithms, based rather on **stochastic optimisation methods** (such as: simulated annealing method, genetic algorithms, pseudo-heuristic methods) than on more conventional methods (such as: linear, square or dynamic programming). There are commercial software packages for optimisation of nuclear fuel management, in particular based on stochastic methods[167].

Planning fuel campaigns with optimising calculations must be performed on a rolling basis with at least five years in advance (on the basis of long-term plans for electricity production). Results of the planning will provide data necessary to place orders for nuclear fuel. Since production of nuclear fuel for potential nuclear power plants is not planned in Poland in a foreseeable time perspective, it should be assumed that ready-to-charge fuel assemblies will be imported.

The most apparent and probable nuclear fuel suppliers are obviously suppliers of reactors of a given type (as a standard, the first core loading is supplied in terms of a "turnkey" contract for construction of a nuclear power plant). However, it is also possible to order fuel from other supplier (although sometimes it may involve some technological problems). For instance, for the Czech nuclear power plant Temelin[168] and South Ukrainian nuclear power plant[169], equipped with Russian reactors (pressurized water reactor type WWER-1000) fuel is supplied by Westinghouse, and for British nuclear power plants with gas graphite reactors (AGR) the fuel is recently supplied by Russian company TVEL[170].

Supply of ready-to-charge fuel assemblies is provide by all leading global nuclear technology suppliers, including French AREVA and American companies: Westinghouse (a part of Toshiba Corporation) and General Electric, and Canadian AECL. Nuclear fuel is also manufactured by British BNFL and Russian TVEL. Currently dominating global position in the nuclear fuel market is occupied by the following 3 groups (satisfying ca. 80% of demand): French **AREVA**, American **Westinghouse** (Toshiba Corporation) + Spanish **Anusa**, and American-Japanese **BNF Genusa** (GE + Toshiba + Hitachi). The highest (ca. 40%) contribution in supplies of fuel for light-water reactors (excluding WWER of Russian construction) is provided by AREVA, supplying fuel to 134 of 308 PWR and BWR reactors operating globally, of which $^{2}/_{3}$ are reactors designed by AREVA (formerly Framatome), and the remaining $^{1}/_{3}$ – by its competitors.[171]

Fig. 4.3.9 Fresh nuclear fuel storage in Finnish nuclear power plant Loviisa. [Imatran Voima Oy: Loviisa Power Plant]

If necessary, it is possible to accumulate a fresh fuel supply in a nuclear power plant for many years. The only limitation is current capacity of fresh fuel storage, which may be expanded if needed.

Fresh fuel is transported (by water, rail, road) in special containers, of which each contains 2 or 4 fuel assemblies. Container structure provides protection against mechanical damage, as well as subcriticality (i.e. it protects against accidental creation of critical mass) in case of falling into water as a result of transport accident. A fresh fuel storage is also designed to exclude creation of critical mass in case of flooding with water.

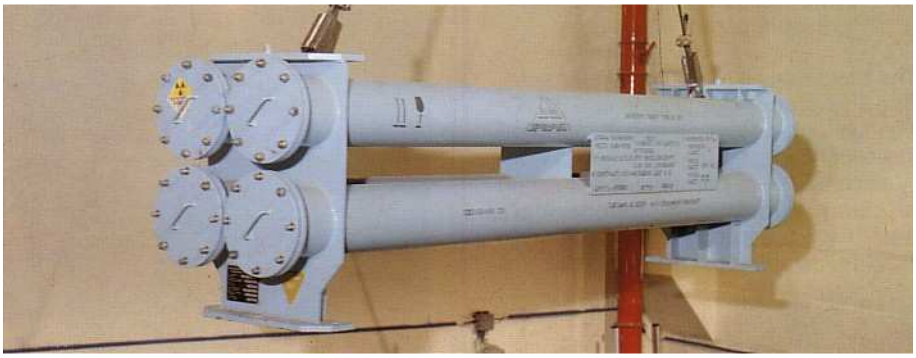


Fig. 4.3.10 Fresh fuel transport container to pressurized water reactors of Russian construction, type WWER-440.[Imatran Voima Oy: Loviisa Power Plant]

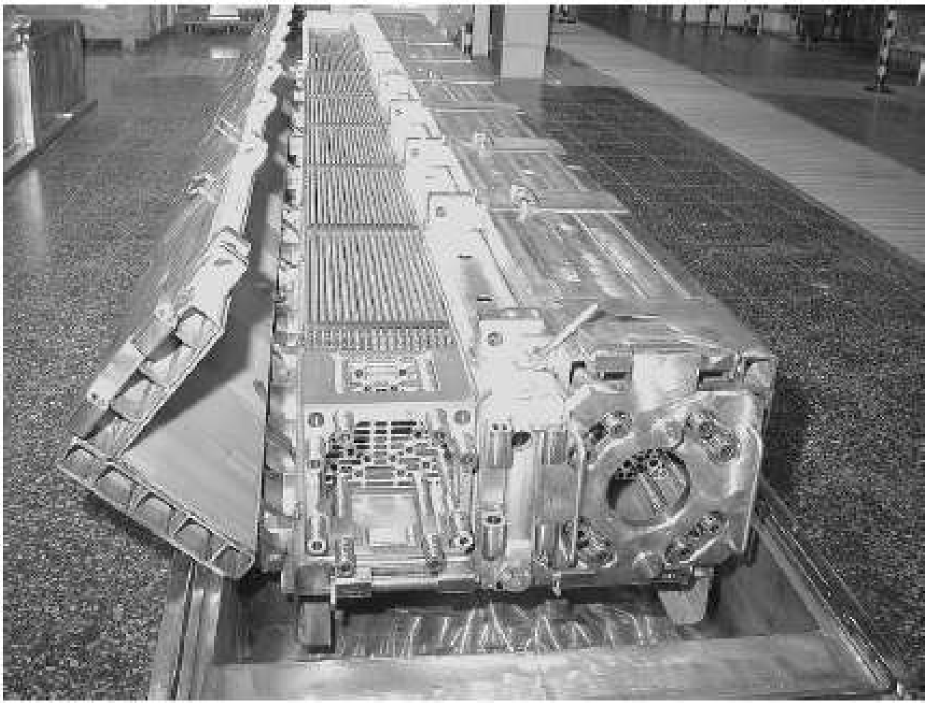


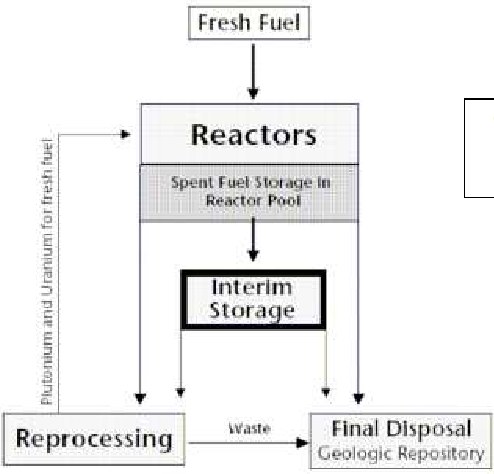
Fig. 4.3.11 ANF-18 type container for transporting fresh fuel to PWR reactors, loaded with two fuel assemblies.[172]

Ionising radiation emitted by fresh uranium fuel is insignificantly small, so no radiation shields are necessary. However, uranium-plutonium MOX type fuel is much more radioactive and therefore it must be transported and stored in shielded containers. Transport of fuel, both fresh and burnt-up, is subject to physical protection, which is required by International Convention of Physical Protection of Nuclear Materials.[173]

4.3.1.5 Handling burnt-up nuclear fuel

Burnt-up fuel discharged from the reactor is placed in **burnt-up fuel tank** filled with water, located in the auxiliary reactor building or fuel building (adjacent to the reactor containment), where it remains for at least 3 years (usually 7-10 years). During this time, it is cooled down and de-activated by tens of per cent. Then, if spent fuel is not reprocessed, it is moved to **the interim storage facility** (usually located on site) - wet or dry,[174] where it can be stored for additional 40-50 years.

The next step is deposition of spent fuel in **the repository in geological formations,** for its periodical *(reversible geological disposal)* or final storage *(final geological repository)* - see Fig. 4.3.12.



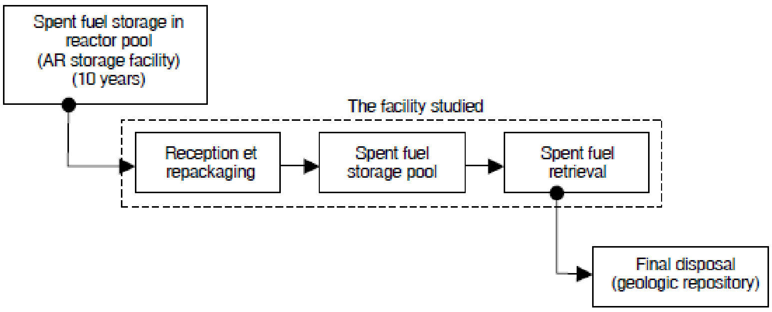


Fig. 4.3.12 Variants of handling burnt-up nuclear fuel [AREVA][175].

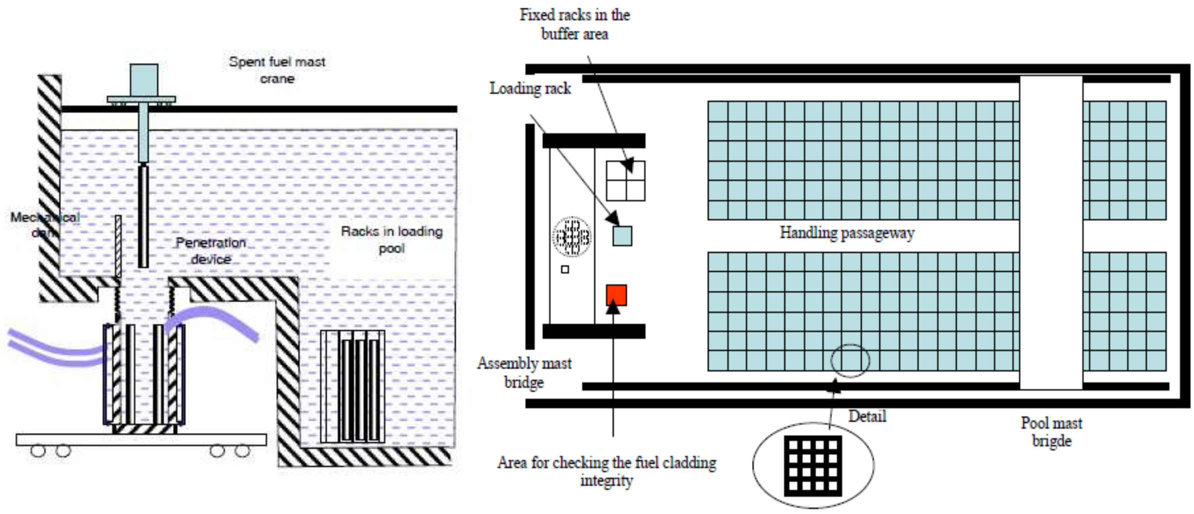


Fig. 4.3.13 Construction diagram of a wet interim storage facility for burnt-up fuel, estimated for 3400 fuel assemblies and 100 years of use [AREVA: UK EPR]

Spent fuel removed from the reactor is highly radioactive and emits heat generated as a result of radioactive decay - mainly fission products and rare actinides. The vast majority of radioactivity of the burnt-up fuel is related to radioactive decay of short and medium-lived fission products, most of which are subject to decay within several years after fuel discharge from the reactor.

As it can be seen in the diagram (Fig. 8.3.14) after approximately 4 years, the activity of fission products contained in spent nuclear fuel declines by 4 times. After about 10 years, the fuel activity is mainly related to radioactive decay of two isotopes: caesium Cs-137 and strontium Sr-90. After ca. 300 years, in case of processing the spent fuel combined with recycling of transuranic elements, activity of fission products decreases 1000-fold and they become practically harmless since [Hannum et al].[176]

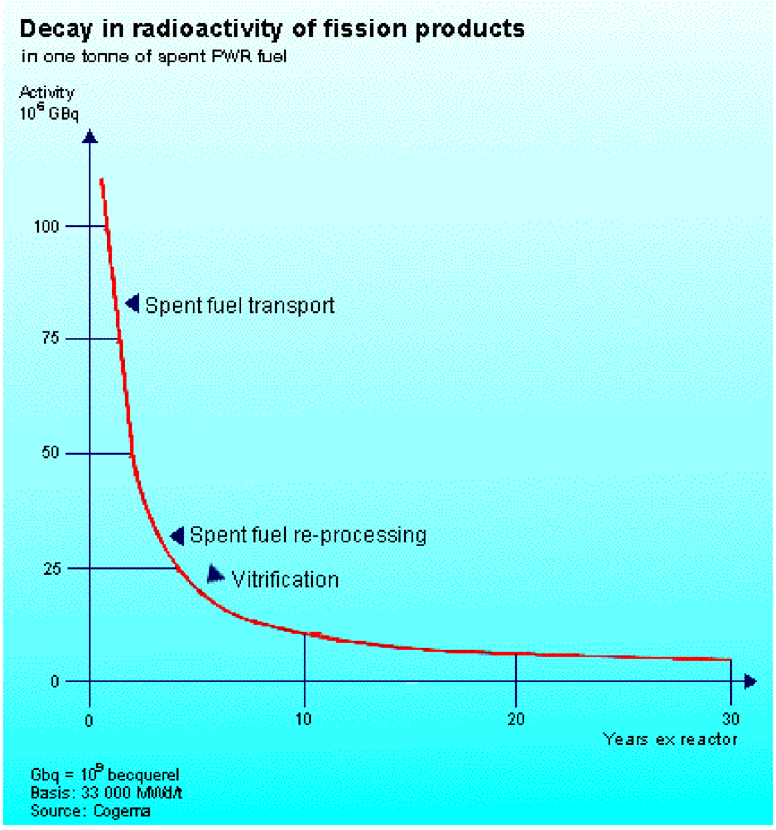


Fig. 4.3.14 Decrease in activity of fission products contained in 1 t of spent fuel PWR (spent fuel transport, reprocessing, vitrification)

Isotopes of transuranic elements (plutonium and rare actinides - including especially americium), although they comprise only about 1% of the spent fuel mass, due to their long-livedness (half-lives reaching tens of thousands years) and high radiotoxicity - constitute a significant problem in terms of long-term storage of spent fuel. It is necessary to provide removal of heat generated due to radioactive decay and its isolation from environment for the period of 10 thousand years. Therefore, plutonium and other actinides should be separated from fission products designated for final repository and "disposed of". The easiest and most effective "disposal" method is using them in reactors as nuclear fuel - then, in the fission process they transform into fission products or, as a result of neutron radioactive capture[177] and further radioactive transformations they transform into short-lived or stable isotopes.

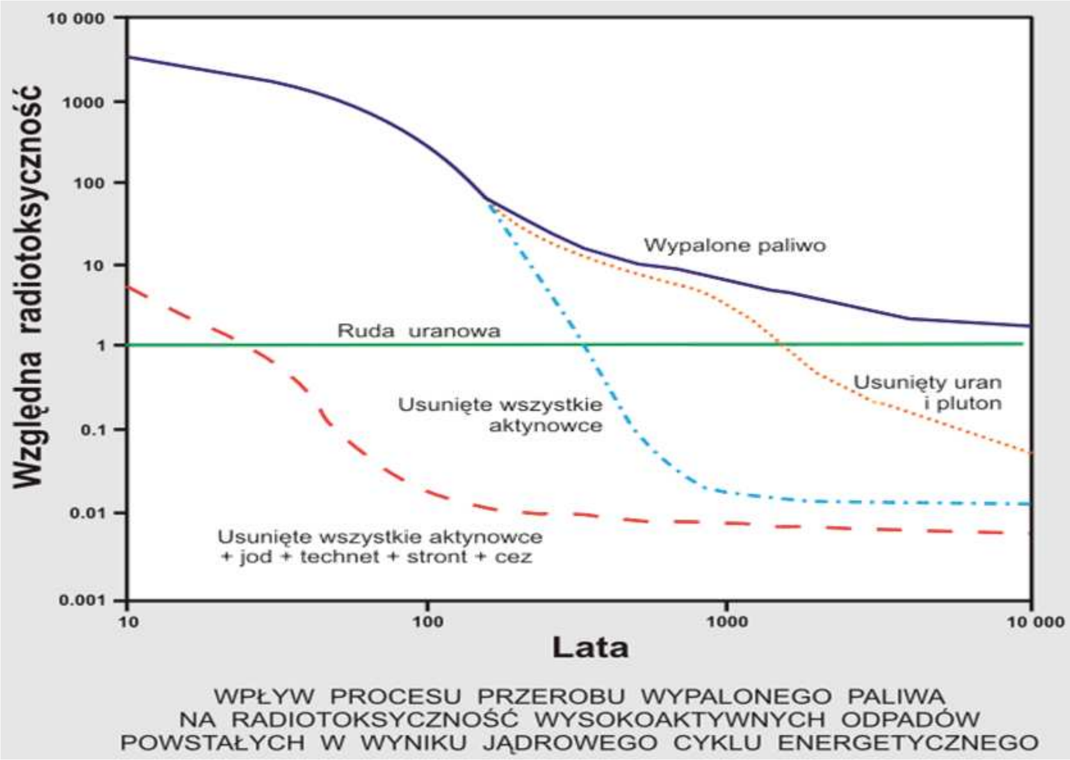


Fig. 4.3.15 Impact of spent fuel reprocessing on radiotoxicity of waste generated in the fuel cycle.[178]

[Względna radiotoksyczność – Relative radiotoxicity
Wypalone paliwo – Spent fuel
Ruda uranowa – Uranium ore
Usunięte wszystkie aktynowce – All actinides removed
Usunięty uran i pluton – Uranium and plutonium removed
Usunięte wszystkie aktynowce + jod + technet + stront + cez - All actinides removed + iodine + technetium + strontium + caesium
Lata – Years
WPŁYW PROCESU PRZEROBU WYPALONEGO PALIWA NA RADIOTOKSYCZNOŚĆ WYSOKOAKTYWNYCH ODPADÓW POWSTAŁYCH W WYNIKU JĄDROWEGO CYKLU ENERGETYCZNEGO – IMPACT OF SPENT FUEL REPROCESSING ON RADIOTOXICITY OF HIGH-LEVEL WASTE GENERATED IN NUCLEAR POWER CYCLE]

Activity of "light" radioactive waste (i.e. without plutonium and other actinides), after approximately 100 years decreases much faster than activity of the spent fuel, and after ca. 300-400 years it reaches the value below uranium ore activity (see Fig. 4.3.15). In this case - with elimination of plutonium and rare actinides - the required period of radioactive waste isolation from environment is decreased to ca. 500 years (see: Fig. 4.3.15).
Spent fuel may be reprocessed even after approximately 3 years from discharge from the reactor. In practice, fuel reprocessing takes place 5 to 25 years after discharge.[179] Early processing of spent fuel is economically profitable, since the duration of fuel cycle is shortened (fuel circulation is faster), but it involves additional difficulties caused by large amount of generated heat and high fuel activity. On the other hand, after a longer period of spent fuel storage, it generates more americium Am-241 isotope (as a result of decay of β isotope of Pu-241 with half-life of 13 years), which creates an additional problem in terms of manipulation with MOX fuel (increases exposure to gamma radiation).

Fig. 4.3.16 illustrates the transformations of fuel isotopes during burn-up of standard uranium fuel in form of uranium dioxide (UO_2), with 4% enrichment in isotope U235, in a typical light water reactor (LWR).[180]

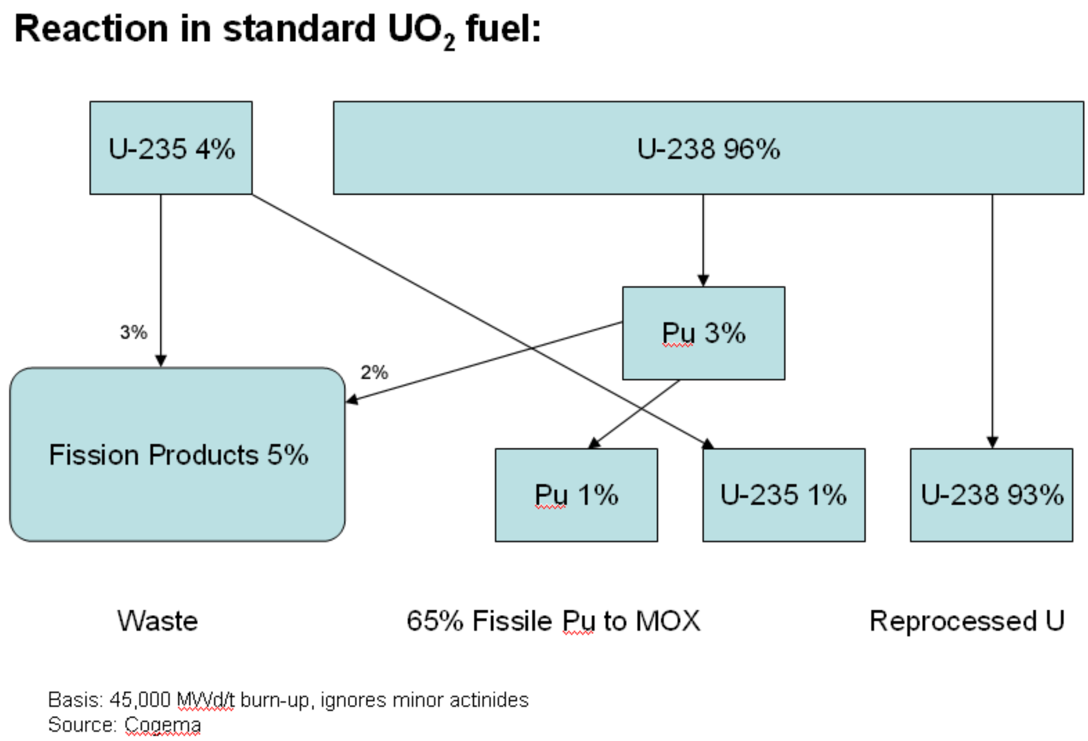


Fig. 4.3.16 Diagram of fuel isotope transformations during burn-up of uranium fuel in PWR

As it is shown in this diagram, in the spent nuclear fuel ca. 93% U-238, 1% U-235 remains (more than in natural uranium), 1% Pu (of which ca. 65% are fissile isotopes: Pu-239 and Pu-241), and ca. 5% are *fission products*. In spent fuel, approximately 200 various fission products are created, in fact they are only "ash" created as a result of nuclear fuel burn-up. Among fission products, approximately 2.9% are stable isotopes; 0.3% caesium and strontium; 0.1% iodine and technetium; and 0.1% long-lived fission products. The content of rare actinides is about 0,1%[181].

Every year, spent fuel is discharged from a typical large LWR with power of 1000 MWe (in the amount of ca. 30 Mg), therefore it contains ca. 300 kg U-235 and plutonium. Fissile isotopes, as well as "fertile"[182] U-238, may be recovered in *reprocessing* and reused in power reactors (recycling of uranium and plutonium).

If fuel is used only once in a thermal reactor(*once-through cycle*), the energy-generating potential of fuel materials is utilised to a very limited extent. Reprocessing spent fuel with recycling of uranium and plutonium - in particular for generation of uranium-plutonium fuel (MOX) allows for increased application of fuel energy potential and saving ca. 30% of fresh uranium [Hannum et al].

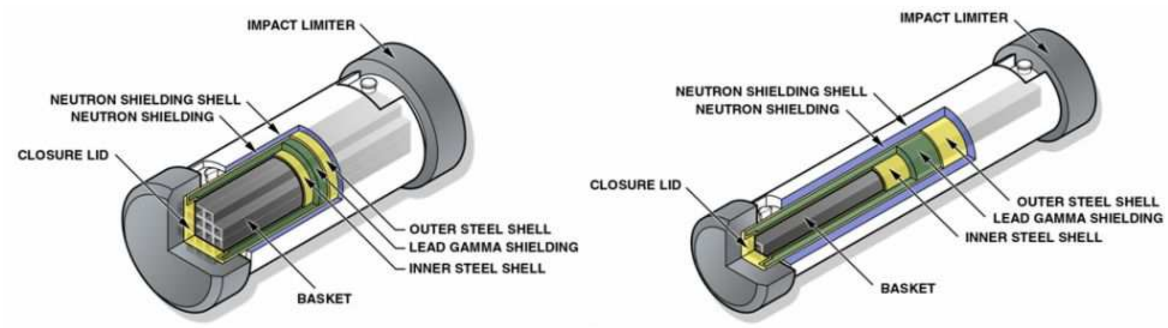


Fig. 4.3.17 Structure of a typical container for transport of spent fuel: on the left - railway container, on the right - road container.

Fuel reprocessing also allows significant reduction of volume of highly active waste. According to the data from AREVA[183] volume of highly active waste may be reduced even 4-5 times, and radiotoxicity of long-lived isotopes approximately 10 times. Taking into account saving of "fresh" uranium - costs of MOX fuel (0,177 €c/kWh) are only about 5% higher than costs of standard uranium fuel (0.168 €c/kWh). With increase of uranium concentrate prices, reprocessing spent fuel will become more profitable.

Spent nuclear fuel is transported in special containers that ensure protection from radiation and absorption of heat, meeting the strict safety requirements specified in MAEA[184] (Fig. 4.3.17).

4.3.1.6 Storage of radioactive waste

As it results from "Programme of Polish Nuclear Power Engineering" (point 14.2 and 14.3), currently studies are conducted concerning radioactive waste management in Poland, coordinated by the Team for development of *National plan of handling radioactive waste and spent nuclear fuel*. The team has already started the works and commissioned analyses concerning estimation of real costs of application of various radioactive waste and spent nuclear fuel management methods. These analyses, forming a basis for recommendations regarding an approach to spent nuclear fuel (whether spent fuel should be processed or, ultimately, fully stored in Poland), taking into account costs and advantages of application of each of the two solutions.

The issue of spent fuel from research reactors was solved by means of concluding agreements with the USA and Russia, which provide disposal of highly radioactive fuel from research reactors to Russia. However, development of nuclear power engineering in Poland in the near future poses an obligation to develop a strategy for radioactive waste management, whose main objective will be to specify a manner of handling radioactive waste derived from various activities and to suggest an approach to spent nuclear fuel and assumptions and recommendations concerning further works in this field.

Activities of the aforementioned Team do not refer directly to construction of a deep underground repository for high-activity waste and spent fuel. As it results from experiences of other countries, the need to build such a repository will occur about 30-40 years from commissioning the first nuclear power plant - that is no sooner than around 2050. Until then, spent nuclear fuel (unless it is reprocessed earlier) will be kept in water pools next to the reactor (for 10 years) and then moved to a wet or dry interim storage facility on site, where it can be stored for 40-50 years[185]. It must be emphasised that also in case of reprocessing spent fuel, the problem of high-activity waste storage will not disappear - however quantity and activity of the waste directed to repository will be decreased multiple times and required time of its isolation from environment will shorten drastically (see: point 0).

The radioactive waste management plan should be adopted by the Council of Ministers in 2011, following the adoption of the Polish Nuclear Programme.

The most urgent task in terms of radioactive waste management is building a new domestic repository of low and mid-activity waste, needed due to filling up of KSOP in Różan (expected in ca. 2020-2022).

For the next 2 years, intensive works on selecting location for the new domestic repository of low and mid-activity waste will be conducted, as a result of which 3 most advantageous locations will be chosen, from among which - after detailed research and analysis in 2013 - the most optimal location will be selected. Subsequently, design and construction works will be conducted, so that in 2020 at the latest the new repository cab ne put into service. This is important due to the fact that the introduction of nuclear power will lead to magnification of the scale of activities in terms of low and medium activity waste disposal.

Medium and low-activity waste will be processed and conditioned in individual nuclear power plants (decrease in volume, solidification and chemical binding, packing) to the form required in transport and storage - according to the provisions in force. Radioactive waste so processed may also be temporarily stored in surface repositories on site.

Types of radioactive waste

High-activity radioactive waste from a nuclear power plant is mainly spent nuclear fuel, consisting of ca. **99%** of entire waste activity, or waste from fuel processing. The remaining ca. **1%** of activity is contained in **medium and low-activity** waste. The following are included among them: filter inserts from contaminated process media and air treatment systems, sewage from decontamination of devices, rooms, showers and protective clothing laundry, used protective garments and certain decommissioned devices. Medium and low-activity waste is stored similarly to medical and industrial waste, as they do not differ much. A technical and economic problem is mainly the spent fuel, which contains high-activity and long-lived radioactive isotopes. Furthermore, with disassembly of a nuclear power plant, it is necessary to secure some devices and materials which constitute radioactive waste.

The time needed for decreasing activity of radioactive waste contained in spent fuel depends on whether we apply recycling or separation of fissile materials and their reuse as fuel in the reactor.

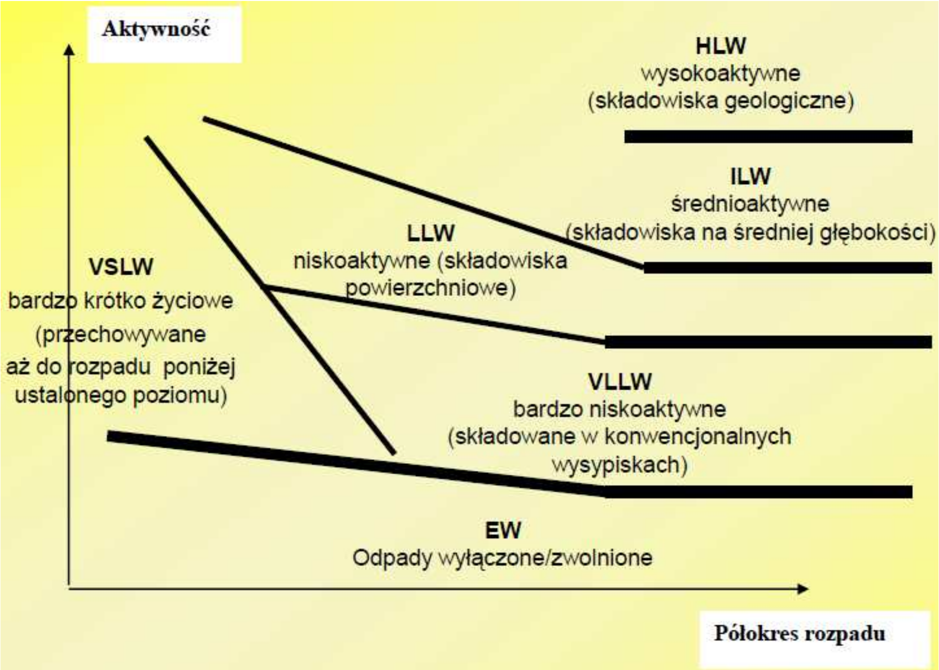


Fig. 4.3.18 Half-life periods of various types of radioactive waste

[Aktywność – Activity
Półokres rozpadu – Half-life
Wysokoaktywne (składowiska geologiczne) – High-level waste (geological repositories)
Średnioaktywne (składowiska na średniej głębokości) – Intermediate-level waste (repositories at medium depth)
Niskoaktywne (składowiska powierzchniowe) – Low-level waste (surface repositories)
Bardzo niskoaktywne (składowane w konwencjonalnych wysypiskach) – Very low-level waste (stored in conventional landfills)
Odpady wyłączone/zwolnione – Excluded waste
Bardzo krótko życiowe (przechowywane aż do rozpadu poniżej ustalonego poziomu) – Very short-lived waste (stored until decay below established level)

Radioactive waste from a nuclear power plant is relatively **small in volume**, which greatly facilitates careful preservation. Nuclear power plant with capacity of 1000 MW_e consumes up to 20 Mg of uranium per year (in form of UO_2), generating radioactive waste of total volume **ca. 180 m^3**, including:

- ca. **3 m^3** of high-activity waste - after processing spent fuel (or ca. 13 m^3 of unprocessed spent fuel),
- ca. **10-22 m^3** of medium-activity waste,
- ca.**155-160 m^3** of low-activity waste,

4.3.1.7 Transport of radioactive materials

Radioactive materials are transported by air, railway, road and sea[186] (Fig. 4.3.19, Fig. 4.3.20). Most transported shipments contain very small amounts of radioactive substances. However, one always must consider the risk of exposing people. In order to minimise this risk, the UN Social and Economic Council authorised the International Agency of Atomic Energy (IAAE) to prepare and recommend provisions and standards concerning safe transport of radioactive materials.

Fig. 4.3.19 Loading a container with spent fuel on a ship, Japan (photo John Mairs/IAEA)

Fig. 4.3.20 Transport of radioactive waste by road in Germany (photo Philipp Schulze)

Radioactive materials are transported in various packaging, guaranteeing integrity of shipment and radiation protection specified in the regulations.
Type of radioactive material packaging mainly depends on type of the material, its volume, amount, physical form and activity. Therefore, individual packaging types must be constructed differently and have different resistance and material parameters. Some of them prior to being permitted for use are subject to very strict tests: mechanical (squeezing, fall from height), thermal (resistance to increased temperature), immersion etc.

B type packaging (Fig. 4.3.21)

Type B is characterised by increased mechanical and thermal resistance, because it has to provide tightness and protection of the load even in serious transport accidents. They are used for shipping most radioactive materials (spent nuclear fuel, radioactive sources of very high activity, e.g. used in telegamma therapy or high-activity radioactive waste). B-type packaging is subject to particularly strict mechanical, thermal and immersion tests. Furthermore, they must be authorised, i.e. they must obtain a certificate issued by competent nuclear inspection and radiological protection bodies in a given country.

A type packaging (Fig. 4.3.21)

This packaging must provide load tightness and protection in case of smaller transport accidents. They are also subject to resistance tests, but not as strict as in case of B type packaging; they must be resistant to rain and potential fall from a vehicle. It is however assumed that the packaging may be damaged in transport and its content may be released. Therefore, regulations specify maximum amount of radioactive substances which may be transported in this type of packaging. Risk of irradiation or contamination - even in case of releasing such substance to environment - is very small.

Type A

Type B

Fig. 4.3.21 Containers for transport of radioactive waste type B and A

Transport packaging of radioactive waste must meet rigorous international requirements specified in IAEA regulations (IAEA Safety Standards. Publ. 1255 Safety Requirements TS-R-1, Regulations for the Safe Transport of Radioactive Materials, 2005 Edition, IAEA, Vienna, 2005.) - depending on waste category.

Containers with radioactive waste are designed to provide safety not only during regular transport but also after failures, and design failures are selected to be more serious than failures which can be expected on the basis of experience and pessimistic forecasts.

B type containers for road or water transport of spent fuel must be resistant to all possible transport accidents. Test series for B and C type containers includes the following tests:

- Impact of a train at full speed against concrete dam
- Impact of a train against the container side
- Fall of B container from 9 m to hard concrete surface
- Resistance to piercing with a metal rod
- Fire

- Sinking the container.

The risk associated with accidents during transport of spent fuel and radioactive waste is well known and low. High level of safety was achieved due to the following factors:

- Strict safety requirements in designing, construction, tests and operation of transport containers, specified in international regulations, commonly recognised as mandatory.
- Container tests at a full 1:1 scale in the conditions of most serious failures.
- Increasingly improved computational and computer models of packaging behaviour in emergency.
- Reconstructions of emergencies during transport accidents, which did not refer to radioactive material, in order to check behaviour of protection containers in such situations.
- Physical protection of transported nuclear materials.

By observing these safety standards, no radiological threats have occurred so far for the society or environment, which would be caused by failures of shipments with radioactive materials. Statistics show that transport of radioactive materials has been performed successfully for ca. 60 years, and currently about 50 million of radioactive shipments are transported per year. Nobody has lost their life or health due to release or radiation of transported radioactive materials.

Storage of radioactive waste

Proper handling of radioactive waste may effectively protect people and environment against harmful impact of emitted ionising radiation. Therefore, during disposal and storage of waste, certain principles are in effect:

- minimising the amount of generated waste;
- proper sorting (separation of liquid, waste, waste for break-up, waste for compaction, incineration etc.);
- decreasing volume (compacting, evaporation etc.);
- solidification and packing to obtain chemical and physical stability;
- waste storage in locations with proper geological structure and application of all possible technologies and barriers which effectively isolate the waste from people and environment [Włodarski][187].

Radioactive waste is deposited depending on its activity and radioactive half-life period in surface waste sites (low-activity and short-lived) and underground repositories (medium and high-activity) (Fig. 4.3.22).

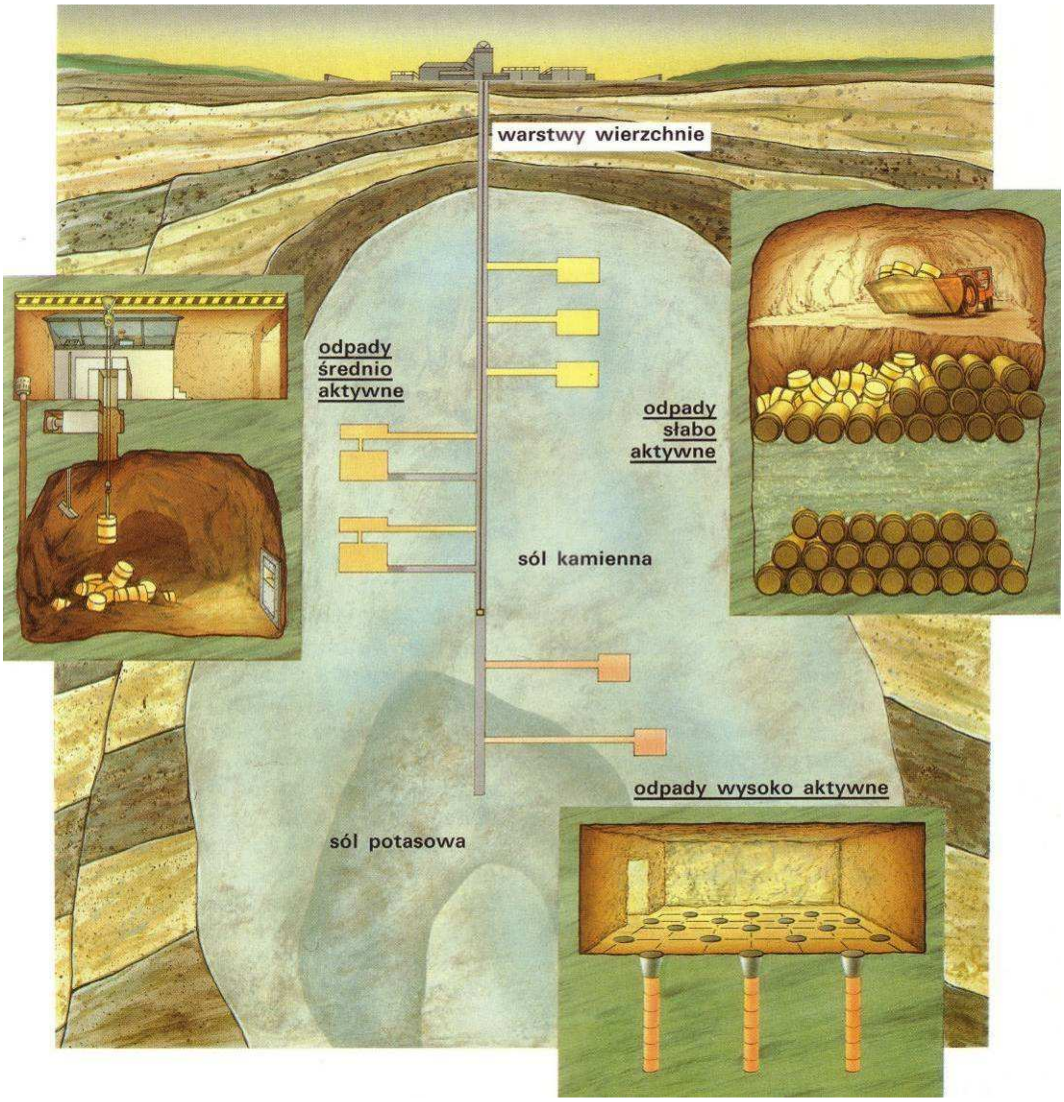


Fig. 4.3.22 Diagram of underground radioactive waste storage [Erich Übelacker: „Nuclear energy"]

[Warstwy wierzchnie – Surface layers
Odpady średnioaktywne – Intermediate-level waste
Odpady słaboaktywne – Low-level waste
Sól kamienna – Rock salt
Odpady wysokoaktywne – High-level waste
Sól potasowa – potassium salt]

Costs of disposal of radioactive waste only slightly affect the price of electricity from nuclear power plants, as they are ca. 1% of total electricity generation costs - it mainly results from economic analyses performed by the American Massachusetts Institute of Technology (MIT 2009[188]).

High Level Waste

Modern approach to the fuel cycle is the reason for the fact that with increasing frequency spent fuel is not treated as burdensome high level waste, but as a precious raw material for reprocessing and recycling fuel materials. It provides many times greater application of energy contained in fissile materials and at the same time it radically diminishes the problems related to disposal of radioactive waste.

Plutonium contained in spent fuel has a very long half-life period, which means that waste containing plutonium and rare actinides must be stored for tens of thousands of years. Therefore, the countries applying an open fuel cycle, in which spent fuel is removed to underground radioactive waste repository - were forced to developed waste storage methods ensuring their isolation from the environment for a very long time. The task was successfully solved in several countries.

Direct radiation from radioactive waste does not pose a threat – several meters of soil are enough to confine this radiation underground. Radioactive waste is usually stored several hundred meters below the surface. Therefore, the only risk is that radioactive waste could be washed up to the surface by water. Radioactive substances could be dissolved in water, reach the surface, and be consumed by people, which will cause a radiological threat. To reduce this threat, when storing spent fuel, a number of successive physical barriers are used to contain the possible spread of radioactive substances and absorb radiation. This barrier system consists of:

- ***Making slow-dissolving chemical compounds*** (concentrates) binding radioactive isotopes.
- ***Using a binding material*** **(binder),** for waste solidification, which prevents spilling, dispersion, spraying and washing out radioactive substances. A binder may be concrete (simultaneously acting as a biological shield), asphalt, organic polymers and ceramic mass.
- ***Waste packaging****,* protecting against mechanical damage, impact of weather conditions and exposure to water. Solid or solidified waste is usually closed in metal or concrete containers and transported and stored in this form.
- ***Concrete repository structure,*** forming an additional waste protection against impact of weather conditions, preventing corrosion of packaging and migration of radioactive substances from their storage place.
- ***Geological structure of an area*** determining the location of storage site. The repository area must be aseismic, unfloodable (e.g. during floods), of low economic utility and removed from human agglomerations. Appropriate geological and hydrological conditions must prevent propagation of radionuclides in soil and their penetration to ground and surface water.
- ***Impregnating bituminous layer*** covering the top concrete layer, which reduces, among others, water migration, slows down corrosion of packaging and washout of radioactive substances.

The effectiveness of these barriers depends on their multi-stage design that prevents radioactive substances contained in nuclear waste from getting released, scattered, sprayed, or washed away with water. Therefore, the degree of exposure of the environment to the negative effects of ionising radiation emitted by nuclear waste is very small, even if we assume a worst-case scenario.

The barrier systems used globally are different depending on geological conditions of repository location, but they have several common characteristics. Below, a model system of barriers is presented: vitrified material binding radioactive material, copper fuel container, flexible bentonite clay surrounding the container, and stable geological formation (Fig. 4.3.23). If one barrier fails, the others take over.

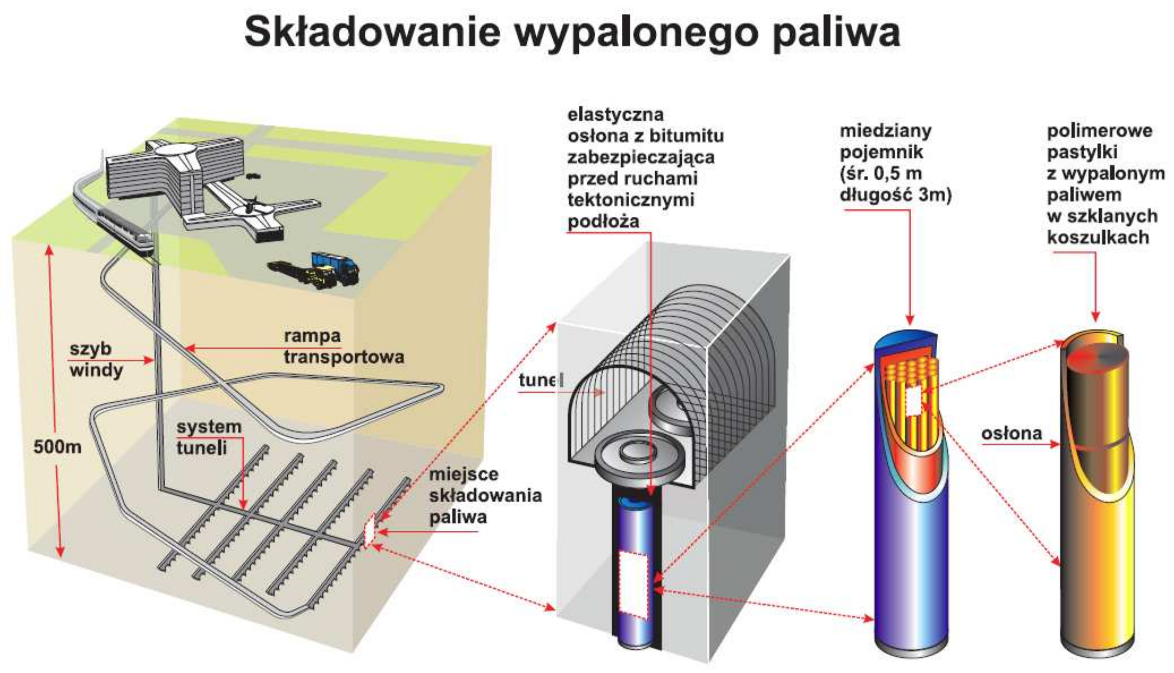


Fig. 4.3.23 System of barriers protecting spent fuel in underground storage [189].

[Składowanie wypalonego paliwa – Spent fuel storage
Szyb windy – Elevator shaft
Rampa transportowa – Transport ramp
System tuneli – Tunnel system
Miejsce składowania paliwa – Fuel storage location
Tunel – Tunnel
Elastyczna osłona z bitumitu zabezpieczająca przed ruchami tektonicznymi podłoża – Flexible bituminous casing protecting against substrate movements
Miedziany pojemnik (śr. 0,5 m, długość 3 m) – Copper container (diameter 0.5 m, length 3 m)
Osłona – Casing
Polimerowe pastylki z wypalonym paliwem w szklanych koszulkach – Polymer pellets with spent fuel in glass cladding]

First of all, melted fuel is drowned in glass with high resistance to washing out. Resistance of such vitrified material is counted in tens of thousands years. Vitrified fuel is surrounded with the first barrier, being a copper container. Its task is to isolate the fuel from the environment. As long as the container remains tight, no radioactive release may occur. The greatest threat to the whole of the container is corrosion (mainly caused by oxygen and sulphur compounds dissolved in underground water), as well as rock movements, which may cause breaking the container. Copper is a material which withstands effects of aggressive substances in underground water very well. Cast iron inserts allow withstanding very high mechanical load.
The container is surrounded by a layer of bentonite clay referred to as a buffer, as it protects the containers against small movements of rock layer and keeps it in place. The buffer has two additional functions. Bentonite absorbs water and increases its volume, which practically excludes penetration of ground water through the clay layer to the container. At the same time, bentonite acts as a filter. Radionuclides adhere to the surface of clay particles. In a very improbable case of damaging the container, huge majority of radionuclides will remain in the container. Most of those leaking out will be captured in bentonite. Thus, we delay transport of radionuclides to the surface, which ensures further natural radioactive decay and reduction of activity.

A rock, where a repository is located plays an important role in delaying radionuclide transport. Its main task is to protect the container and buffer against mechanical damage and to provide stable chemical medium. It is important that underground water does not contain dissolved oxygen, which could corrode the container. Moreover, low rate of water flow in the rock is an advantage in terms of maintaining barrier integrity. The following countries have developed fuel storage containers and repository designs: Switzerland, Finland (Fig. 4.3.24), Sweden, USA and France. Tests of underground rocks were performed successfully in those countries. It appeared that technical problems had already been solved and that the selected locations offered good conditions for waste isolation for thousands of years.

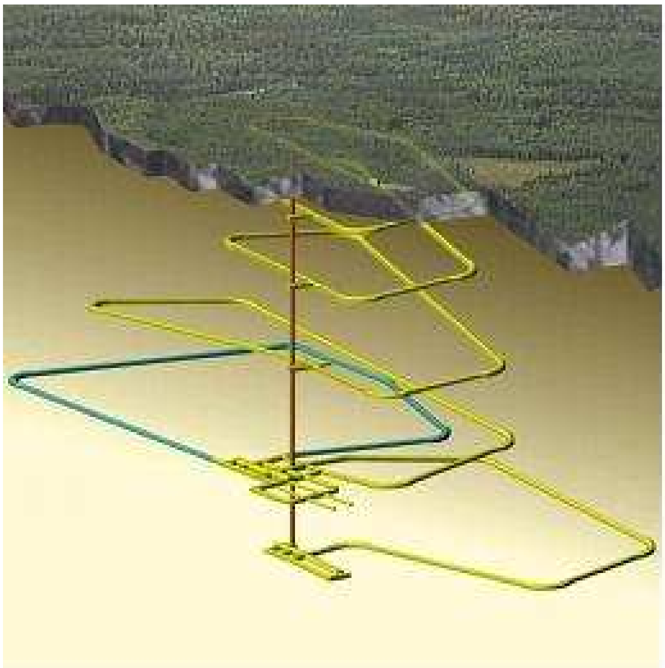


Fig. 4.3.24 Diagram of the deep radioactive waste storage in Onkalo, Finland[190]

Geologists concur that the waste washout processes are very slow and even if the waste was not in containers and was not vitrified, it would not penetrate to the surface from the depth of 500 m earlier than in 20-100 thousand years.

In Finland, construction of a deep repository in Onkalo was initiated; it will be put into service in 2020.

Medium and low level waste

Storage of medium and low activity waste is conducted in all countries where radionuclides are used in medicine and industry. Such repositories operate in the entire European Union, also in Poland (in Różan on Narew). Introduction of nuclear power engineering means expanding the scale of activities and not substantial quality changes in commonly applied and very effective waste disposal methods.

Medium and low level radioactive waste is stored in **surface** repositories(low level and short-lived) or **underground medium-deep** repositories (medium level) - in stable geological formations: salt domes, argillaceous rocks or igneous rocks.

Especially salt deposits are useful for repositories, because salt is characterised with very high tightness and thus it well prevents penetration of radioactive substances to the environment, and especially to ground water.

Before being transported to the storage, waste must be properly processed and conditioned in order to meet specific conditions of radiological safety in transport and storage. The conditions - compliant to IAEA requirements - are specified in relevant Polish regulations.[191]

Radioactive waste processing methods depend on its physical form and chemical composition. In particular, the following methods are applied (Fig. 4.3.25) [Włodarski]:

Liquid waste:

- treatment with application of non-organic sorbents,
- concentration on evaporator,
- membranes
- ion exchange filters,
- solidification (cement, asphalt, plastics),
- vitrification

Solid waste:

- fragmentation,
- compaction,
- fixing (cement, plastics).

Biological waste:

- setting in urea-formaldehyde resins.

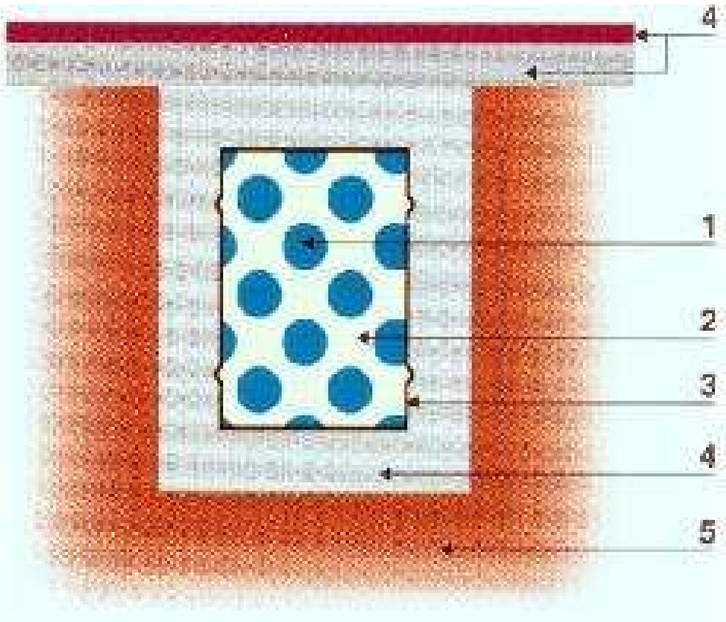


Fig. 4.3.25 Protective barriers in radioactive waste storage (ZUOP Świerk)

1- chemical, 2-physical, 3- I engineering, 4- II engineering, 5- natural

In Poland, the problem of radioactive waste disposal occurred in 1958, upon commissioning of the first research nuclear reactor EWA in Świerk and commencement of production of artificial radioactive isotopes for science, medicine and industry. In 1961, after proper engineering and technical preparations, radioactive waste repository in Różan on Narew was put into service. It still operates successfully.

This storage was located in the former military fort from 1905-1908, with thick (1,2 - 1,5 m) concrete walls and ceilings, which provide full biological protection to the waste located within (Fig. 4.3.26).

Ground water is found under the layer of clay with very low permeability and a layer of soil with sorptive properties at the depth of several meters below the storage. Soil composition effectively prevents waste migration which could penetrate the soil due to unfortunate events.

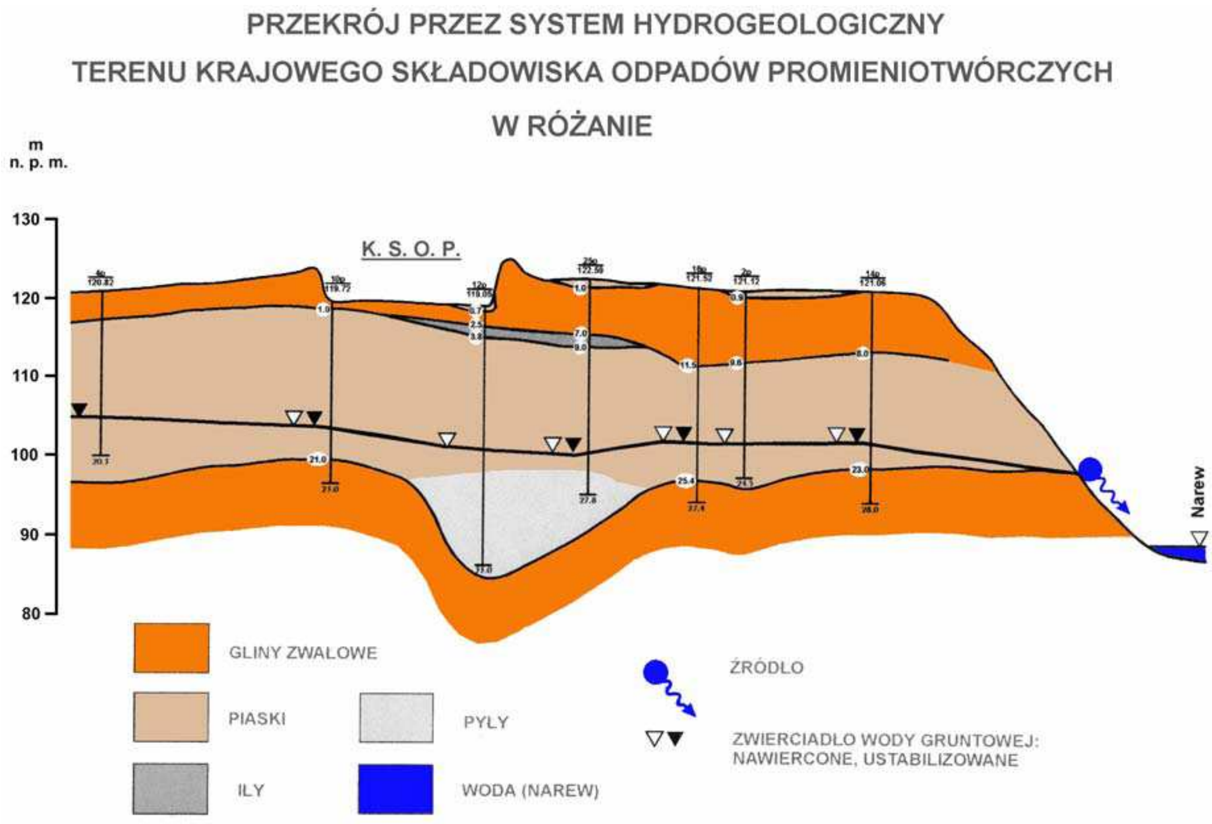


Fig. 4.3.26 Cross-section of hydro-geological system of National Waste Storage in Różan

[PRZEKRÓJ PRZEZ SYSTEM HYDROGEOLOGICZNY TERENU KRAJOWEGO SKŁADOWISKA ODPADÓW PROMIENIOTWÓRCZYCH W RÓŻANIE – CROSS-SECTION OF HYDROGEOLOGICAL SYSTEM OF NATIONAL RADIOACTIVE WASTE REPOSITORY IN RÓŻAN
M n.p.m. – Meters above sea level
Gliny zwałowe – Boulder clay
Piaski – Sands
Iły – Silts
Pyły – Dust
Woda (Narew) – Water (the river Narew)
Źródło – Source
Zwierciadło wody gruntowej: nawiercone, ustabilizowane – Groundwater surface: drilled, stabilised]

Although radioactive waste has been stored in Różan for half a century, adverse health effects were not stated among the local community. On the contrary, mortality due to neoplastic diseases in Różan commune is among the lowest in Poland. This indicates lack of adverse effect of the repository on the environment and residents.

Fig. 4.3.27 Low level radioactive waste prepared for transport to the storage [ZUOP Świerk].

4.3.1.8 Assessment of environmental effects of storage and production of radioactive waste

Selection of fuel cycle type and the best (in Polish conditions) radioactive waste storage method will be discussed and developed in terms of **National Plan of Handling Radioactive Waste and Spent Nuclear Fuel [Krajowy Plan Postępowania z Odpadami Promieniotwórczymi i Wypalonym Paliwem Jądrowym]** (**KPPzOPiWPJ**). It will be one of the main challenges facing the Government Representative for Polish Nuclear Industry. KPPzOPiWPJ should include all actions related to processing, relocation, storage and deposition of radioactive waste, including removal of radioactive waste and decommissioning of a nuclear facility.

This study attempts not to avoid the issue of generation, transport and storage of radioactive waste. However, it should be emphasised that this part of fuel cycle is not included in the discussed scope of environmental impact forecast of Polish Nuclear Programme.

KPPzOPiWPJ like the Polish Nuclear Energy Program will be subject to strategic environmental assessment, which will assess the environmental effects of its introduction, and thus the environmental effects of transport, storage and disposal of radioactive waste, including removal of radioactive contamination and nuclear decommissioning.

This approach also arises from Article 5.2 of SEA Directive:

„Report[…], made according to excerpt 1, contains information which may be rationally required, including […] content and level of specification of a plan or programme, its stage in decision-making process and scope in which certain issues may be more appropriately evaluated at various process stages, <u>In order to avoid multiplication of assessment</u>."Impact related to operation of cooling systems

4.3.2 Impact of cooling systems

4.3.2.1 Applied cooling system installations

Below, two basic types of cooling systems for turbine condensers and auxiliary devices are presented: open (flow) system - without cooling tower[192], and closed (circulation) system with cooling tower (wet with natural draft or hybrid).

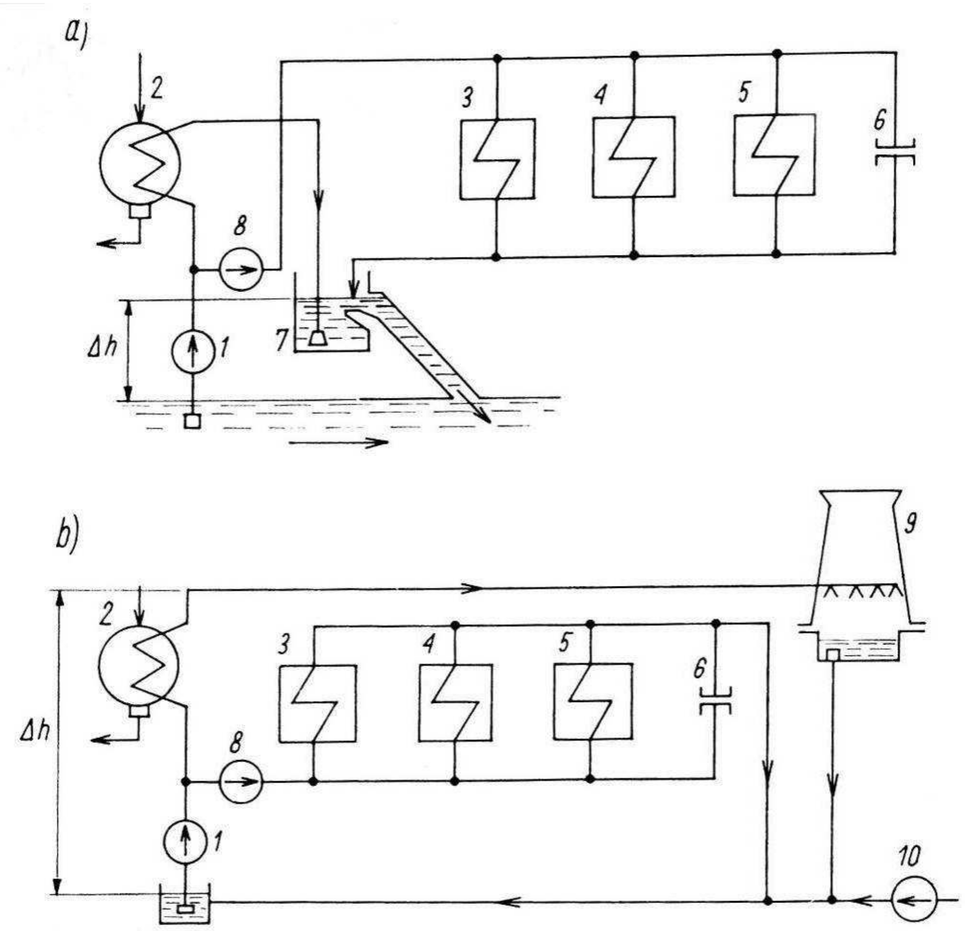


Fig. 4.3.28. Basic types of cooling systems for turbine condensers and auxiliary devices [193].

a) open system - flow cooling, b) closed system with cooling tower - circulation cooling:

1 – cooling water pump, 2 – condenser, 3 – coolers for hydrogen, air and cooling water for generator stator, 4 – oil coolers, 6 – bearings of auxiliary devices, 7 – siphon well, 8 – service water pump, 9 – cooling tower, 10 – make-up water pump.

The type of cooling system has significant effect on efficiency of electricity generation and consumption for internal load. Increase of final cooling water temperature by 1°C will cause decrease in efficiency by ca. 0.4% (temperature in closed cycles is typically higher by 5°C as compared to closed cycles, which may result in decrease in deficiency by 2%).

On the other hand, typical electricity consumption by a cooling water system [BAT[194]] is ca.:

- kWe/MW$_t$ for an open system (intake by cooling water pumps),
- 15 kWe/MW$_t$ for a closed system with a natural-draught wet cooling tower (increased consumption by cooling water pumps),
- 23 kWe/MW$_t$ for a closed system with a hybrid cooling tower (increased consumption by cooling water pumps + intake by cooling tower fans).

At this stage, **designs of cooling systems** for nuclear power plants in Poland have not been developed yet. They will be developed for specific locations selected by the investor.

Upon commission of PGE Energia Jądrowa S.A., BSiPE „Energoprojekt Warszawa" S.A. conducted in 2010 a more specific study of the following 6 locations (from 28 proposed)[195]: Żarnowiec, Lubatowo-Kopalino, Choczewo, Kopań, Warta-Klempicz and Nowe Miasto. Based on this study, the Investor has selected 3 locations for preliminary closer assessment: Żarnowiec (closed cycle) and Lubatowo-Kopalino and Kopań (open cycle - cooling with sea water). According to Polish Nuclear Programme[196], the final selection of location for the first nuclear power plant will be made by the end of 2013. One of the selection criteria will be information in this forecast.

4.3.2.1.1 Open (flow) cooling systems without cooling tower

This cooling system in a nuclear power plant may be used in locations with an access to large reservoirs of cooling water, without hydrothermal limitations.

In practice, this option is possible only for the following locations: coastal, on the river - in lower course of big rivers, and situated at the estuaries of big rivers (including bays).

For a nuclear power unit with net capacity of **1000 MW_e** expenditure of cooling water, with 10 K heating, is ca. **50.2 m^3/s** (with 12 K: ca. 41.8 m^3/s).

Option of sea water cooling is attractive due to lower temperature, which allows for deeper vacuum in turbine condensers and obtaining higher energy generation efficiency) and practically no limits in terms of resources and hydrothermal limitations.

However in technical terms, sea water intake and discharge presents technical problems due to:

- low depth in coastal zone and sandy bed;
- dynamic effect of sea water in coastal zone (variable sea currents, waves);
- intense rubble movement along the coast;
- tendencies for changing coastal line and embacles.
- Basic parameters of Baltic Sea:
- area: 415,266 km^2;
- capacity: 21,721 km^3;
- temperature of surface water in coastal zone: from -0.5°C (in winter) to +18÷20°C (in summer).

Cooling water intakes are planned at the depth of 10 m, in the following distance from the coast: 400-500 m (Kopań), 500-800 m (Lubatowo-Kopalino)[197]. Discharge of cooling water should be in the distance of ca. 1-2 km from the intake in the direction of dominating sea currents - in order to avoid re-suction of heated water.

Fig. 4.3.29 presents a model design solution of sea water intake and discharge executed in South Korea for Shin-Kori 2 & 4 APR-1400 reactor (thermal power: 3983 MW_t, gross capacity: 1455 MW_e, net capacity: 1350-1400 MW_e). Water intake is at the depth of 20 m, and water is fed and discharged via drain adits (6.3 m in diameter).

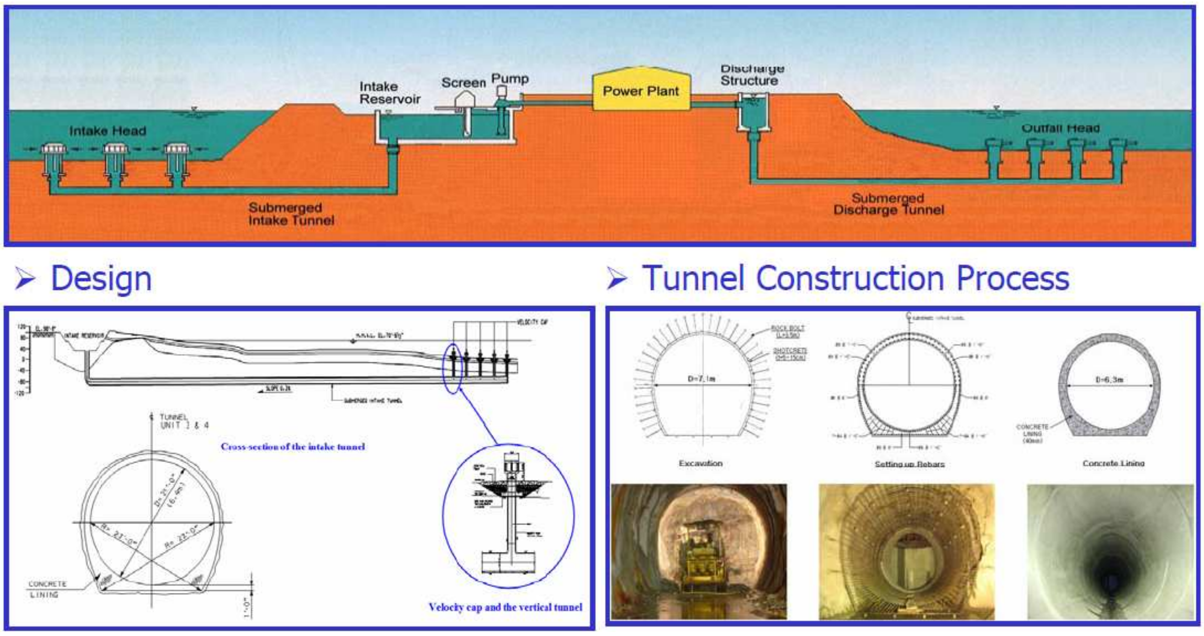


Fig. 4.3.29 A model concept of sea water intake and discharge at Shin-Kori 3 & 4 (South Korea)[198]

When taking advantage of rivers for cooling power plants in open cycle, one must take into account hydrological and hydrothermal constraints. Flow rate in rivers and water temperature change during a year; the fluctuations are smaller in lowland rivers. The highest intake of cooling water cannot exceed 1/3 ÷ 1/2 of mean minimum flow (SNQ), and water temperature after mixing cannot exceed 26°C.

Irrecoverable losses of cooling water due to additional evaporation depend on temperature and air humidity, wind velocity, cooling zone (cooling water heating scale), and season and fluctuate between **0.4% and 0.6%** of cooling water flow rate [Andrzejewski][199]. Irrecoverable losses practically are not an issue in big rivers, however a significant constraint can be caused by hydrothermal conditions - especially in upper and mid-course of the rivers, including Wisła. Still, irrecoverable losses are always very significant for lake water balance.

Hydrotechnical devices for cooling water intake and discharge (from/to river or bay) for nuclear power plant will be substantially similar to the technical solutions currently applied in large thermal power plants, namely river water is fed through the bank pumping station channel - with grates, screens and intake, from where it is pumped to the power plant via reinforced concrete or steel pipes. Water discharge takes place through steel pipes to siphon wells and then via an open channel to the river.

4.3.2.1.2 Closed-cycle cooling systems with cooling tower

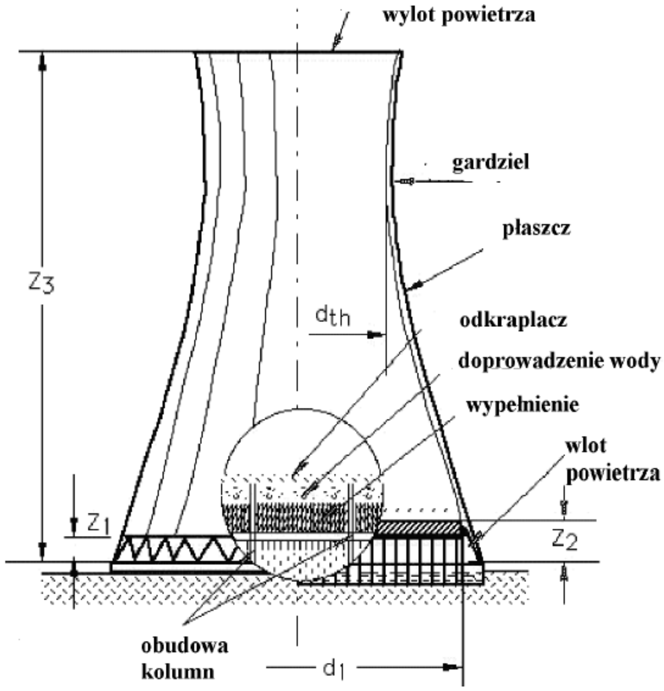


Fig. 4.3.30 Wet natural-draught cooling tower [BAT]

[Wylot powietrza – Air outlet
Gardziel – Throat
Płaszcz – Jacket
Odkraplacz – Condenser
Doprowadzenie wody – Water supply
Wypełnienie – Fill
Wlot powietrza – Air inlet
Obudowa kolumn – Column casing]

For cooling large power units - including nuclear units localised in places where water resources are not sufficient for open-cycle cooling, closed-cycle cooling systems are applied with the following cooling towers:
1) **natural draught wet cooling towers**

2) **hybrid cooling towers** with fan-forced draught.

So far, in Poland only **natural draught wet cooling towers** have been used. The largest operated cooling towers are located in:

- Bełchatów power plant - one per 2 units 370 MW_e: height 132 m, diameter at the base 105.5 m, outlet diameter 57.9 m; hydraulic load 80 000 m^3/h = 22.2 m^3/s, thermal load 3500 GJ/h = 972 MW_t;

- Łagisza power plant – new unit 460 MW_e: height 133.2 m, diameter at the base 98.8 m, outlet diameter 55.08 m.

However, the largest cooling tower will be the one designed for the new unit of Ostrołęka power plant (Ostrołęka C), with capacity of 1000 MW_e: height 185.0 m, diameter at the base 145.0m;

hydraulic load 95 500 m^3/h = 26,5 m^3/s, thermal load 950 MW_t, cooling zone 9K), total water intake estimated at ca. 0.57 m^3/s).[200].

The biggest cooling towers in the world were applied in **nuclear power plants**. In particular wet natural draught cooling towers:

- in Germany, nuclear power plant with Konvoi reactor – Isar II (3950 MW_t, 1475 MW_e gross, 1400 MW_e net): height 165 m, diameter at the base 153 m, outlet diameter 86 m, hydraulic load 216 000 m3/h = 60 m3/s; and Elmstad (3950 MW_t, 1400 MW_e gross, 1329 MW_e net): height 152 m;
- in France in nuclear power plant with N4 reactors (4250 MW_t, 1560 MW_e gross, 1500 MW_e net) – Civaux (2 units) and Chooz B (2 units): height 180 m, diameter at the base 153 m, outlet diameter 85 m.

Fig. 4.3.31 Nuclear power plant Isar II (Germany) with wet natural draught cooling tower.

Fig. 4.3.32 Nuclear power plant Civaux 1&2 (France) with wet natural draught cooling tower.

The highest wet cooling tower in the world was built in Germany, in Niederaussem thermal power station. Brown-coal fuelled K Unit with supercritical parameters (1012 MW_e gross, 965 MW_e net): height: 200 m, diameter at the base: 152.54 m, outlet diameter: 88.41 m; hydraulic load: 91 000 m^3/h = 25.3 m^3/s.

Fig. 4.3.33 Niederaussem power plant (Germany) with the tallest wet natural draught cooling tower in the world (200 m)

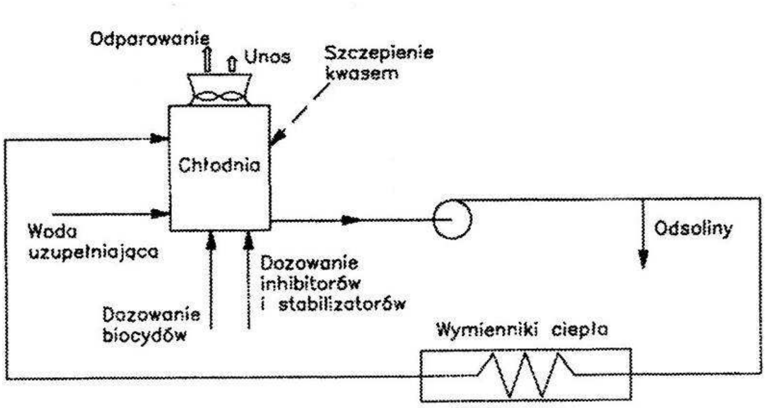


Fig. 4.3.34 Diagram of closed-cycle cooling system with cooling tower[201]

[Odparowanie – Evaporation
Unos – Windage
Szczepienie kwasem – Acid grafting
Chłodnia – Cooling tower
Woda uzupełniająca – Makeup water
Dozowanie biocydów – Biocide dosing
Dozowanie inhibitorów i stabilizatorów – Dosing inhibitors and stabilisers
Wymienniki ciepła – Heat exchangers
Odsoliny – Blowdown]

During water cooling with air stream in a cooling tower, partial water evaporation takes place (evaporation loss), as well as water drops capture by air stream (windage loss) - this water is irreversibly lost (evaporation and windage loss together constitute irreversible losses). Furthermore, in order to prevent salt content thickening in the cycle due to water evaporation, some water is discharged as blowdowns (blowdown discharge). Water deficits in the cycle are made up with water from the cooling basin. In order to prevent creation of carbonate deposits (calcium and magnesium carbonates), the make-up water is treated. Treatment includes decarbonisation (with lime) and grafting (with hydrochloric or sulphuric acid). It also allows to significantly decrease water loss on blowdown. (see diagram: Fig. 8.3.34).[201]
Hybrid cooling towers, with fan-assisted draught were introduced in the 1980s. A hybrid cooling tower has a special structure enabling decrease in cooling water consumption and vapour generation. It is a combination of a wet and dry cooling tower. Depending on external air temperature, a hybrid cooling tower may be operated exclusively as a wet tower or as a combined wet and dry tower.

Heated cooling water passes through the first dry section of the tower, where hot part is discharged by air stream, partially sucked by a fan. After passing through the dry section, water is cooled down in wet section, similarly to a wet natural draught cooling tower. In the upper tower section, heated air from the dry section is mixed with wet section vapours, thus decreasing its relative humidity before leaving the tower, which (almost) completely reduces vapours over the tower. Optimisation oh a hybrid tower is based on optimisation of amount of heat exchanged in the dry zone in order to meet the requirements concerning reduction of vapours. At the same time, basic cooling takes place in the wet zone.

To ensure effective operation of a hybrid cooling tower, many auxiliary devices are used:

- fans with regulated rotation speed;

- devices closing air inlets (such as shutters or flaps);
- water flow valves in dry and wet tower zones;
- shunt systems;
- auxiliary pumps (in special construction types);
- devices for mixing dry and humid air.

Hybrid cooling towers are characterised by low cooling water consumption - even ca. 4 times lower than wet natural draught cooling towers (assuming 75% operation in dry mode) [BAT, Table 3.3][202] i [203] and they are at least 3 times lower, with similar diameter. It has significance not only due to much lower water consumption and hence lower environmental impact, but also due to the fact that such a cooling tower disturbs landscape to a much lesser extent - is less visible and vapours above it are almost imperceptible (which may be very important, particularly for local community). Technical parameters of hybrid cooling towers are similar as with wet cooling towers. Their disadvantage is additional power consumption (apart from consumption by cooling water pumps, ca. 15 kWe/MWt, which is at the same level as for a wet cooling tower) for fan drive – 8 kW_e/MW_t. [BAT]

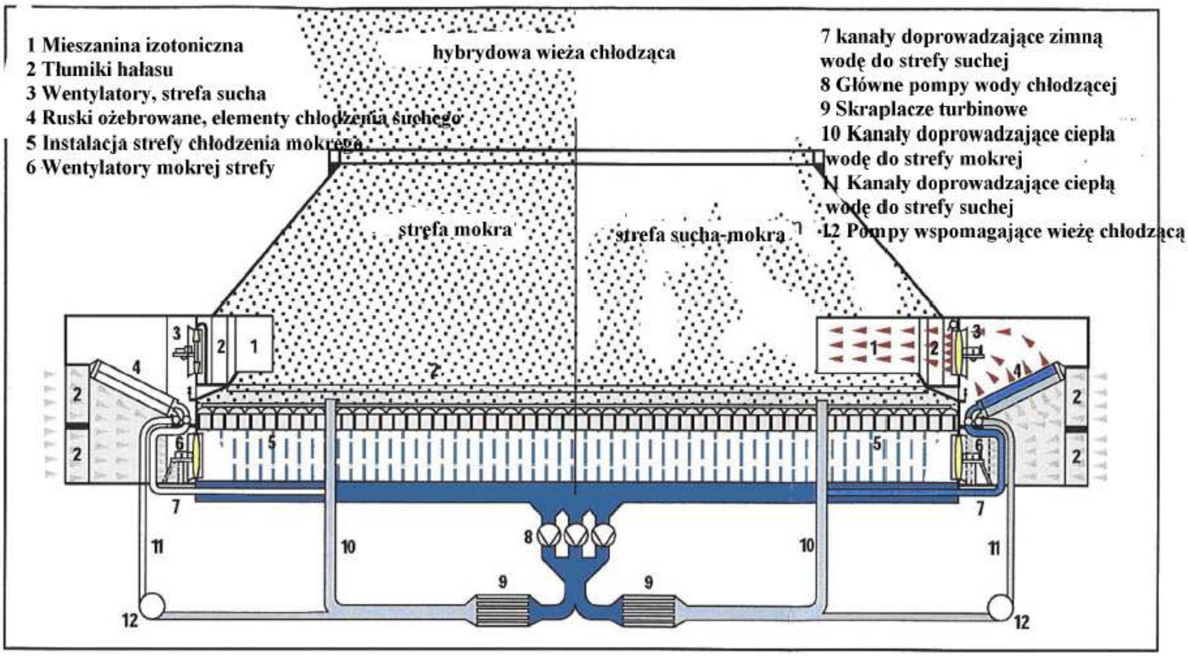


Fig. 4.3.35 Hybrid cooling tower [BAT]

[1 Isotonic mixture
2 Noise attenuators
3 Fans, dry zone
4 Ribbed pipes, dry cooling elements
5 Wet cooling zone installation
6 Wet zone fans
7 Channels feeding cool water to dry zone
8 Main cooling water pumps
9 Turbine condensers
10 Channels feeding warm water to wet zone
11 Channels feeding warm water to dry zone
12 Cooling tower support pumps
Hybrid cooling tower

Wet zone
Dry-wet zone]

The largest hybrid cooling tower was constructed in Neckarwestheim-2 power plant (with Konvoi reactor: 3850 MW_t, 1395 MW_e gross, 1310 MW_e net) in Germany: height 51.22 m, diameter at the base 160.0 m, outlet diameter 73.6 m, thermal load 2500 MW_t, 64 fans.
As we can see, currently cooling water systems are operated with single cooling towers in nuclear power units with capacity similar to capacity of an EPR reactor unit.

Fig. 4.3.36 View of Neckarwesheim power plant (Germany) with a hybrid cooling tower in unit II (unit I is cooled in open cycle from the river Neckar with auxiliary fan cooling towers)

Fig. 4.3.37 Close-up view of hybrid cooling tower in Neckarwestheim-2 power plant

Currently,[204] using hybrid cooling towers is planned in particular in Calvert Cliffs power plant 3 & 4 in the USA – Maryland[205] (unit U.S. EPR: 4590 MW_t, 1710 MW_e gross, 1600 MW_e net), North Anna nuclear power plant 3 (APWR 1700 MW_e, MHI) in the USA – Virginia, and for cooling a new unit in Swiss nuclear power plant Beznau.

Calvert Cliffs cooling towers will have the following parameters: height 54.0 m; diameter 166.4 m; hydraulic load 187 390 m^3/h = 52 m^3/s; power consumption by fans ca. 20 MW_e[206].

Fig. 4.3.38 View of hybrid cooling tower in new nuclear power plant Bezanu (Switzerland) – visualisation.

4.3.2.2 Cooling water demand

$Q_W = \dfrac{P_{tw}}{C_W \cdot \rho \cdot \Delta t} \cdot 10^3$ - cooling tower hydraulic load [m^3/s],

$P_{t,w}$ – thermal power discharged in cooling water [MW_t],

c_w = 4.19 kJ/kg·deg – specific heat of water,

ρ = 998.2 kg/m^3 – water density at 20°C,

Δt = 10 K – cooling zone (typical value).

Below, calculations were performed **for wet natural draught cooling towers** [Andrzejewski] [Kozioł, Stechman].[207]

$p = p_1 + p_2' + p_2''$ - total water consumption (% Q_w),

$p_1 = \alpha \cdot \Delta t$ - evaporation loss (% Q_w),

Table 4.3.3 Values of α coefficient [Andrzejewski]

SEASON OF THE YEAR	COEFFICIENT α
Summer	0,15 ÷ 0,16
Spring and autumn	0,10 ÷ 0,12
Winter	0,06 ÷ 0,08

p'_2 =≤ 0.01 - windage loss (% Q_w) – in state-of-the-art cooling towers with windage eliminators [BAT],

p''_2 - blowdown loss (% Q_w),

Due to evaporation, water thickening in the cooling cycle occurs. In order to maintain constant salt concentration in cooling water, amount of salt discharged with windage and blowdown must equal amount of water fed with makeup water, that is:

$$s \cdot p = K \cdot s \cdot p_2,$$

where:

s – salt content in makeup water [mg/l],

K = s_o/s – acceptable water thickening in the cooling cycle (s_o – acceptable salt content in the cooling cycle, mg/l),

$$p_2 = p'_2 + p''_2;$$

which gives the following dependence:

$$p = \frac{K}{K-1} \cdot \alpha \cdot \Delta t.$$

In practice, values K = 3 ÷ 6 are assumed, then amount of blowdown sewage is 20 ÷ 50% of irreversible loss[208].

According to [BAT, Table 3.3] average water consumption is, for:

open cycle wet cooling towers: 2 $m^3/h/MW_t$ = 0.55 $m^3/s/1000\ MW_t$ (2% Q_w);

open cycle wet-dry (hybrid) cooling towers: 0.5 $m^3/h/MW_t$ = 0.14 $m^3/s/1000\ MW_t$ (0.6% Q_w) - assuming 75% operation time in dry regime.

Assuming (conservatively): upper values of α and K = 3, from the above relations we can calculate individual components of water consumption by wet cooling towers.

Table 4.3.4 Characteristics of wet natural-draught cooling tower

	Summer	Spring and autumn	Winter	Year
α coefficient	0,16	0,12	0,08	0,12
Evaporation loss p_1 (%Q_w)	1,60	1,20	0,80	1,20
Windage loss p'_2 (%Q_w)	0,01	0,01	0,01	0,01
Irreversible loss $p_1 + p'_2$ (%Q_w)	1,61	1,21	0,81	1,21
Water demand p (%Q_w)	2,40	1,80	1,20	1,80

Blowdown discharge p'_2 (%Q_w)	0,79	0,59	0,39	0,59

It results from Table 4.3.4 that mean yearly water consumption indicator by wet natural draught cooling tower is at the level of 1.80% of cooling water expenditure, of which 1.21% is irreversible loss, and 0.59% is blowdown discharge. Maximum values (in summer) are, respectively: 2.40%; 1.61% and 0.79%.

The tables below present selected basic parameters of various types of nuclear power units offered in Poland (Table 4.3.5) and cooling water consumption by those units with cycle cooling with wet natural draught cooling tower or dry-wet hybrid cooling tower (Table 4.3.6)

Table 4.3.5 Basic parameters of nuclear power units

Unit type	Thermal power [MW_T]	Gross electrical capacity [MW_E]	Net electrical capacity [MW_E]	Thermal power discharged in cooling water [MW_T]	Water expenditure in cooling system [m^3/s]
EPR	4590	1710	1600	2880	68,9
AP 1000	3400	1200	1117	2311[209]	55,3
ABWR	3926	1371	1350	2555	61,1
ESBWR	4500	1600	1550	2900	69,3

Table 4.3.6 Cooling water consumption by nuclear power units of various types with cycle cooling with cooling towers: wet natural draught and wet-dry hybrid at K=3

Unit type	Cooling tower hydraulic load [m^3/s],	Cooling tower type	Water demand [m^3/s]		Irreversible loss [m^3/s]		Blowdown discharge [m^3/s]		Irreversible loss per net electrical capacity indicator [$m^3/s/1000\ mw_e$]		Water consumption per discharged thermal power indicator [$m^3/s/1000\ mw_t$]	
			summer	year	summer	year	summer	year	summer	year	summer	year
EPR	68,9	wet	1,65	1,24	1,11	0,83	0,54	0,41	0,70	0,53	0,57	0,43
		hybrid	0,58	0,43	0,39	0,29	0,19	0,14	0,24	0,18	0,20	0,15
AP 1000	55,3	wet	1,33	0,99	0,89	0,67	0,44	0,33	0,80	0,60	0,57	0,43
		hybrid	0,46	0,35	0,31	0,23	0,15	0,11	0,28	0,21	0,20	0,15
ABWR	61,1	wet	1,47	1,10	0,98	0,74	0,48	0,36	0,73	0,55	0,57	0,43
		hybrid	0,51	0,38	0,34	0,26	0,17	0,13	0,25	0,19	0,20	0,15
ESBWR	69,3	wet	1,66	1,25	1,12	0,84	0,55	0,41	0,72	0,54	0,57	0,43
		hybrid	0,58	0,44	0,39	0,29	0,19	0,14	0,25	0,19	0,20	0,15

<u>For comparison purposes</u>: The planned average yearly water consumption for **„Warta" nuclear power plant in Klempicz** (4 x WWER-1000/W-320, $P_{e,net}$ = 4x963[210] = 3852 MW_e, $P_{t,w}$ = 7828 MW_t, Q_w = 187 m^3/s, 8 cooling towers) [Widmoski [211]]:

- raw water demand (p): 4.0 m^3/s (2.14% Q_w),
- irreversible water loss ($p_1 + p'_2$): 2.7 m^3/s (1.44% Q_w),

- blowdown discharge (p''_2): 1.3 m^3/s (0.70% Q_w) – which constitutes 48.3% of irreversible loss $p_1 + p'_2$.

Value K may be calculated based on the following relation: $K = \frac{p}{p - p_1}$; assuming windage loss p'_2 = 0.2% Q_w (for older cooling towers), we obtain for „Warta" power plant: K ≅ 2.4 – these are very low water thickening values (with windage 0.01% Q_w K ≅ 3,0). Mean yearly irreversible loss per net electrical capacity estimated for „Warta" power plant: **0.70** $m^3/s/1000\ MW_e$ – this is a value similar to those obtained from the above calculations (0.53 – 0.60 $m^3/s/1000\ MW_e$), slightly higher probably due to higher windage loss in older cooling towers.

The environmental impact study for **Visaginas nuclear power plant** (new Ignalina power plant) presents the value of irreversible loss **0.45** $m^3/s/1000\ MW_e$ – this value however seems underrated (with reference to cycle cooling losses - as the same value was assumed as with open-cycle cooling).

The concept of water supply for „Warta" power plant[211] assumes that irreversible loss will be covered from current flow of the river Warta exceeding invariant flow (for hydrobiological reasons). Invariant flow in water intake cross-section is 20.7 m^3/s. Statistical hydrological data on the river Warta in 1951-85 show that minimal flow of the river Warta may approach the invariant flow only during several days in a dry year, with mean recurrence period once per 20 years. In order to maintain the invariant flow and full power plant capacity also in this period, water retention was assumed with capacity of ca. 5 million m^3. Such retention would allow covering irreversible water loss on mean yearly level (2.7 m^3/s) for ca. 20 days. Percentage values of decrease of characteristic flows in the river Warta in water intake cross-section due to irreversible water loss were estimated as follows:

- mean low flow SNQ = 45.7 m^3/s, decrease by 5.9%;
- medium flow SNQ = 122.0 m^3/s, decrease by 2.2%;
- mean high flow SNQ = 368.0 m^3/s, decrease by 0.7%;

In **Bełchatów power plant** the cooling water system (of currently operated 12 thermal units with total installed power 4 440 MW_e) consists of 6 wet natural draught cooling towers (one per 2 units), each with hydraulic load 80 000 m^3/h (22.2 m^3/s) and thermal load 3500 GJ/h (972 MWt). Irreversible water losses in Bełchatów power plant amount to 2.08 m^3/s[212] -which is **1.56%** Q_w, and water intake 2.30 m^3/s. Water consumption per discharged thermal power index is **0.39** $m^3/s/1000\ MW_t$[213] – this is the value approaching the value obtained from the above calculations **0.43** $m^3/s/1000\ MW_t$ (Table 10.3.4).

<u>**Assumption**</u>: nuclear power plant in each site should have net electrical capacity ca. 3000 MW_e, therefore it should consist of **2 EPR units** (3200 MW_e), or **ABWR units** (2700 MW_e) or **ESBWR units** (3100 MW_e), or of **3 AP 1000 units** (3350 MW_e).

With the above assumption, cooling water consumption by a single nuclear power plant was calculated (2- or 3-unit, respectively), with cycle cooling – Table 4.3.7

Table 4.3.7 Cooling water consumption by nuclear power plant with cycle cooling with wet or hybrid cooling tower.

Power plant configuration	Cooling tower type	Water demand [m^3/s]		Irreversible loss [m^3/s]		Blowdown discharge [m^3/s]	
		summer	year	summer	year	summer	year

Power plant configuration	Cooling tower type	Water demand [m³/s]		Irreversible loss [m³/s]		Blowdown discharge [m³/s]	
2 x EPR	wet	3,31	2,48	2,22	1,67	1,09	0,81
	hybrid	1,15	0,86	0,77	0,58	0,38	0,28
3 x AP 1000	wet	3,98	2,98	***2,67***	2,01	1,31	0,98
	hybrid	1,39	1,04	***0,93***	0,70	0,46	0,34
2 x ABWR	wet	2,93	2,20	1,97	1,48	0,97	0,72
	hybrid	1,02	0,77	0,69	0,52	0,34	0,25
2 x ESBWR	wet	3,33	2,50	***2,23***	1,68	1,10	0,82
	hybrid	1,16	0,87	***0,78***	0,58	0,38	0,29

On the basis of calculation data presented above, it may be estimated that for river sites, minimum water resources in summer should be sufficient to consume (irreversible losses with 100% margin):

- for nuclear power plant with 3 AP 1000 units: **2.9 m³/s** (wet cooling towers) or **1.0 m³/s** (hybrid cooling towers – minimum);
- for nuclear power plant with 2 units of any type: **2.5 m³/s** (wet cooling towers) or **0.9 m³/s** (hybrid cooling towers – minimum);

In case of big rivers (Wisła, Odra, Warta, Bug), especially in their mid and upper course, uptake of such amounts of water to makeup cooling cycle is not a problem.

Then, assuming time of application of installed power 8000 h/a (which corresponds to installed power use index 91.3%), yearly water consumption by a nuclear power plant in the above configuration was calculated, with cycle cooling and wet natural draught cooling tower or hybrid cooling tower.

The value is particularly significant for assessment of sufficiency of cooling water resources in lake sites and for specification of discharged salt load (Table 4.3.8).

Table 4.3.8 Yearly cooling water consumption by nuclear power plant with cycle cooling with wet or hybrid cooling tower.

Power plant configuration	Cooling tower type	Annual water demand [million m³/a]	Annual irreversible loss [million m³/a]	Annual blowdown discharge [million m³/a]
2 x EPR	wet	71,4	48,0	23,4
	hybrid	24,9	16,7	8,2
3 x AP 1000	wet	85,9	57,8	28,2
	hybrid	30,0	20,1	9,8
2 x ABWR	wet	63,3	42,6	20,8
	hybrid	22,1	14,8	7,2
2 x ESBWR	wet	71,9	48,3	23,6
	hybrid	25,1	16,8	8,2

Nuclear power plant site should have water resources covering annual water demand of a closed cooling water cycle for 3 AP 1000 units or at least 2 units of other type. It results from calculation data presented above that those minimum required water resources (only for covering irreversible losses, assuming that blowdown may be discharged to the same reservoir) with 10% margin are:

- for nuclear power plant with 3 AP 1000 units: **64 million m³/a** (wet cooling towers) or **22 million m³/a** (hybrid cooling towers);

- for nuclear power plant with 2 units of any type: **53 million m³/a** (wet cooling towers) or **18 million m³/a** (hybrid cooling towers);

4.3.2.3 Preliminary assessment of sufficiency of cooling water resources

So far **detailed site analyses have not been performed** for any potential nuclear power plant site in Poland (even for 3 sites initially selected by the investor, PGE S.A., i.e.: Żarnowiec, Lubiatowo-Kopalino and Kopań), **including** in particular **optimisation technical and economic analysis of cooling system variants**, applicable in individual locations.

With regard to the above and due to deficiencies in hydrological data for some sites, a fully credible assessment of sufficiency of water resources for all locations - at the current stage and within a month - is practically unfeasible. Thus, the assessments below must be treated as **very preliminary**, based on incomplete hydrological data and expert knowledge.

The problem of insufficiency of cooling water resources does not apply to **coastal** locations where seawater will be used for cooling.

In case of **river** sites, located **on lower Wisła and Odra** (including Zalew Szczeciński) open-cycle cooling systems are planned, however such an option is not determined: as long as detailed hydrological and hydrothermal analyses are not conducted[214] and water-legal permit is not obtained (in terms of an integrated permit).

With **lake** sites – with existing hydrological and water legal constraints - open-cycle cooling systems seem unfeasible (especially if a nuclear power plant were to have more than 1 unit - which is proposed). Therefore, a closed-cycle system (rather with hybrid cooling towers) should be planned.

For **other river** and **inland** sites, closed-cycle cooling systems are planned - principally with wet natural draught cooling towers, optionally with hybrid towers. There are not any hydrothermal constraints, however in some cases available (in a reasonable distance of ca. 35 km) cooling water resources to make up irreversible losses may be insufficient - however, without relevant hydrological data it cannot be ascertained with certainty and authority.

The preliminary assessment of cooling water sufficiency was made with an assumption that the resources should suffice for max 3 AP 1000 units (with net capacity of ca. 3350 MW_e)[215], according to data specified in points **4.3.2.1.1** and **4.3.2.2**, i.e.:

- In open cooling cycle: ca. **168 m³/s**;
- In closed cooling cycle (makeup of irreversible losses):
- with wet natural draught cooling tower: max (in summer) - **2.9 m³/s**; annual irreversible losses:
  ca. **64 million m³**;
- with hybrid cooling tower (minimum consumption – at 75% operation in dry regime): max (in summer) - 1,0 m³/s; annual irreversible losses: ca. 22 million.

Table 4.3.9 Results of cooling water sufficiency assessment for individual potential nuclear power plant sites

No.	Name	Geographical data	Site type	Cooling cycle	Cooling / raw water source	Hydrological data	Sufficiency of cooling water
1	**Chełmno**	Commune Chełmno, District Chełmno, Province Kujawsko-Pomorskie	River - Wisła	Open	River Wisła km 806+800	SSQ = 1,013 m^3/s SNQ = 382 m^3/s	Sufficient
2	**Nieszawa**	Commune Nieszawa, District Aleksandrów Kujawski. Kujawsko-Pomorskie	River - Wisła	Open	River Wisła (after Mień estuary)	SSQ = 929 m^3/s SNQ = 309 m^3/s	Sufficient
3	**Gościeradów**	Commune Gościeradów, District Kraśnik, Province Lubelskie	Inland (5 km from Wisła)	Closed (wet cooling towers)	River Wisła or San (13 km) – better water quality	SSQ = 408 m^3/s (Wisła, Zawichost) SNQ = 258 m^3/s (Wisła, Zawichost) SSQ = 123 m^3/s (San, Radomyśl) SNQ = 81 m^3/s (San, Radomyśl)	Sufficient
4	**Chotcza**	Commune Chotcza, Province Mazowieckie	Inland (5 km from Wisła)	Closed (wet cooling towers)	River Wisła, Iłżanka (add.)	SSQ = 408 m^3/s (Wisła, Zawichost) SNQ = 258 m^3/s (Wisła, Zawichost)	Sufficient
5	**Bełchatów**	Commune Kleszczów, District Bełchatów, Province Łódzkie	Inland	Closed (hybrid towers?)	River Warta (Raduczyce, 36 km), Widawka, Krasówka	No data: currently, closed cooling cycle of Bełchatów power plant is supplied mainly with KWB drainage water (this source will not be available in the future).	? Lack of sufficient hydrological data.[216]
6	**Karolewo**	Commune Nowy Duninów, District Włocławek, Province Kujawsko-Pomorskie	River - Wisła	Open	River Wisła	SWQ = 5020 m^3/s SSQ = 1140 m^3/s SNQ = 352 m^3/s NNQ = 216 m^3/s	Sufficient
7	**Kozienice**	Commune Kozienice, District Kozienice, Mazowieckie	River - Wisła	Closed (wet cooling towers)	River Wisła	SWQ = 2,922 m^3/s SSQ = 502 m^3/s SNQ = 166 m^3/s NNQ = 115 m^3/s	Sufficient
8	**Małkinia**	Commune Zaremby Kościelne, District Ostrów Mazowiecka,	Inland (2 km from Bug)	Closed (wet cooling towers)	River Bug (Dębe dam area)	SSQ = 120 m^3/s (Bug, Frankpol) SNQ = 96 m^3/s (Bug,	Sufficient

No.	Name	Geographical data	Site type	Cooling cycle	Cooling / raw water source	Hydrological data	Sufficiency of cooling water
		Mazowieckie				Frankpol)	
9	**Nowe Miasto**	Commune Nowe Miasto, District Płońsk, Mazowieckie	Inland	Closed (wet cooling towers)	Zalew Zegrzyński (32 km) – basic River Wisła (33 km) – reserve	Zalew Zegrzyński: 30 km^2, 94.3 million m^3, tributary from Bug and Narew >20 m^3/s; River Wisła SWQ = 5020 m^3/s SSQ = 1140 m^3/s SNQ = 352 m^3/s NNQ = 216 m^3/s	Sufficient
10	**Wyszków**	Commune Zabrodzie, District Wyszków, Mazowieckie	Inland	Closed (wet cooling towers)	River Bug (Kamieńczyk region, 10 km)	SSQ = 163 m^3/s (Wyszków) SSQ = 127 m^3/s (Wyszków)	Sufficient
11	(podlaskie)	During assignment					
12	**Choczewo**	Commune Choczewo, District Wejherowo, Pomorskie	Sea	Open	Baltic Sea (8 km) Raw water: basic - Lake Żarnowieckie (10 km), serve - river Łeba (30 km)	Baltic Sea: 414 266 km^2, 21 721 km^3, temp.: -0,5°C (winter) ÷ 18-20°C (summer) River Łeba (above outlet to Lake Łebsko): SWQ = 48.30 m^3/s SSQ = 15.90 m^3/s SNQ = 9.95 m^3/s NNQ = 8.30 m^3/s	Sufficient
13	**Lubatowo-Kopalino**	Commune Choczewo, District Wejherowo, Pomorskie	Sea	Open	Baltic Sea (on the sea) Raw water: basic - Lake Żarnowieckie (10 km), reserve - river Łeba (27 km)	Baltic Sea: as in point 12 River Łeba (above outlet to Lake Łebsko): as in point 12	Sufficient
14	**Tczew**	Commune Tczew, District Tczew, Pomorskie	River - Wisła	Open	River Wisła km 908+600	SSQ = 1,046 m^3/s SNQ = 441 m^3/s	Sufficient

No.	Name	Geographical data	Site type	Cooling cycle	Cooling / raw water source	Hydrological data	Sufficiency of cooling water
15	**Żarnowiec**	Commune Krokowa, District Wejherowo, Pomorskie	Lake - Lake Żarnowieckie	Closed (hybrid towers)	Lake Żarnowieckie, additionally: river Łeba (35 km) Raw water: underground water intake	Lake Żarnowieckie: 14.31 km^2, 114.5 million m^3; depth: average – 8.4 m, max – 16.0 m, retention layer: 29.4 million m^3, River Łeba (Cecenowo): SSQ = 11.0 m^3/s SNQ = 8.95 m^3/s NNQ = 4.46 m^3/s	Sufficient
				Open	Baltic Sea (10 km) Raw water: Lake Żarnowieckie	Baltic Sea: as in point 12	Sufficient
16	**Połaniec**	Commune Połaniec, District Staszów, Świętokrzyskie	River - Wisła	Closed (wet cooling towers)	River Wisła	SSQ = 253 m^3/s (Wyszków) SNQ = 155 m^3/s (Wyszków)	Sufficient
17	**Pątnów**	Commune Konin, District Konin, Wielkopolskie	Lake - Lake Pątnowskie	Closed (wet or hybrid towers?)	5 lakes (total ca. 12 k^2): Gosławskie + Pątnowskie + Licheńskie + Wąsowsko-Mikorzyńskie + Ślesińskie River Warta (7 km)	Lake Gosławskie: 4.54 km^2; depth: average - 3.0 m, max – 5.3 m Lake Pątnowskie: 3.07 km^2; depth: average - 2.6 m, max – 5.4 m Lake Wąsosko-Mikorzyńskie: 2.45 km^2; depth: average - 11.9 m, max – 38.0 m Lake Ślesińskie: 1.48 km^2; depth: average – 7,5, max – 25.7 m	? Lack of sufficient hydrological data. Currently, 5 lakes are used for cooling (in open cycle) of Pątnów and Konin power plants (1448 MW_e)[216].
18	**Warta-Klempicz**	Commune Lubasz, District Piła, Wielkopolskie	Inland	Closed (wet cooling towers)	Warta (7 km) km 178 (4 km below Obrzycko)	SWQ = 368.0 m^3/s SSQ = 118.0 m^3/s SNQ = 53.4 m^3/s NNQ = 39.1 m^3/s	Sufficient
19	**Kopań**	Commune Darłowo, District	Sea	Open	Baltic Sea (3	Wieprza:	Sufficient

No.	Name	Geographical data	Site type	Cooling cycle	Cooling / raw water source	Hydrological data	Sufficiency of cooling water
		Sławno, Zachodniopomorskie			km) Raw water: Wieprza (6 km) – basic, Słupia (25 km) – reserve	SWQ = 60.50 m³/s SSQ = 14.20 m³/s SNQ = 7.68 m³/s NNQ = 5.60 m³/s	
20	**Krzywiec**	Commune Marianowo, District Stargard Szczeciński, Zachodniopomorskie	Inland	Closed (hybrid towers?)	Stawy Dzwonowskie, river Krąpiel, Lake Miedwie (22 km)	Lake Miedwie: 35 km², depth max – 43.8 m Complex of 36 Dzwonowskie Ponds: in total 2.78 km²	? Lack of sufficient hydrological data.[217]
21	**Lisowo**	Commune Marianowo, District Stargard Szczeciński, Zachodniopomorskie	Inland	Closed (hybrid towers?)	Lake Marianowowskie, stawy Lutkowskie, river Krępa, Lake Miedwie (30 km)	Lake Marianowskie: 0.82 km² Stawy Lutkowskie: 0.43 km² Lake Miedwie: as in point 20	? Lack of sufficient hydrological data.
22	**Wiechowo**	Commune Marianowo, District Stargard Szczeciński, Zachodniopomorskie	Inland	Closed (hybrid towers?)	Lake Szadzko, Wiechowskie and Marianowskie; rivers Krępa and Pęzinka; Lake Woświn (20 km) Lake Miedwie (26 km)	Lake Szadzko: 0.78 km², depth max – 2.6 m Lake Wiechowskie: 0.19 km², Lake Woświn: 8 km², 75.84 million m³; depth.4 m, max – 28.1 m, Lake Miedwie: as in point 20	? Lack of sufficient hydrological data.
23	**Pniewo**	Commune Gryfino, District Gryfino, Zachodniopomorskie	River	Open	River Odra	SSQ = 620 (Gozdowice) SNQ = 536 m³/s (Gozdowice)	Sufficient
24	**Pniewo-Krajnik**	Commune Gryfino, District Gryfino, Zachodniopomorskie	River	Open			Sufficient
25	**Dębogóra**	Commune Widuchowa, District Gryfino, Zachodniopomor	River	Open			Sufficient

No.	Name	Geographical data	Site type	Cooling cycle	Cooling / raw water source	Hydrological data	Sufficiency of cooling water
		skie					
26	**Krzymów**	Commune Chojna, District Gryfino, Zachodniopomorskie	River	Open			Sufficient
27	**Stepnica 1**	Commune Stepnica, Zachodniopomorskie	Zalew	Open	Zalew Szczeciński	911.8 km^2 (457.3 km^2 in Polish territory); 2.75 km^3; average depth 4m; average annual Odra outflow 16.3 km^3; salinity 0.5-2.0 ‰	Sufficient
28	**Stepnica 2**	Commune Stepnica, Zachodniopomorskie	Zalew	Open			Sufficient

Explanations: SSQ – average annual flow; SNQ – average low flow value per year; SWQ – average high flow value in a year; NNQ – the lowest observed flow value

4.3.2.4 Raw water demand

Annual water demand of a PWR unit with net electric capacity of **1000 MW$_e$** (estimated on the basis of data for EPR[150]– **total 195 000 m^3/a** (which corresponds to average intake ca. 530 m^3/d = 22 m^3/h = 0.0062 m^3/s), of which:

Make up water for process cycles (except for a cooling water cycle) - demineralised: ca. **94 000 m^3/a** (demineralised water demand of the unit falls between ca. 256 m^3/d – during normal operation, and ca. 694 m^3/d – during start-up);

Water for other process purposes, not requiring treatment: ca. **72,000 m^3/s**;

Treated (potable) water for household needs (drinking, sanitary - WC and showers, preparing meals)[218] and industrial purposes (laundry, labs, washing electrolysers, air conditioning etc.): **29,000 m^3/s**;

<u>For comparison purposes</u>: raw water intake (underground water from the second water-bearing layer of Quaternary) for **"old" Żarnowiec power plant** (1830 MW$_e$ gross, ca. 1700 MW$_e$ net) has maximum capacity exceeding 500 m^3/h = 0.14 m^3/s, i.e. per 1000 MW$_e$ net: 294 m^3/h = 0.08 m^3/s.[219]

Therefore, raw water demand of a nuclear power unit with net capacity **1000 MW$_e$** is relatively small (on average ca. 530 m^3/d) and **it will not restrict a nuclear power plant location.**

The sources of raw water for filling and making up process systems will be - depending on availability and hydrological and hydrogeological conditions at a specific site - surface or underground waters (from Quaternary or Tertiary formations).

4.3.2.5 Impacts of waste heat discharge into water

According to the Ordinance of Minister of Environment[220], discharge of cooling water (from open and closed cooling cycles) with temperature ≤35°C (for lakes and their affluents the limit specified in Water law[221] is 26°C)

This ordinance also specifies acceptable parameters of pollution of discharged cooling water and sewage.

The regulations currently in force do not specify separate requirements concerning introducing cooling water to the sea, however provisions of Water law are applicable to: inland waters, internal sea waters and territorial sea waters (art. 7 excerpts 1 and 2). Thus - since the Ordinance was issued pursuant to Water law (art. 45, excerpt 1, point 1 and 3) – it should be assumed that the limit of 35°C also refers to cooling water discharged to the sea.

Moreover, it should be emphasised that pursuant to the relevant Ordinance of Council of Ministers[222], introduction to water or soil of cooling water with temperature exceeding 26°C is charged with proper fees, according to differentiated rates depending on temperature and updated annually by Minister of Environment.[223].

Amount of heat discharged in cooling water from nuclear power plants is ca. **2100 MW_t/1000 $MW_{e,net}$**.

Amount of heat emission to surface water depends on a cooling system type. In open-cycle systems, heat id discharged in total by cooling water to a reservoir, whereas in closed systems with cooling towers, ca. 98.5% is given up to the air, and remaining ca. 1.5% is discharged with water (blowdown).

In an open-cycle system, with typical heating of cooling water ("cooling zone") by 10 K, discharge of **1 MW_t** heat stream requires expenditure of ca. **86 m^3/h** of cooling water**.** Discharge of **1000 MW_t** requires expenditure of ca. **23.9 m^3/s** of cooling water (with 12 K: 19.9 m^3/s). **For a nuclear power** unit with net capacity of **1000 MW_e** expenditure of cooling water is ca. **50.2 m^3/s** (with 12 K: 41.8 m^3/s).

In power engineering, tests were conducted on factors significant in dispersing large amounts of heat in surface waters. Calculations should include a number of physical phenomena, such as:

- seasonal differences in temperature of water receiving the discharge stream
- seasonal differences in water level in rivers and differences in current velocity,
- degree of mixing discharge water with dispersing water (in place of cooling water discharge and in a distance from it),
- condition of a coast and sea currents
- and convection movements in water and air.

Although ultimately the entire heat emitted by a power plant is passed into atmosphere, the large part of it is passed through aquatic environment. During heat transfer, the following physical processes take place:

- eddy diffusion,
- heat convection in water,
- flow of liquid of various density,
- evaporation, radiation and convection of heat in the air.

The amount of discharged heat and type of environment determine which process will be decisive in heat exchange and distribution process. When describing processes occurring in discharged cooling water, two characteristic areas must be distinguished: the first - in the direct vicinity of discharge and the second - remote from discharge. Before water is cooled down, heat contained in it may affect aquatic ecosystem, which should be avoided.

Direct vicinity of discharge is an area where complete mixing of heated cycle water with river water does not occur. Water temperature in this area depends on the degree of mixing discharge water with water in the receiving medium. Water heating in this area may be reduced by proper devices for quick mixing discharge water and receiving water.

The area distanced from discharge is where water was mixed at full depth. This area is a background for further emissions. Temperature increase in the remote area is gradually reduced by inflow of external water and heat exchange with the atmosphere.

In **atidal seas** (Baltic Sea) processes occurring in heated water zone mainly depend of stratified flows. Temperature drops there quickly due to mixing caused by friction and turbulence between layers. In such waters (as well as **in lakes**) dispersion or transfer of cooling water largely depend on currents caused by wind and thermocline conditions. It is estimated that **for 1MW_e 1 ha of water surface is needed.**

Assessment of water heating **in river** related to warm water discharge from a power plant is a complex issue. Water cooling process in a river is mainly associated with heat exchange between a river and atmospheric air. Thermal energy flow between water surface and atmosphere changes significantly depending on weather conditions and time of day. For better distribution and mixing of heated water at the **distance of several tens to several hundred meters**, distribution structures are located along the entire width of a river. If water discharge takes place along the river bank, complete **natural water mixing occurs at the distance of several kilometres**.

Re-suction of heated water should be avoided. In case of discharge to the sea or estuary, a degree of heated water return to the system should be reduced to minimum in order not to decrease efficiency and safety of power plant operation.

Location and construction of water intake and discharge should be designed to prevent recirculation of cooling water. Preliminary tests usually allow designing a construction of water intake and discharge and devices which will prevent recirculation and provide thorough and quick mixing of heated water. Such tests are based on physical (hydraulic) and numerical models. Using those tools in assessment of environmental impact of the planned facility ensures that **acceptable values of maximum water heating in mixing area or water temperature after mixing will not be exceeded**.

Heat emissions to surface water **may have negative environmental impact**. Factors shaping such impact are for example: Possible dispersion capacity of receiving cooling water, actual temperature and the ecological status of surface waters. Emissions of heat in heated cooling water may cause exceeding environmental quality standards (for temperature during warm summer seasons). An important factor in terms of impact of heat emission on environment is not only water temperature but also temperature increase at the border of mixing zone as a result of heat discharge to water.

Temperature increase may lead to **increased respiration and biological growth (eutrophication).** Cooling water discharge to surface waters affects the entire aquatic system, and in particular **fish population**. The temperature of water has a direct impact on all living organisms and their physiological processes, and an indirect impact on **oxygen balance in water**. Water heating **decreases amount of oxygen** dissolved in water and facilitates decomposition of organic matter, which leads to faster consumption of oxygen.

4.3.2.5.1 *Case study - analysis of discharge heat emission impact for referential facility Flamanville nuclear power plant.*

Analysis of discharge heat impact on surface waters: Flamanville nuclear power plant

Impact of heat discharged in heated cooling water on water reservoirs will be modelled with 3D models. Due to the fact that heat impact analyses are based on complicated calculations, perfumed on the basis of data specific for a given site and that simplified calculations do not give reliable results, **analyses may be performed only for a specific site**, in order to specify impact of discharged heat on local aquatic environment (sea, river, lake).

Such analyses have not been yet performed for any nuclear power plant site in Poland[224]; they will be performed in future only for selected sites.

Assessment for a specific site will refer to impact of heat releases on water temperature in a reservoir: near cooling water discharge and in more remote locations. 3D modelling will be used for assessment of various possible configurations of water discharge in various hydrodynamic conditions. The data needed for 3D modelling include: data on temperatures of surrounding water, temperature of discharged cooling water and flow intensity, geometrical data, data on currents and bathymetric data. The analyses will specify the scope of thermal impact (temperature growth isotherm by 1°C), temperature distribution (surface and stratification), maximum temperatures in least favourable conditions, temperatures in specific locations (particularly in the area of water intake). After discharge of heated water into cooler reservoir water, heated water rises, therefore thermal impact is located on and near reservoir surface, hence the greatest temperature increases occur **in surface layer**.

Furthermore, aquatic ecosystem will be monitored during nuclear power plant operation in order to specify the scope and character of impact of discharged heat.

Below, as an example, some analysis results for the sea location (Atlantic Ocean) of **Flamanville power plant** in France are presented. The analyses were performed with 3D Telemac model (developed in France). Of course, they were performed for specific site conditions (with strong tides, among others) and therefore the conclusions should not be projected onto other sites.

Simulations were performed for maximum cooling water heating (cooling zone) **14°C**, with minimum flow intensity **58 m^3/s** (in normal operation conditions the parameters are 12°C and 57 m^3/s), for neap tide and spring tide conditions. Typical water outflow velocity from the distribution structures on discharge: **4 m/s**.

First, impact analyses were performed during operation of unit FA3 with EPR alone, and then with operation of 2 already existing units (with "P4" reactor) with capacity 1300 MW$_e$ each - for each unit, discharge of water heated by 15°C, with flow intensity 45 m^3/s was assumed.

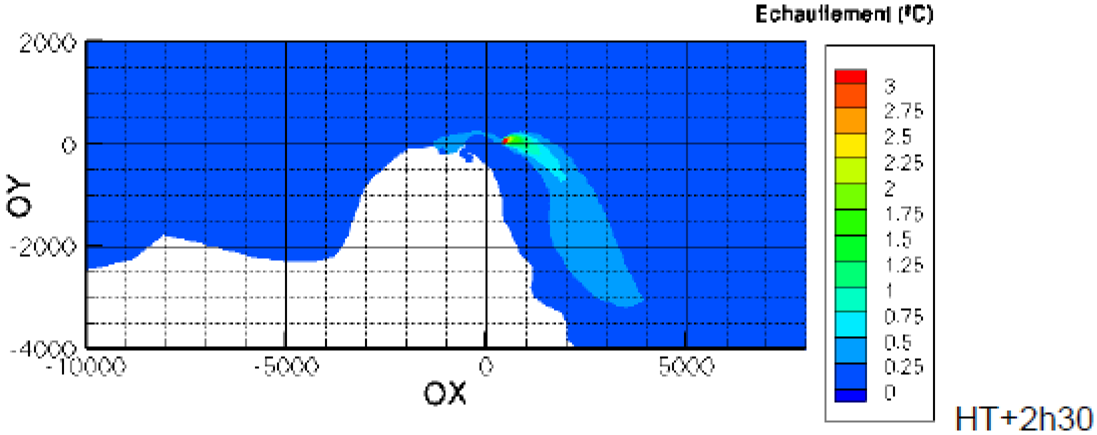
During operation of FA3 unit alone it was stated that:

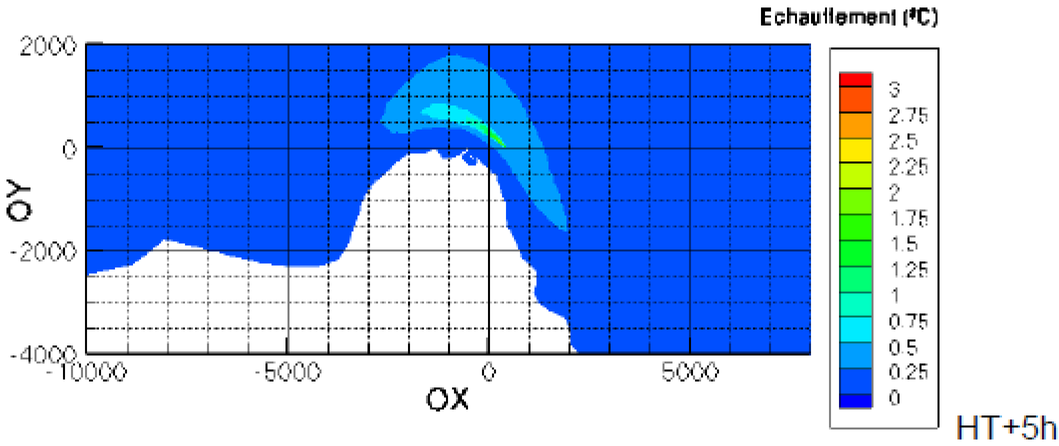
Maximum water heating in the intake area and at the shore will be ca. 0.5.

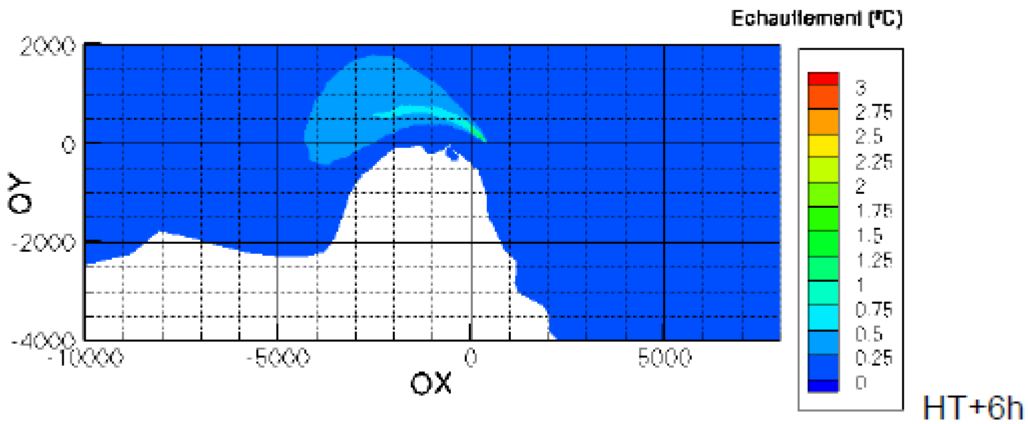
"Thermal cloud" displays vertical stratification, but becomes homogenous at a distance from discharge location.

"Thermal cloud" corresponding to increase in surface temperature by 1°C covers the area of: ca. 0.4 km^2 - in mean spring tide conditions and 0.6 km^2 - in mean neap tide conditions; whereas maximum **temperature increase at the distance of 50 m from discharge** is lower than: 6.3°C - in mean spring tide conditions, 6.3°C - in mean neap tide conditions.

Below, graphic results of simulation of maximum "thermal cloud" range are presented, +1°C with operation of FA3 unit alone, in mean neap tide conditions.



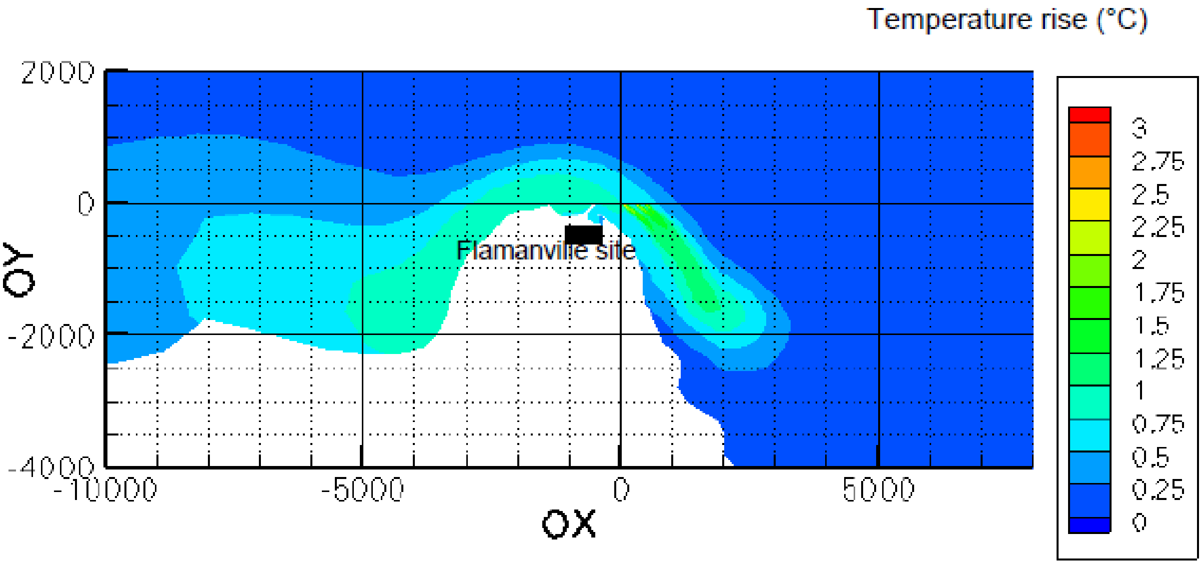




During operation of 3 units it was stated that (see figures below):

Separate "thermal clouds" from three discharge locations quickly blend together (at the distance of less than 500 m from the discharge locations).

In least favourable conditions, maximum water heating in the intake area and at the shore will be ca. 1.2℃.



- "Thermal cloud" displays vertical stratification, but becomes homogenous at a distance from discharge location.

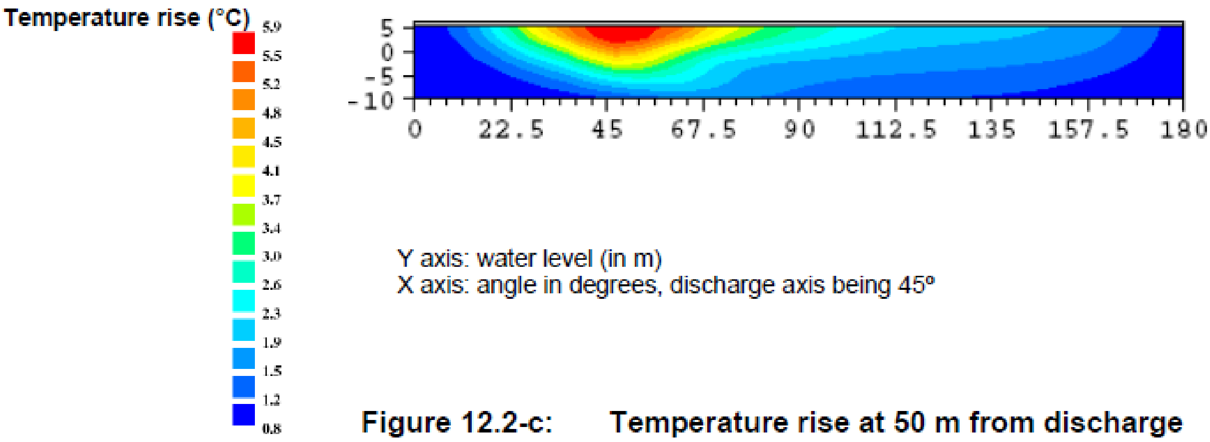
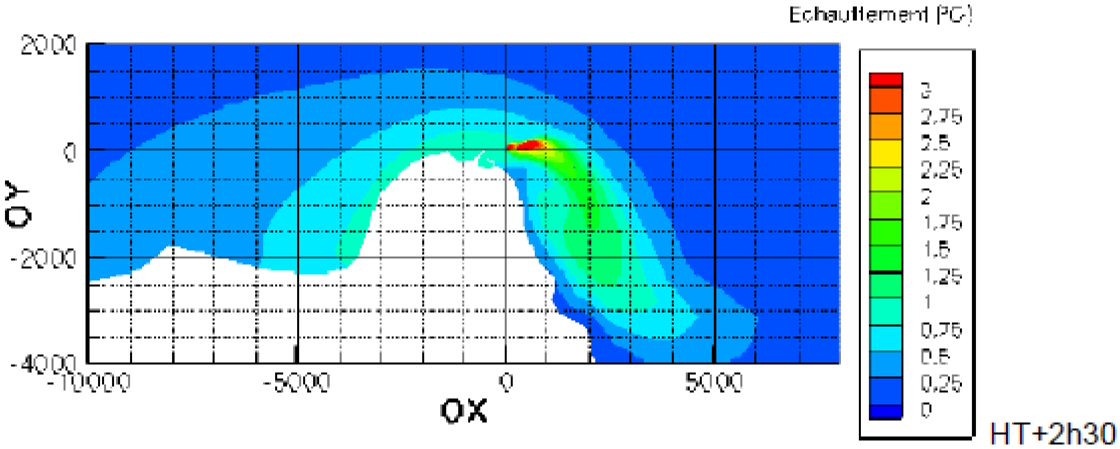
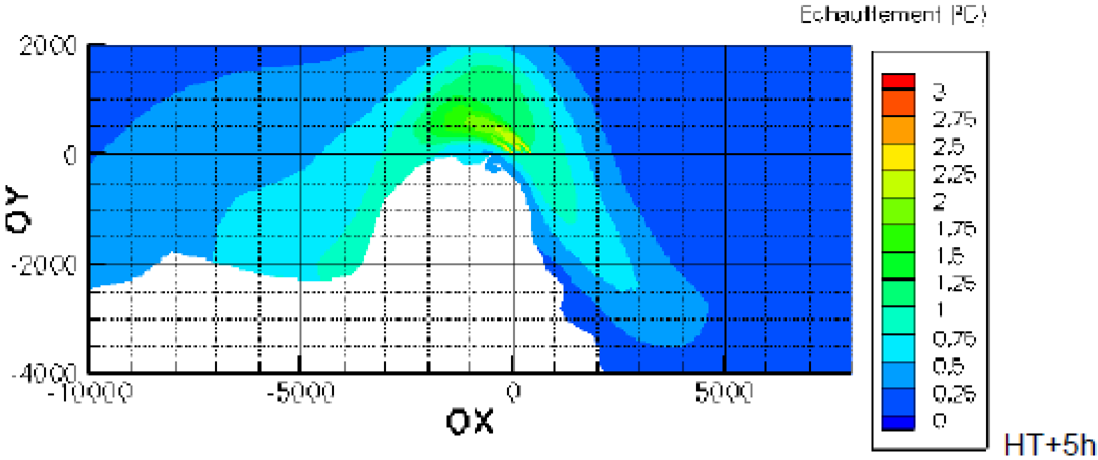
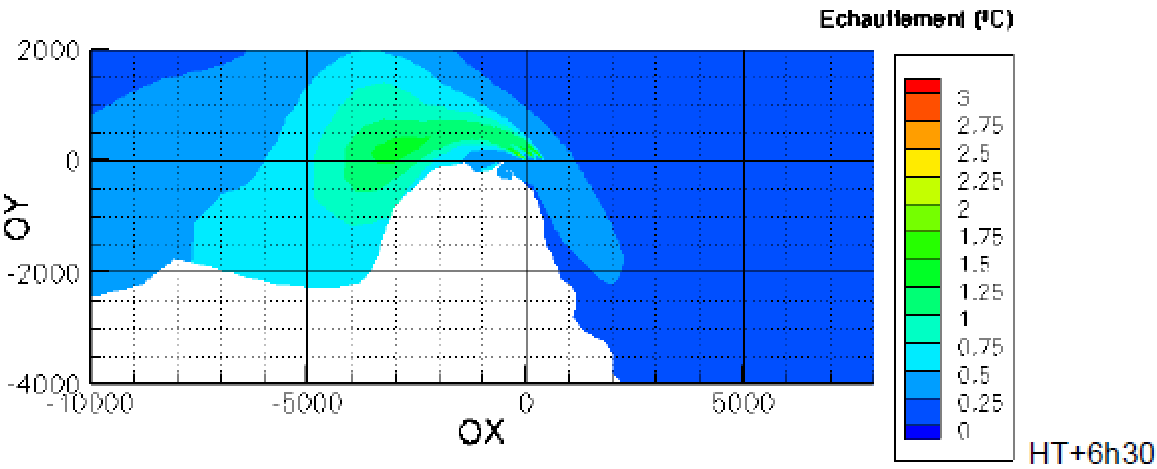


Figure 12.2-c: Temperature rise at 50 m from discharge point 3 (EPR), cross section, HT+3h30

"Thermal cloud" corresponding to increase in surface temperature by 1°C covers the area of: ca. 2.5 km^2 - in mean spring tide conditions and 8.5 km^2 - in mean neap tide conditions; whereas maximum **temperature increase at the distance of 50 m from discharge** is lower than: 6.7°C - in mean spring tide conditions (max temp. occurs in the discharge area from unit 2, which is affected by FA3), 7°C - in mean neap tide conditions (in the discharge area from unit 2).







4.3.2.5.1.1 Analysis conclusions

During operation of 3 units, water heating at the intake and at the shore, as well as in the distance o 50 m from discharge sites is the same as in case of 2 units with capacity 1300 MWe. Discharge from FA3 has partial impact on temperature at unit 2 discharge, however it contributes to temperature increase by no more than 0.3°C. therefore, adding FA3 unit does not significantly change temperature increases.

The main effect of heat discharge from FA3 is increase in heat impact surface: the surface of +1°C "thermal cloud" increases from 2.5 km^2 to 8.5 km^2.

Temperature increases, mainly observed on the surface, have minimal impact on marine ecosystem, mainly consisting of bottom-dwelling species.

Hydrobiological monitoring conducted for the last 20 years for Paluel nuclear power plant (4 units) and Gravelines (6 units) did not detect any impact of discharged heat on marine ecosystem, therefore probably adding EPR (FA3) unit at Flamanville site will not adversely affect the ecosystem.

4.3.2.6 Impacts of waste heat discharge into atmosphere

Regardless of cooling manner, all waste heat is ultimately transferred to atmosphere. In case of cooling towers, heat is directly transferred to atmosphere. In case of open-cycle cooling connected with a river, sea or lake, heat is transferred into atmosphere through the surface of water reservoir receiving discharge, which takes place on a large area and with some delay, depending on local conditions.

4.3.2.6.1 Open-cycle cooling systems

In open-cycle power plants, withy unit operating at rated power, water is usually heated by ca. 10 K. In such a system, discharged water is gradually cooled down by mixing with receiving water. Heat is then transferred to atmosphere by means of three basic processes: evaporation (35 to 45% of released energy), radiation from water surface (25 to 35%) and penetration into air (20 to 30%).

Amount of energy discharged due to evaporation corresponds to 20 kg/s of steam per 100 MW_t of discharged heat stream. The **only atmospheric phenomenon which may occur in the vicinity of water outlet is creation and maintenance of fog**. It happens due to high temperature difference, however the scope is limited.

It is worth mentioning that in the same conditions, temperature of fog creation and disappearance is higher in case of saltwater than in case of fresh water. It is beneficial for power plants located at estuaries or near the sea.

4.3.2.6.2 Closed-cycle cooling systems

In power plants with closed cycle equipped with wet cooling towers, heat is directly discharged into atmosphere. Heat discharge occurs in a concentrated manner on a small area.

Cooling towers transfer into atmosphere 70% of heat in form of latent heat (saturated steam) and 30% in form of sensible heat. It results that amount of steam discharged to atmosphere is, more or less, twice as large as with an open cycle. Humid air gets absorbed into atmosphere, with temperature exceeding ambient temperature by ca. 10 - 20 K. Outflow velocity in case of natural draught cooling tower is 3 - 5 m/s, and in case of forced draught cooling tower the velocity is twice as high. The humid air, cooled down by mixing with external air, may cause **a vapour cloud**. Shape and volume of a visible vapour cloud are affected by temperature and relative humidity of atmospheric air as well as wind speed. The colder and more humid surrounding air, the more stable is a vapour cloud. Therefore, this problem may occur mainly in winter.

The risk of **ground level fog** due to settlement of humid vapour when it is cold, humid and without wind, may occur mainly in case of forced draft towers, due to their smaller height, i.e. (40-50 m). However, using **hybrid cooling towers** usually prevents **creation of vapours**. The taller the tower, the more rare the phenomenon. It may be assumed that on the plains, settlement of vapours occurs only in exceptional situations, when a cooling tower is 50-75 m tall, depending on local conditions. With nuclear power plants, wet cooling towers will be much taller (certainly above 160 m) - which practically **eliminates the risk**.

In winter in the cooling tower area there may also occur **frost build-up** due to settling vapours of water splashed at the tower base coming into contact with frozen ground surface. However this phenomenon is only limited to **direct vicinity of a cooling tower** within the radius of several meters. The result of large amount of vapours and condensation in extreme weather conditions may also be **icy roads**.

The main climatic change related to wet cooling tower operation is **increased haze in the vicinity of cooling towers** due to generation of vapours. As a result, decrease in insolation may occur.

4.3.2.7 Protection of living organisms from being sucked into the cooling system

When cooling water is pumped, small living organisms (algae or plankton) as well as animals found in water (molluscs and fish) are sucked into the cooling system. Plankton passes through the grid of rotating filters with mesh size between 1 and 5 mm. Such a filter stops crustaceans and fish, which are flattened out on filtration panels, and then collected and ejected with filter washing water. The tests show that aspiration into cooling systems mainly refers to small organisms, such as: larvae and fry.

In the last several years, many repellent systems and devices were designed and applied, mounted on inlets to hydroelectric and thermal power plants, among others:

- In fresh water, energized screens deter some fish species, but they do not work on fingerlings, or even draw them;
- Air bubble curtains generally produced poor effects;
- Light is partially effective with certain organisms, but fish may get used to it and then the deterrent effect is only temporary;
- In some cases, acoustic deterrent systems produced good results, in some other cases - just the opposite.
- In large water inlets equipped with sliding filtration screens, organisms are removed with fish pump or low-pressure water nozzles (1 bar).

Furthermore, cooling water pumping stations are designed to reduce algae aspiration and risk of clogging the devices.

4.3.3 Impacts of chemical substance emission to water

Emission of chemical substances to surface water was estimated for a PWR reactor unit with net capacity **1000 MW_e**, on the basis of available data for EPR units [UK EPR: PCER, Chapter 12][225] and AP 1000 [UK AP1000 Environment Report][226], specified for typical sites of new nuclear power plants in Great Britain (on the sea or at estuaries - with open-cycle cooling). The data include emissions due to (raw) water treatment for process and maintenance purposes and due to fighting biological sediments in cooling system.

Operation of nuclear power plant generates liquid waste due to: the process itself, conditioning and maintenance/overhauls of process systems, leaks and maintenance/overhauls of power plant facilities and premises. Liquid waste may be divided into:

Radioactive waste water: containing chemical substances from processes in nuclear section (reactor and its auxiliary systems); they are processed, stored and monitored before discharge;

Non-radioactive waste water from conventional section, including sewage, mainly from:

- Raw water demineralization and potable water treatment;
- Chlorination of cooling water and generation of sodium hypochlorite;

- Products generated in cooling water chlorination (organo-halogenated compounds);
- Precipitation water from drainage and treated sewage from sewage treatment station;
- Oiled water and process sewage from engine room building.
- Below, emissions of non-radioactive substances are described.

4.3.3.1 Discharges from demineralization station

Substances produced during raw water demineralization:

Iron: partially originates from raw water, but mainly is introduced as iron chloride added as a coagulant to the settling tank. Most iron is precipitates in coagulation and flocculation processes, which are the initial stage of raw water processing. Mainly, it is in form of liquid sludge from the settling tank or washing sand filters.

Solid particle suspension: this is sludge from demineralization station and solid particle suspension from washing sand filters.

Sulphides: they are introduced during ionite regeneration with sulphuric acid or neutralisation of alkaline sewage with sulphuric acid in neutralising well.

Sodium: introduced in three stages: 1) during dosing sodium hypochlorite at the outlet from raw water storage tanks, 2) during ionite regeneration with sodium hydroxide, and 3) during sewage neutralisation from demineralization station in neutralising well.

Chlorides: introduced during dosing iron chloride and sodium hypochlorite to raw water.

Waste water from demineralization station (after neutralization) are discharged to sewage system.

Maximum annual amounts of substances discharged from water demineralization for PWR unit with net capacity **1000 MW$_e$**, estimated on the basis of data for EPR unit [UK EPR: PCER, Chapter 3]:

Solid particle suspensions: 1010 kg/a;

- Iron: 530 kg/a;
- Chlorides: 2,260 kg/a;
- Sulphides: 7,330 kg/a;
- Sodium: 8,450 kg/a;
- Detergents: 195 kg/a.
- Brine with 70 g/l concentration is discharged to discharge channel with flow intensity ca. 94 m^3/s).

4.3.3.2 Discharge from chlorination of cooling water

Cooling water cycles are protected against bio film and biological sediments by chlorination, performed when seawater temperature exceeds 10°C. Sodium hypochlorite is produced from seawater by means of electrolysis. Chlorination is related with discharge to sea of both residual oxidizers (both unbound and as chlorine compounds) and tribromomethane (bromoform). Also chlorides from washing devices are discharged into sea.

Regular chlorination: with active chlorine concentration **0.5 mg/l**, sequential dosing every 30 minutes for each cooling water channel.

In exceptional cases: when change in water quality may cause excessive biological sediments, which requires **1 mg/l** concentration for 10 days for each unit, to chlorinate various service water cycles. Apart from that, some service water cycles may need shock chlorination at concentration **6 mg/l**.

The amounts of discharge due to eradication of bionic sediments estimated for PWR unit with net capacity 1000 MW_e, estimated on the basis of data for EPR unit [UK EPR: PCER, Chapter 3]:

Realistic concentrations in discharge tank:

- Residual oxidizers: 0.14 mg/l.
- Bromoform: 0.0027 mg/l.

Estimated maximum concentrations in discharge tank:

- Regular chlorination:
- Residual oxidizers: 0.5 mg/l.
- Bromoform: 0.02 mg/l.

Exceptional chlorination:

- Residual oxidizers: 1 mg/l.
- Bromoform: 0.04 mg/l.

Shock chlorination:

- Residual oxidizers: 0.72 mg/l.
- Bromoform: 0.0244 mg/l.

Annual estimated weight of discharged chlorides: **1,630 kg/a**.

Total residual oxidizers (TRO) occur in cooling water cycle chlorination against biological sediments. Estimated TRO concentration in discharge tank is 0.5 mg/l. The assumed EQS is **10 µg/l** (although this is not the value specified by regulations).

As a result of dilution with cooling water and additional demand for oxidizers generated by chlorine, TRO level in the receptor water is significantly decreased. Assessment of TRO concentration in discharge tank does not include the dilution and disintegration processes.

4.3.3.3 Discharges from sewage system

Typically, sewage system accumulates:

- Precipitation from power plant premises;
- Sewage ("black" and "grey") from toilets and showers, after treatment in treatment plants, the content of discharged substances is specified by BZT_5 (**<35 mg/l**);
- Process waters not polluted with hydrocarbons or deoiled;
- Waste water from water demineralization and potable water treatment.

Phosphates or nitrogen-containing substances are not discharged into sewage system.

4.3.3.4 Discharges containing oils and hydrocarbons

Water accumulated from the unit, which may contain oil (from transformers, engine room, oil and lubricant storage) are directed into oiled sewage system, equipped with oil separator, where oil and sludge are separated before discharge into rainwater sewage system, which reduces hydrocarbons discharged to surface waters.

Water containing hydrocarbons is treated on scrubbers and oil filters, content of hydrocarbons in discharged water is below **5 mg/l**.

Furthermore, there is a subsystem collecting other polluted water (from extinguishing fires or accidentally contaminated with chemicals) to a retention tank, where its chemical composition is controlled. The water is treated in the power plant premises, if possible, or if necessary, transported to external treatment plants.

4.3.3.5 Other hazardous substances

Liquid chemicals[149] used for conditioning (cleaning) process systems may contain pollutions such as mercury, cadmium and arsenic. Nuclear power plant operators however in their specifications indicate very rigorous levels of pollutions, which must be met by suppliers. Cadmium and arsenic are not acceptable in cooling water in order to prevent corrosion and activation of those pollutions in the reactor. Therefore, they may only occur in trace amounts in chemicals used for cycle conditioning, such as phosphoric acid.

waste water before being directed to retention tanks are filtered and treated on ion-exchange columns. It may be assumed that only small fraction of pollution introduced to the cycles will get to discharge tanks and be discharged to surface waters. Therefore, it may be stated that these substances, introduced temporarily to the systems in trace amounts, may be found in liquid discharge only in trace amounts.

Silver[149] may occur **in trace amounts** as Ag110m, as control rod corrosion product. Impact of those releases is included and assessed in terms of radioactive releases. Occurrence of silver in chemicals applied in power plant is not expected. Chemical specifications concerning content of other contaminations (e.g. arsenic in boric acid) serve as indicators of total pollution content in chemicals (including silver). Analyses of those indicators have shown that in chemicals for conditioning **measurable traces of silver do not occur.**

4.3.3.6 Assessment of total amounts of chemicals discharged into surface waters

Substances discharged into cooling reservoir during operation of EPR or AP 1000 unit, for which acceptable environmental quality standards were specified (EQS) are: ammonia or ammonium hydroxide, boron, iron, copper, chromium, nickel, zinc, lead and total residual oxidizers (TRO).

- Ammonia / ammonium hydroxide is dosed into secondary cycle (steam-water) to obtain pH value at which corrosion is lowest.
- Boron is needed in various process cycles as neutron-absorbing substance.
- Metal contamination as a result of material wear in process cycles can be found in liquid waste related to radioactive releases. These are metals of pipelines or certain devices (iron, nickel, zinc, copper, chromium and lead). The main factor reducing the amount of metal pollution is maintaining proper chemical regime conditions. Despite the fact that liquid discharge is filtered and treated on ion-exchange columns, still small amounts of those metals are found in discharge water reservoirs.

- Iron comes from chemical conditioning (cleaning) of process cycles and from water demineralization.
- Sodium perchlorate is a biocide for eradication of biological sediments in open seawater cooling cycle (AP 1000).
- Ammonium chloride is used for eradication of algae in open seawater cooling cycle (AP 1000).
- Hydrazine is used for removing oxygen in primary cycle during cold unit start (AP1000).
- Monoethanolamine is used for chemical correction (pH) in secondary cycle (AP1000).
- Lithium hydroxide is used for chemical correction (pH) in primary cycle (AP1000).
- Zinc acetate is used as corrosion inhibitor in primary cycle (AP1000).
- Total residual oxidizers (TRO) are produced due to water processing in cooling cycle to eradicate biological pollution.

The table below (Table 4.3.10) presents maximum annual amounts of discharged substances during operation of PWR unit with net capacity **1000 MW_e**, estimated on the basis of data for EPR unit [UK EPR: PCER, Chapter 12] and AP 1000 [UK AP1000 Environment Report].

Table 4.3.10 Maximum annual amounts of discharged substances during operation of PWR unit with net capacity 1000 MWe.

Substance	Cycle conditioning [kg/a]	Production of demineralised water [kg/a]	Annual amount discharged to environment [kg/a]
Ammonia (non-ion) [EPR]	104	-	104
Ammonium hydroxide [AP1000]	26 300	-	26 300
Boric acid [EPR – AP1000]	4 375 – 6 970	-	4 375 – 6 970
Boron* [EPR – AP1000]	765 – 1 220	-	765 – 1 220
Hydrazine [AP1000]	330	-	330
Monoethanolamine [AP1000]	99,4	-	99,4
Lithium hydroxide [AP1000]	5,7	-	5,7
Zinc acetate [AP1000]	1,1	-	1,1
Iron [EPR]	10,2	530	540,2
Copper [EPR]	0,1	-	0,1**
Nickel [EPR]	0,1	-	0,1**
Zinc [EPR]	1,8	-	1,8**
Lead [EPR]	0,06	-	0,06**
Chromium [EPR]	2,43	-	2,43***
Aluminium [EPR]	1,54	-	1,54***
Magnesium [EPR]	0,96	-	1,54***

Trace metal contamination from chemicals [AP1000]	2,9	-	2,9
Ammonium chloride - algaecide [AP1000]	5 610	-	5 610
Sodium hypochlorite - biocide [AP1000]	120 400	-	120 400

** Boron contained in H_3BO_3*
*** Among metals for which EQS was specified, emission amounts are insignificant for copper, nickel, zinc and lead; despite that impact assessment is performed.*
**** Emissions of metals for which EQS was not specified (aluminium and magnesium) are insignificant.*

In environmental impact assessment, only the substances were included for which environmental quality standards (EQS) were specified – Table 4.3.11. Impact of other substances is assessed in reference to a specific site.

Table 4.3.11 Environmental quality standards (EQS)

Substance	Type of eqs	Eqs [µg/l]
Ammonia (non-ion)	-	21*
Boron	Total average annual	7 000
Iron	Dissolved average annual	1 000
Copper	Dissolved average annual	5
Nickel	Dissolved average annual	30
Zinc	Dissolved average annual	40
Lead	Dissolved average annual	25
Chromium	Dissolved average annual	15
Mercury	Dissolved average annual	0,3
Cadmium	Dissolved average annual	2,5
Arsenic	Dissolved average annual	25
Total residual oxidizers (TRO)	Maximum acceptable concentration	10

** Value proposed in IPPC H1 guidelines (July 2003).*

Table 4.3.12 Assessment of emission of substances to surface waters during operation of PWR unit with net capacity 1000 MWe. [UK EPR: PCER, Chapter 12] and [UK AP1000 Environment Report]

Substance	Annual discharge [kg/a]	DC** [µg/l]	EQS [µg/l]	DC/EQS [%]	PC** [µg/l]	PC/EQS [%]
Ammonia (non-ion) [EPR]	104	0,08	21	0,4	0,015	0,075
Ammonium chloride [AP1000]	5 610				≤11	
Boron [EPR – AP1000]	765 – 1 220	0,58	7 000	0,008	0,12 - 0,19	0,002 - 0,003
Hydrazine [AP1000]	330		-		0,3	
Monoethanolamine [AP1000]	99,4		-		0,09	
Lithium hydroxide [AP1000]	5,7		-		≤0,005	
Zinc acetate [AP1000]	1,1				$<3.4x10^{-5}$	
Iron [EPR]	540	0,41	1 000	0,04	0,08	0,008
Copper [EPR]	0,12	0,0001	5	0,002	0,00002	0,0004
Nickel [EPR]	0,13	0,0001	30	0,0003	0,00002	0,00007
Zinc [EPR]	1,7	0,0013	40	0,0033	0,0003	0,0007

Lead [EPR]	0,09	0,00007	25	0,0003	0,00001	0,00005
Chromium [EPR]	2,43	0,002	15	0,0122	0,0004	0,002
Trace metal contamination from chemicals [AP1000]	2,9		Table 10.3.9		0,0027	
Ammonium hydroxide - algaecide [AP1000]	26 300		-		≤11	
Sodium hypochlorite - biocide [AP1000]	120 400		10 (TRO)		≤200	≤2000
Total residual oxidizers (TRO)* [EPR]	-	500	10	5000	100	1000

** Value estimated according to assumptions below.*
*** For all metals, the discharge concentration refers to total content and not to dissolved fraction, therefore discharge assessment is conservative, as EQS for metals refer to dissolved fraction.*

If **concentration in discharge reservoirs DC** (Discharge Concentration) and **discharge concentration after dilution PC** (Process Contribution) of a given substance are lower than 1% of environmental quality standard (EQS) , its environmental impact is not analysed.

<u>Conclusion</u>: The forecasted **DC and PC are below 1% EQS** for all substances except TRO. Therefore, their impact on receptor reservoir environment is insignificant. Thus, more precise assessment of their environmental impact is not necessary, except for TRO.

4.3.3.1 Impacts of salt discharge into water

Using surface waters for cooling is connected with **emission of chemicals to environment**.[227] These may be, in particular:

- agents for protection against scale settlement in cooling systems with cooling towers;
- agents for eradication of biological sediments, and reaction products of some of them;
- corrosion products of heat exchangers and pipelines;
- substances suspended in the air, introduced via a cooling tower.

The common materials in heat exchangers, channels, pumps, and screens are carbon steel, cupro-nickel and various stainless steel variations; titanium is used increasingly often. For surface protection, paints and coats are used.

In case of **marine environment**, to maintain proper purity of systems and provide their proper operation, **biocides** are used. In seawater cooling systems, prevention from mollusc growth is most important. Currently, **chlorine** is used for this purpose (in form of sodium hypochlorite). It is usually produced on site in seawater electrolysis. It allows avoidance of hazards related to transport of NaOCl.

Chlorination may be constant and periodical (seasonal) depending on many factors, such as weather, water quality, cooling system structure or typology of biological sediments (settlement periods and rate of growth). Usually, chlorine is applied in small doses so that concentration of free chlorine in system outlet is within **0.1 and 0.5 mg/l** (sporadically 0.7 mg/l). However, when chlorine reacts with some organic compounds, it may create organo-halogenated substances (in seawater mainly bromoform). Tests show that bromoform concentration in heated water zone near cooling water outlet from a power plant located on the coast is very low (ca.15 µg/l).

Chlorination with sodium hypochlorite is a chemical treatment method which protects against sediments and is **commonly** applied for system protection **in coastal power plants**. Another successfully applied oxidizer is chlorine dioxide.

For many years, coastal power plants have been using alloys with titanium for construction of heat exchangers. For this reason, corrosion in those systems is insignificant or non-existent. In standard designs of III and III+ generation nuclear power plants stainless steel of titanium alloys were used for turbine condenser pipes.

In **river power plants** effect of chemicals largely depends on the type of cooling system and various biological factors.

In closed-cycle cooling system scale settlement occurs, which requires application of a proper manner of **makeup or cooling water treatment**. The following treatment methods may be applied:

- makeup water softening (decarbonisation) with lime,
- water processing (grafting) with acid in cooling cycle,
- processing with precipitating retardant,
- combination of the following treatment types: acid grafting and inhibitors of scale settlement or softening with lime and acid grafting.

Selection of treatment method depends on many criteria. Among them are the following:

- cycle thickening coefficient (K);
- river water chemical composition;
- cooling system structure.

With high thickening coefficient (3 to 7) **makeup water softening with lime** is used, which can be **supplemented with light acid grafting** (in most cases, sulphuric acid is used).

The aim of softening makeup water with lime is to increase water pH to 10 in order to precipitate calcium and some magnesium in form of carbonate and hydroxide. At the decarbonizer outlet, concentration of residual calcium is between 0.5 and 1 [mequivalent]. However, it is combined with carbonate which is responsible for high settlement of scale from treated water. To maintain balance in decarbonised water, sulphuric acid grafting is often performed.

Softening with lime causes **generation of large amounts of sludge** (mainly containing calcium carbonate $CaCO_3$ and magnesium hydroxide $Mg(OH)_2$). Moreover, due to pH increase, softening with lime may cause precipitation of certain heavy metals, which will be present in discharge water.

Sludge resulting from precipitation in softening process collects at the bottom of settling tank. It is usually pumped to sludge thickener, where due to further settlement, concentration of solid particles increases. The process is usually aided by feeding polyelectrolyte. Clear water returns to settling tank, and concentrated sludge is further dried in vacuum drum filters or band filters. Granulated sludge generated from drying with water content at ca. 50% is removed to dumps. No adverse environmental effect from sludge collected on dumps after water softening was noted.

Desalination of closed cooling cycle does not result in introduction of additional salt into the reservoir from which makeup water is taken. On the contrary: it is a smaller amount, as in decarbonisation process, significant amounts of calcium and magnesium are removed, which then as removed as sludge.

Constant **chlorination of cycle systems**, aiming at elimination of biological sediment on **condenser tubes** was eliminated a long time ago and replaced with mechanical methods (Taprogge, Techno systems etc.). Despite that, chlorination is still an effective treatment method. In practice, five chlorination methods may be used:

- end of season chlorination: for example constant chlorination with low concentration (0.5 mg/l) for 2-4 weeks at the end of period of settlement of freshwater clams Dreissena polymorpha (zebra mussel);
- periodical chlorination: several periods of constant biocide adding during the settlement period;
- irregular chlorination: frequent short-term dosing (e.g. once per day or three days, for several minutes to one hour);
- constant chlorination with low concentration during clam settlement;[228]
- semi-constant chlorination is based on short dosing periods (15-60 minutes) and identical periods without dosing.[229]

Intense chlorination (shock dosing) is a special method developed to remove fibrous algae occurring in open reservoirs and cooling tower fills. Concentration at dosing point is 5 to 25 mg Cl_2/l. To avoid releasing chlorine to environment, outlet pipes are closed for several hours. They are open when free chlorine concentration in water decreases below maximum discharge concentration. Depending on local requirements, the value may be from 0.1 to 0.5 mg TRO/l.[230] Some local requirements are specified according to flow rate. This treatment method is not applied in all facilities. Frequency of intense dosing largely depends on water quality, thickening coefficient and general cycle purity. It may be used weekly, monthly or quarterly.

Chlorine reaction with hummus and fulvic substances creates **organo-halogenated compounds**. In fact, concentration of bromide ions in river water is small. In such conditions, only organo-halogenated compounds are created. There are also such volatile compounds as chloroform, dichloromethane, (POX) and adsorbable organically bound halogens (AOX).

However, similarly to seawater, presence of halogenated carbohydrates in surface inland waters is not only caused by chlorination in cooling systems. Other possible sources are particularly agriculture and natural processes. In clean lakes, e.g. in Sweden - concentration of adsorbable organohalogens (AOX) is from 10 to 190 µg Cl/l. The highest concentrations were noted in very eutrophic lakes.

Chlorination in open-cycle cooling systems does not cause significant increase in halogenated carbohydrates. It is because the exposure time is very short - max. ca. 10 minutes, and free chlorine concentration is low. Depending on applied chlorination method, measured peak concentrations of POX and AOX are respectively 0-10 µg Cl/l and 20-150 µg Cl/l. The values correspond to free chlorine concentration at dosing point between 0.5 and 10 mg/l.

Chlorination in closed cycle may lead to higher concentrations of organo-halogenated compounds. The following factors play a negative role in this process:

- longer exposure time
- circulation increases precursor concentration.

It should also be mentioned that pH increase related to release of CO_2 favours creation of POX. These are easily transferred to atmosphere via cooling towers.

With free chlorine concentration at dosing point between 5 and 25 mg/l and with exposure time 2-70 hours, POX concentration is 0-10 µg Cl/l, and AOX 200-2,500 µg Cl/l.

It should be mentioned however that presence of small amount of ammonium ions in natural water may significantly reduce concentration of POX and AOX. It happens because kinetics of reaction Cl-NH_4^+ ids faster than kinetics of reaction between chlorine and aromatic compounds.

Area exposed to concentration of TRO (total residual oxidizers) > 10 µg/l will be limited to direct surroundings of discharge location. Moreover, it is improbable that aquatic organisms suffer negative effects from TRO discharge. Sea bottom-dwelling organisms will not be in the discharge cloud, fish (and other mobile organisms) will not remain within the discharge cloud for a long period of time, before its dilution. Chlorine dosing and TRO discharge estimation largely depend on specific site, information on water quality and thermal cloud modelling are necessary. Thus, assessment of impact of TRO discharges will be performed in future for specific sites.

4.3.4 Impacts of chemical substance emission to atmosphere

In considerations regarding air, long-term forecast of air quality change must be included at national scale for main power engineering pollutions – SO2, NOx and PM10 and PM 2.5 – included in air quality assessment.

4.3.4.1 Emissions to atmosphere from cooling towers

Wet or wet-dry cooling towers may emit pollution by lifting and escape of chemical substances for water treatment, in particular biocides. It is known that escape of chemical substances increases with temperature increase, but the mechanism leading to emission of pollutions is more complex and dependent on many factors. Therefore, it is difficult to specify quantitatively, Quality and quantity of direct pollution emission from cooling towers is specific for each case and depends on treatment substances, their concentration in circulating water and effectiveness of mist elimination.

However, pollution emissions are significantly reduced by windage eliminators, mounted in all modern wet cooling towers; they allow reduction of water lift to 0.01% or less with regard to entire flow.

An attempt was made at estimation of pollution emission with a simplified model[231]. It results from the data that emission concentrations are low (µg/m^3), but should not be neglected and that structure and location of cooling tower outlet are important - due to location of air inlets to A/C systems or other cooling installations.

Water drops released from wet cooling towers may be contaminated with chemical substances for water treatment, micro-organisms or corrosion preventing products. Using windage eliminators and optimised water treatment program will allow for decreasing potential risk.

Forming vapours is also taken into account where fog effect occurs or where a risk occurs that the vapours will reach ground level.

Emission to atmosphere occurring in wet cooling towers becomes particularly significant in direct vicinity of urban areas, however compared to other industrial air pollutions, it may be deemed relatively insignificant.

The problems which may occur during operation are as follows:

- water drops containing certain water treatment substances,
- growth of bacteria (leading, e.g. to legionellosis) in case of improper water treatment with biocides and improper maintenance of a cooling tower.

4.3.4.2 Gas emissions related to the process

During normal operation, potential sources of non-radioactive emissions are chemical releases, including vehicle exhaust emissions.

In terms of chemical releases, the following main groups were identified:

- sulphur and nitrogen oxides contained in exhaust gases from emergency generator motors, supplying power during their periodical tests;
- formaldehyde and carbon monoxide emitted by insulation to ventilation system and released via ventilation chimney;
- ammonia released from steam generators during temperature increase accompanying power unit start-up.

According to H1 methodology[232] and conservative assumptions, it was stated that:

- emissions of formaldehyde, nitrogen oxide and ammonia should not have significant impact on air quality, further impact modelling is not justified;
- emissions of sulphur and nitrogen oxides are above significance limits for environment, therefore they require further assessment - at the stage of detailed environmental impact assessments at specific sites.

With regard to unpleasant odours, sources of odour emissions exist during construction and operation stages (diesel exhausts, formaldehyde, ammonia), but they occur for short periods of time. Therefore their significant adverse effects seem improbable.

4.3.4.2.1 Emissions during emergency tests of diesel generators

Maximum emissions for PWR unit with net capacity **1000 MW_e** were estimated on the basis of data for EPR unit [150] with 4 emergency diesel generators (*"Emergency Diesel Generators"* – to supply 4 groups of security systems) each with capacity 7.5 MW_e, and additional 2 generators (*"Ultimate Emergency Diesel Generators"* – in case of failure of power supply from external grid) each with capacity 2.5 MW_e. <u>For comparison purposes</u>: AP 1000 unit has 2 generators with capacity 4 MW_e each and 2 generators 35 kW each.

Total annual test duration for each generator is estimated at less than 20 hours.

Estimated emissions of sulphur and nitrogen oxides:

- sulphur dioxide: annual emission - 517 kg/a, emission intensity – 1.63 g/s,
- nitrogen oxides: annual emission - 5,425 kg/a, emission intensity – 17.13 g/s,.

4.3.4.2.2 Emissions due to heating of new insulation materials

Some pipelines in reactor building have insulation made of materials from which after heating - due to thermal decomposition - steam is released, containing formaldehyde, which in turn may produce carbon monoxide.

Estimated gas release rate: formaldehyde – 15.2 mg/s; carbon monoxide - 14.3 mg/s.

Ammonia emissions

Ammonia emissions from steam generators during unit start-up are estimated with a conservative assumption that all hydrazine contained in water will disintegrate into ammonia and that 2/3 of ammonia in water will be released to atmosphere.

Annual amount of released ammonia: 12.5 kg, maximum release rate: 1.95 g/s (estimated duration of ammonia emission - 88 hours).

4.3.4.3 Reduction potential of atmospheric pollution emissions

One of the outcomes of the Programme will include the partial replacement of electricity generation in coal-fired power plants with electricity production in nuclear power plants. As the emissions of pollutants to the air are much lower for nuclear power plants, the Programme will reduce the emissions of pollutants in the atmosphere resulting from electricity generation. This Chapter attempts to estimate the possible reduction of these emissions. To estimate them, one has to assume the amount of produced power which will be replaced with nuclear power engineering. Polish power engineering policy until 2030 assumed contribution of nuclear power in total power production above 10%. In Polish Nuclear Programme, contribution of nuclear power in fuel structure in 2030 was assumed at 15.7%. Emission reduction potential in nuclear power plants should result from proportion of nuclear power plant contribution in covering the amount of power production. Decrease in production of coal-fired power plants must be included [assumption: 141 TWh(2008) – 110 TWh(2030)] and increase in gross demand for power [217 TWh(2030) – 141 TWh(2010)]. This means that power demand of 107 TWh will be covered by other sources than coal-fired power plants, being nuclear power plants, OZE and gas power plants. It results from the share proportion of the sources in 2030 assumed in the Programme, that ca. 38% of this demand will be covered by nuclear power engineering, which gives ca. 40TWh. Such amount of power can be produced by the designed power units with total capacity ca. 5000 MWe[1], because III generation power plants are characterised with very high installed power consumption coefficient (ca. 92%). Should the Programme not be implemented, the power would be generated by coal-fired power plants, which would generate larger emissions to atmosphere. To sum up, ca. 18% of power produced in 2030 will be replaced with nuclear power engineering (40TWh/217TWh=0.18). It should be emphasised that the calculated amounts are estimated values, calculated on the basis of the above assumptions and serve to show the order of magnitude and not precise figures. On current stage due to limited technical data, more precise analyses are not feasible.

4.3.4.3.1 Reduction potential of greenhouse gas emissions

Nuclear power plants (NPP) during power generation do not directly produce CO_2. Small CO_2 emissions are related to construction, operation and decommissioning of NPP. Main part of carbon dioxide emission by nuclear power industry is related to fuel cycle (uranium extraction and processing, fuel production and disposal of radioactive waste).

Nuclear power plants will not have adverse impact on climate, on the contrary – their implementation will reduce emission of CO_2 by avoiding emissions from power plants fuelled with fossil fuel. Emissions from individual power plants of various types are presented in Table 4.3.13. Data presented in the table refer to the entire life cycle, therefore they include emission from fuel extraction and processing through power plant operation to its construction and decommissioning. They are taken from a German study[233], in which the authors analysed emission and raw material consumption for various power sources on the basis of material and power flow modelling for a lifecycle of power production from various primary sources. The analyses show that definitely lowest

[1] It seems realistic, since the investor – PGE S.A. – plans building 2 nuclear power plants with total capacity ca. 6000 MWe.

emissions related to power production cycle are generated by nuclear power plants; they are 17 kg CO_2/MWh. It should be emphasised that this amount corresponds to emissions during the entire life cycle, including:

- 8 kg/MWh – related to fuel cycle;
- 5 kg/MWh – related to power plant operation (mainly transport and accompanying infrastructure);
- 4 kg/MWh – related with stages of construction and decommissioning.

Additionally, the table presents data quoted from the document by the European Commission[234], which divides power production-related emissions from individual sources into direct emissions (related to power production) and indirect emissions (related with operation of auxiliary infrastructure, fuel cycle and stage of construction and decommissioning).

Table 4.3.13 Emission of CO_2 from individual power plant types [233] [234]

POWER PLANT TYPE	CO_2 EMISSION [kg/MWh] acc. to [Marheineke, 2000] 233	CO_2 EMISSION [kg/MWh] acc. to [COM, 2008,744] [234]
Brown coal-fuelled power plants	829 - 1054	820-960*
including direct emissions	791-998	725-850 *
Hard coal-fuelled power plant	740-897	
including direct emissions	679-766	
Gas-fuelled power plant	370-417	420-640
including direct emissions	349	350-530
Nuclear power plant, EPR	16-17	15
including direct emissions	5	0

**emissions are given in total for coal-fuelled power plant, without division into brown and hard coal combustion*

Discrepancies in the quoted emissions according to various sources may result from the dates of material publications and available technologies assumed in calculations. Also in case of NPP, emissions largely depend on applied technologies, in case of NPP it involves particularly applied uranium enrichment technology. The quoted study 233 from 2000 is not fully up-to-date, as technological progress in this period allowed for further emission reductions, e.g. AP1000 reactor needs twice less materials that 2nd generation reactors. When quoting emissions of CO_2 in the entire nuclear cycle, literature sources present significant discrepancies from 4 to 20 kg CO_2/MWh. The upper limit is due to diffusion enrichment, consuming a lot of power and thus causing large releases of CO_2 (large for nuclear cycle). The lower limit corresponds to centrifugal enrichment, which requires much less energy. Currently, centrifugal enrichment becomes a preferred technology mainly due to the fact that it is much cheaper and besides emission indicator for CO_2 for nuclear cycle decreases. Therefore, we may assume that in 2020 centrifugal enrichments will be applied as the only technology and emissions will remain at the lowest forecast level.
However, even calculating emission reduction unfavourably for nuclear power engineering - the potential is very significant. Production of 1 MWh in Poland with current power production structure (chapter 6.1: 54% - hard coal, 37% - brown coal, 2% - natural gas) results in emission (OZE emission assumed at 0, conventional power industry emissions at the lowest level possible - assumption of retrofitting production cycles) at the level of ca. 714 kg CO_2. If, according to the Programme ca. 18% of power production will be replaced with nuclear power production, the emission will decrease by ca. 125kg/1MWh, taking into account the entire power production cycle in NPP. It should be emphasised that this is the minimal emission reduction potential (due to the assumptions). However, according to the presented uranium resources and technological capabilities (chapter 4.3.1.1), the initial nuclear cycle phase, producing largest emissions, will be executed outside Poland, therefore **actual reduction of CO_2** emission in Poland would be higher, exceeding **127 kg CO_2/1MWh. Therefore, execution of the Programme indicates potential of reduction of CO_2 emission by ca. 18% in relation to current emission.** Assuming the demand for gross power in 2030 in the amount of 217 TWh – **the entire emission reduction potential** in Poland due to Programme implementation would exceed **27 Tg ($27*10^{12}$g = 27 million t) CO_2.**

With assumptions presented in Polish Power Engineering Policy until 2030, assuming construction of first NPP units in 2020 and obtaining power until 2030 from NPP at the level exceeding 10% of domestic power production and more than 15% share of renewable power, forecast for changes in CO_2 emission to atmosphere shall be as presented in Fig. 4.3.39.
The data in Fuel and Power Demand Forecast until 2030 indicate that despite growing demand for final power, CO_2 emission will be decreasing by 2020 in order to slightly increase later. Growing consumption of renewable power and cogeneration largely affect this state of matters. Introduction of nuclear power in 2020 and constant expansion until 2030 (up to 4.8 GW) will allow to maintain emission in this period by ca. 8.5% below the state from 1990.

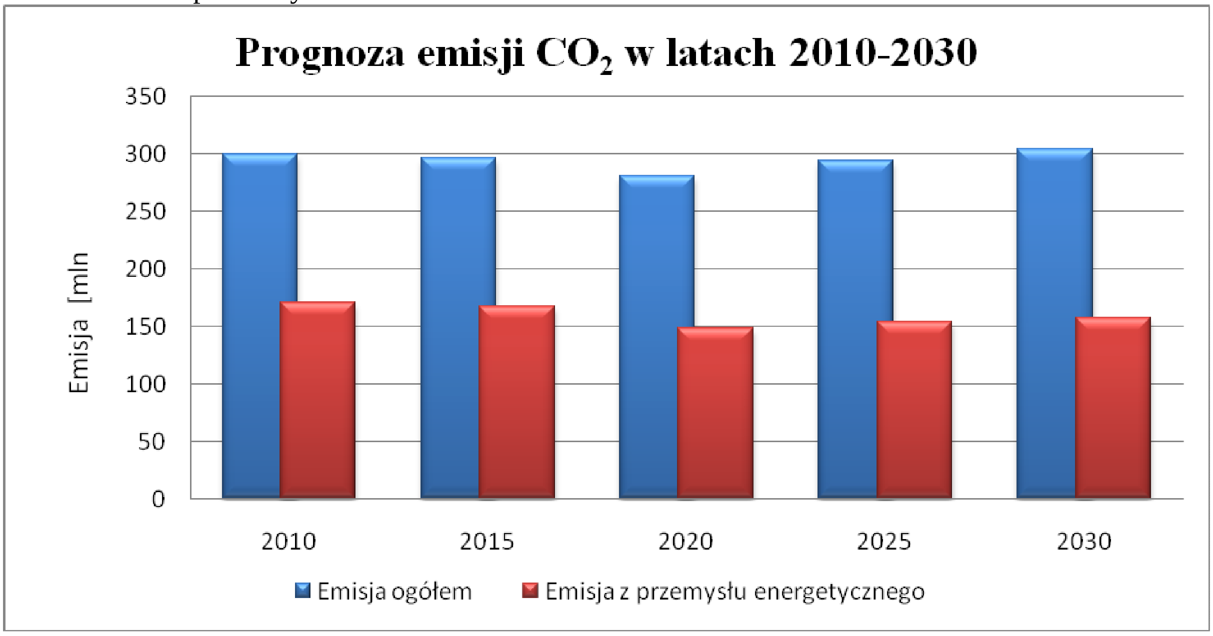


Fig. 4.3.39 Forecast of CO_2 emission based on Fuel and Power Demand Forecast by the year 2030

[Prognoza emisji CO2 w latach 2010-2030 – Forecast of CO2 emission in 2010-2030
Emisja [mln] – Emission [million]
Emisja ogółem – Total emission
Emisja z przemysłu energetycznego – Power industry emission]
In the assessment of potential of greenhouse gas emission reduction in Poland by 2030**Błąd! Nie zdefiniowano zakładki.**, 5 scenarios were presented for potential of reduction of CO_2 emission in power industry. 3 of them forecast introduction of power engineering, the other two focus on gas and renewable power industry. The highest reduction potential is forecasted for variants including construction of nuclear units in Poland. The most effective CO_2 reduction, according to the forecasts, would be achieved according to the scenario providing natural decommissioning of coal-fuelled units and covering the increase in demand for power mainly with: nuclear power - 6 GW (more than provided for in Polish Power Production Policy by 2030) and power from renewable resources - 16 GW (more than provided for in Polish Power Production Policy by 2030). Reduction potential in this case is 120 Tg $C0_2$. The second place with regard to CO_2 reduction belongs to **the scenario executing the assumptions of Polish Power Production Policy by 2030 with forecasted reduction of 97 Tg $C0_2$ (=97 million t CO_2)**.

4.3.4.3.2 Potential of reduction of emissions to atmosphere – SO_2, NO_x and dust

Besides reduction of greenhouse gas emissions, nuclear power plants will contribute to reduction of other emissions to atmosphere, such as: NOx, SO_2 and dust. As with CO_2, during normal operation of nuclear power plant significant emissions of harmful substances do not occur. Those emissions, caused by nuclear power engineering - relatively small compared to plants using fossil fuels - are mainly related to uranium extraction and processing and production of nuclear fuel. Differences in individual emissions during an entire cycle from individual types of power plants are presented in Table 4.3.14. Data presented in the table refer to the entire life cycle, therefore they include emission from fuel extraction and processing through power plant operation to its construction and decommissioning. They are taken from a German study[235], in which the authors analysed emission and raw material consumption for various power sources on the basis of material and power flow modelling for a lifecycle of power production from various primary sources. The analyses show that the lowest emissions of all analysed pollutions related to power production cycle are characteristic for nuclear power plants. It must be emphasised that in terms of total low NPP emissions, their very small part is related directly to NPP operation. Most emissions are related to fuel cycle, mainly ore extraction and enrichment, which will mostly take place outside Poland.

Table 4.3.14 Emissions to atmosphere from individual power plant types [233]

POWER PLANT TYPE	DUST EMISSION [mg/kWh]	NOx EMISSION [mg/kWh]	SO2 EMISSION [mg/kWh]
Brown coal-fuelled power plants	222-263	354-830	232-401
including direct emissions	12-20	300-763	150-318
Hard coal-fuelled power plant	56-197	414-1529	275-1762
including direct emissions	11-20	284-551	142-207
Gas-fuelled power plant	19-75	279-497	80-215
including direct emissions	0	208	0
Nuclear power plant, EPR	25	44-47	66-72
including direct emissions	5	12	18
fuel cycle	14	19-22	30-35
construction and decommissioning	7	12	18

In calculating emission reduction, the most favourable emission parameters for conventional power engineering (assuming its dynamic modernization) and the least favourable parameters for nuclear power engineering were conservatively adopted. Production of 1 kWh in Poland with current power production structure (chapter 6.1: 54% - hard coal, 37% - brown coal, 2% - natural gas) gives emission (OZE emission assumed at 0) at the level of ca. 141 mg of dusts, 349 mg NO_x and 228 mg SO_2. If, according to the assumptions, ca. 18% of power production will be replaced with nuclear power production, the emission will decrease by ca. 21 mg/kWh of dusts, 54 mg/kWh NO_x and 28 mg/kWh SO_2, taking into account the entire power production cycle in NPP. However, according to the presented uranium resources and technological capabilities (chapter 4.3.1.1), the initial nuclear cycle phase, producing largest emissions, will be executed outside Poland, therefore **actual emission reduction** in Poland would be higher, exceeding **23 mg/kWh of dusts, 58 mg/kWh NOx and 34 mg/kWh SO_2**. Therefore, execution of the Programme indicates **potential of dust emission reduction by ca. 16%, NO_x emission by ca. 17% and SO_2 emission by ca. 15%.** Assuming power demand in 2030 at 217 TWh – **the total emission reduction potential** in Poland due to Programme implementation would be ca. **5 Gg (5* 10^9g = 5 thousand t) of dust, 12.6 Gg (12.6* 10^9g = 12.6 thousand t) NOx and 7.4 Gg (7.4* 10^9g = 7.4 thousand t) SO_2.**

The data in Fuel and Power Demand Forecast by 2030 indicated expected large decrease in SO_2 emission. According to those forecasts, we can be almost certain that in 2010 SO_2 emission will be below the emission limit resulting from 2nd Sulphur Protocol, which assumes that by that year we will decrease general SO_2 emission to below 1398 thousand Mg/year. Limits for large fuel combustion facilities adopted during accession negotiations according to Directive 2001/80/WE may be harder to obtain. In 2008, we failed in Poland to keep the limit below 454 thousand Mg/year limit in 2008 r. resulting from stocktaking was ca. 500 thousand Mg[236]) but forecasts in Fuel and Power Demand Forecast by 2030 show a chance for keeping the limits in next years (426 thousand Mg/year in 2010 and 358 thousand Mg/year in 2012). Reduction of SO_2 emission will be largely affected by desulphurization installations mounted in coal and gas power plants and introduction of low emission power sources such as renewable power sources and nuclear power plants. It is expected that by 2030 emissions from large combustion sources will drop to 312 thousand Mg/year.

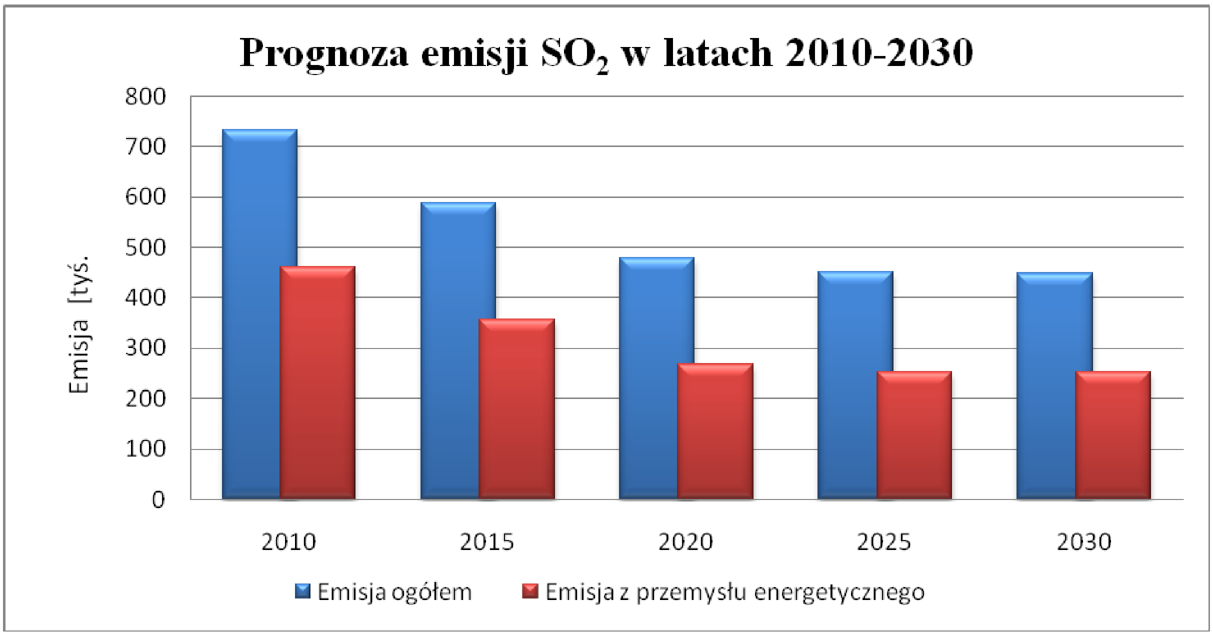


Fig. 4.3.40 Forecast of SO_2 emission based on Fuel and Power Demand Forecast by the year 2030

[Prognoza emisji SO2 w latach 2010-2030 – Forecast of SO2 emission in 2010-2030
Emisja [tys.] – Emission [thousand]
Emisja ogółem – Total emission
Emisja z przemysłu energetycznego – Power industry emission]

Limits of domestic NO_x emission, similarly to SO_2 emission will be kept. 2nd Nitrogen Protocol specifies acceptable 880 thousand Mg in 2010, and expected emission is ca. 786 thousand Mg. In terms of emissions from large power fuel combustion sources, the limit specified in UE Accession Treaty in 2008 was kept (the limit was 254 thousand Mg, and emission in 2008 was ca. 243 thousand Mg[236]). Keeping the limit in the following years (2010 - 251 thousand Mg, 2012 - 239 thousand Mg) is related to forecasted economic slowdown, due to which power demand will fall[237]. Only after 2015 significant reduction of NO_x emission will be visible, caused among others by introduction of increasing number of renewable energy sources and first nuclear units in 2020.

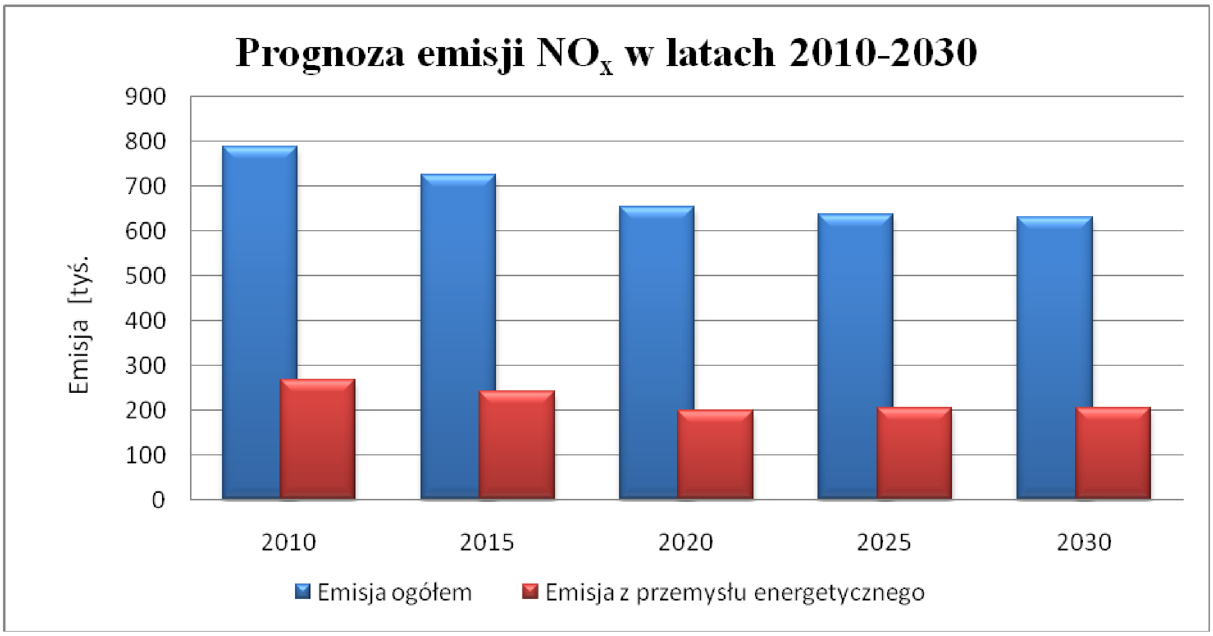


Fig. 4.3.41 Forecast of NO_x emission based on Fuel and Power Demand Forecast by the year 2030

[Prognoza emisji NOx w latach 2010-2030 – Forecast of NOx emission in 2010-2030
Emisja [tys.] – Emission [thousand]
Emisja ogółem – Total emission
Emisja z przemysłu energetycznego – Power industry emission]

In the following years, dust emission will decrease every year. The factors causing those changes will be similar as with SO_2 reduction. However, the percentage share of power industry in general emission will increase. This is due to significant emission reduction outside the power industry, among others by decreasing coal consumption in small combustion sources.[237]

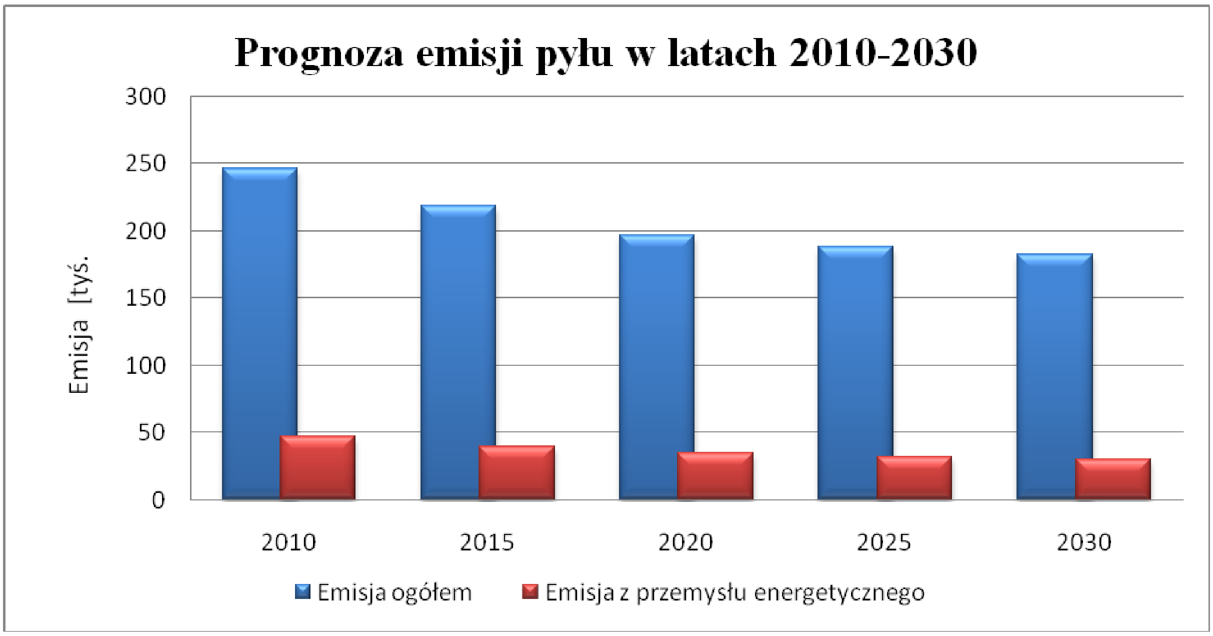


Fig. 4.3.42 Forecast of dust emission based on Fuel and Power Demand Forecast by the year 2030

[Prognoza emisji pyłu w latach 2010-2030 – Forecast of dust emission in 2010-2030
Emisja [tys.] – Emission [thousand]
Emisja ogółem – Total emission
Emisja z przemysłu energetycznego – Power industry emission]

4.3.5 Impact of noise

For EPR unit (for Europe, Flamanville 3 – FA3 is referential) it was assessed that noise level during operation, not including noise background and specific topography, will not exceed **45 dB(A) in the distance of 350 m** from primary noise sources. **Therefore, operation of the nuclear power plant will not increase the level of noise in the environment to a considerable extent.**

Noise emission is a local issue for large natural draught cooling towers and all mechanical cooling systems. Levels of non-attenuated sound fall between 70 dB(A) for natural draught cooling towers to ca. 120 dB(A) for mechanical draught towers. Those discrepancies are due to various types of equipment and various measurement places, since the measurement produces different values at air inlet and outlet.

Three main noise sources in cooling systems are:

- fans (rotor, transmissions, drive) - all forced draught cooling towers;
- pumps - all cooling water systems;

- liquid drops falling on water surface in water pans - only in wet cooling towers.

Noise generation may be direct or indirect. Sound is directly generated by:

- air intakes;
- air discharges.

Indirect sources are:

- fan drive motors;
- outlet screens from fans and linings in cooling towers.

In wet cooling towers, noise is generated only due to falling water drops (with natural draught or falling drops and operation of mechanical equipment. Generally, non-attenuated nose from fans dominates compared to noise generated by falling drops. Noise emission does not depend on the size of wet towers.

In case of wet natural draught cooling towers, the noise **in the 100 m radius** may reach **60 dB(A)**, and in case of hybrid cooling towers, noise level at the same distance reaches **70 dB(A)**.

4.3.6 Impacts related to the land take

4.3.6.1 Exclusion of biologically active area and reduction of water infiltration

A nuclear power plant is a facility that occupies a large area. Therefore, its construction and operation involves exclusion of a large bioactive area. Depending on a specific NPP site, it usually is an agricultural area or meadow ecosystem. Deforestation may be also necessary in the area of the planned development.

The actual built-up area depends on the adopted technology – the type of reactor and installation of cooling towers. The largest area occupation takes place in case of installation of EPR reactor. The figures below present the planned land development for a power plant with EPR and AP1000 reactor (Fig. 4.3.43, Fig. 4.3.44).

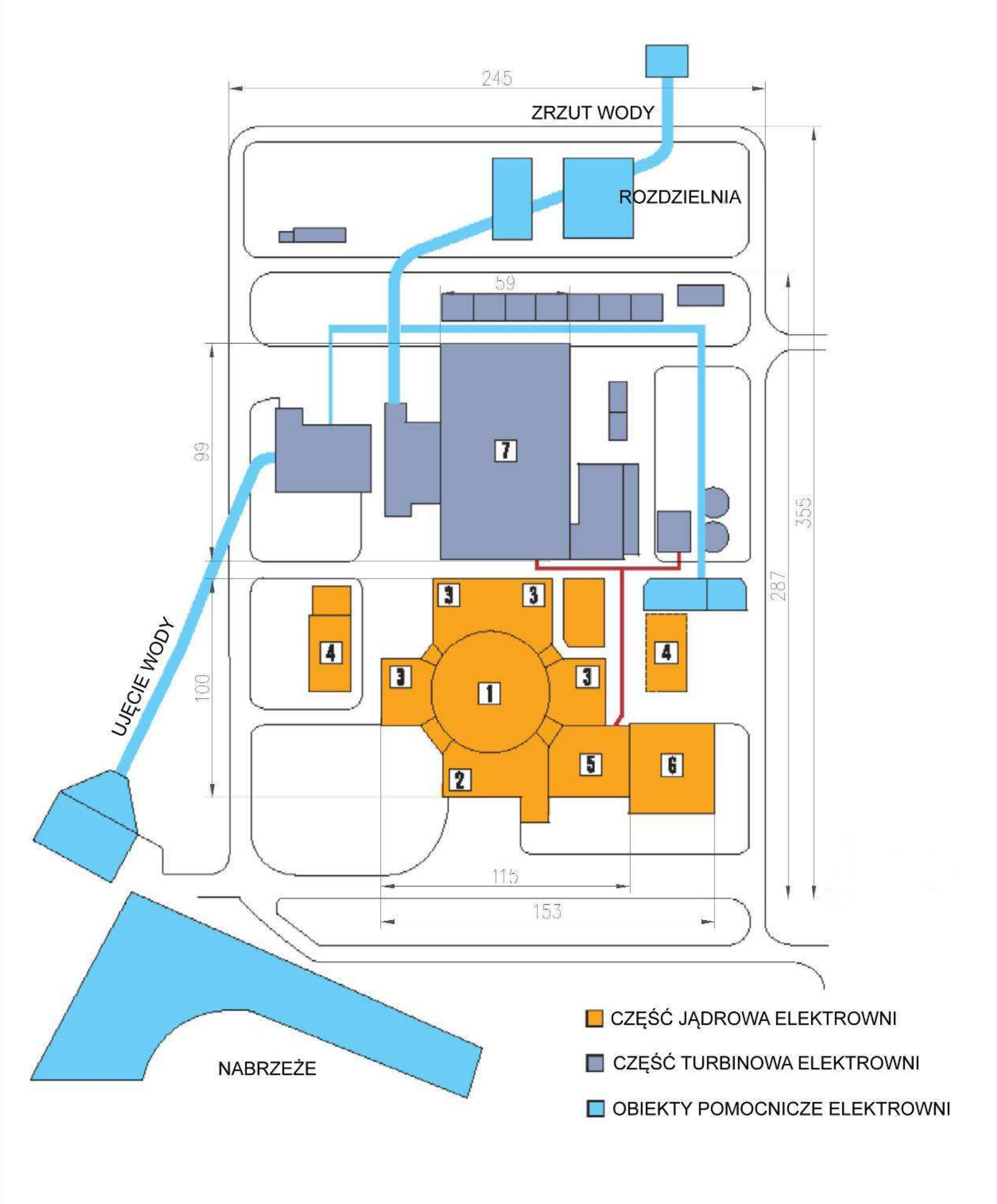


Fig. 4.3.43 Model land development for a nuclear power plant area with EPR reactor

1 - reactor building; 2 – fuel building – fresh and spent fuel; 3 – safety system buildings – UACR and emergency makeup water; 4 – emergency diesel generator and emergency power supply buildings; 5 – auxiliary nuclear building; 6 – waste building, 7 – engine room.

[Zrzut wody – water discharge
Rozdzielnia – Switching station
Ujęcie wody – water intake
Nabrzeże – Shore
Część jądrowa elektrowni – Nuclear section
Część turbinowa – Turbine section

Obiekty pomocnicze – Auxiliary facilities]

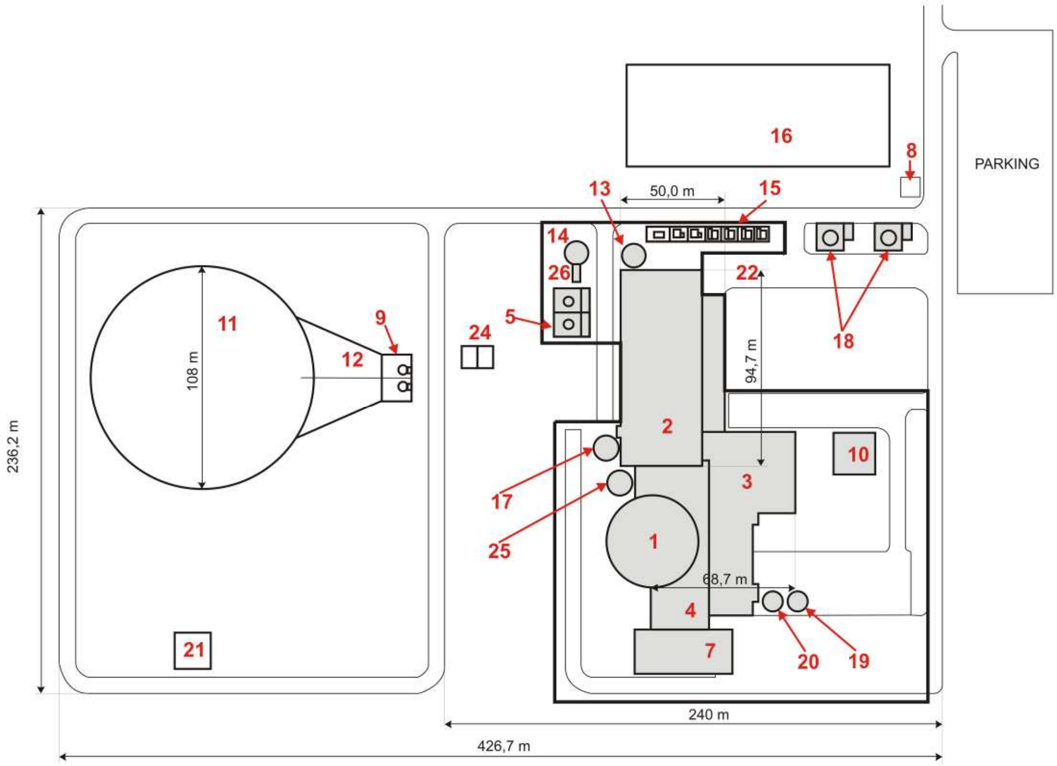


Fig. 4.3.44 Model land development for a nuclear power plant area with AP1000 reactor

1 – Containment / containment building, 2 – engine room, 3 – additional building (outhouse), 4 – auxiliary building, 5 – service water system coolers, 7 – radioactive waste building, 8 – entrance to power plant premises, 9 – water intake for cooling water cycle pumps, 10 – diesel generator building, 11 – cooling tower of cooling water cycle, 12 – water intake channel for cooling water cycle, 13 – fire water storage tank /settling tank, 14 – – fire water storage tank, 15 – transformer zone, 16 – switching station, 17 – condensate storage tank, 18 – diesel oil storage tank for generators, 19 – demi water storage tank, 20 – boric acid storage tank, 21 – hydrogen storage tank zone, 22 – engine room deposition zone, 24 – waste water retention tank, 25 – auxiliary water storage tank for passive containment cooling, 26 – diesel fire water pump / railing.

On the basis of presented model diagrams, it may be estimated that minimum (estimated) area demand (per 1 power unit) is as follows:

- EPR (Fig. 4.3.43): $245m \times 355m \approx 9ha$
- AP1000 (Fig. 4.3.44): $240m \times 236m \approx 6ha$
- cooling tower (Fig. 4.3.44): $236m \times 187m \approx 4ha$

For instance, 1 EPR OL3 unit in Finland occupies ca. 12 ha. It may be assumed that the entire power plant area, assuming construction of 2 EPR units with infrastructure will take ca. 40ha. As no detailed location analyses have been performed yet including the determination of land use, these are only estimates based on previous projects involving the construction of similar installations.

Due to sealing a significant area, infiltration will be limited, which may lead to decrease in underground water resources. Assuming estimated hardened surface to be 40 ha, mean annual precipitation in Poland at 600mm, and mean infiltration for Poland at 18%, estimated decrease in underground water supply was calculated at ca. 43.2 thousand m^3. The value should be calculated separately for specific data upon site and NPP construction technology selection, since for a specific site, annual precipitation and soil infiltration may differ, whereas technology selection determines the size of occupied area.

Amount of water by which the underground supply will be decreased will mainly get to surface water reservoirs. Rain water management is as follows:

- the power plant area is drained - usually with a ditch, then water is discharged to a lake or river);
- NPP area is drained with drainage ditches and rainwater sewage system;
- roof drainages and building drainages are usually directed to this sewage system, as well as neutralized sewage from treatment station (potable and demi water);
- rain water from sewage system is treated in rain and industrial water treatment station, after treatment water is discharged to the reservoir.

Therefore, for a specific site, impacts must be considered related to limiting underground water supply and additional surface water supply, including existing hydraulic connections between individual water-bearing levels.

4.3.6.2 Impact on availability of natural resources

When examining impact of nuclear power engineering development in Poland on natural resources, one must consider two direct impact options: limiting access to mineral deposits due to foundation of the entire power plant complex and direct impact on natural resources demand and application in power industry.

Due to the growing power demand in Poland and planned construction of a nuclear power plant, an issue arises of nuclear fuel supply to power plants. The balancing and availability analysis of radioactive deposits in Poland indicates that they are rather limited and economically non-viable, and the demand will rather be covered from external sources. We can expect that the development of nuclear power will result in a significant reduction in the demand for fossil fuels – which may decrease from 20% to 25% depending on the adopted option [238].

When planning investment sites, one should include an option of mineral deposits in the area of future investment. Upon analysing the available distribution maps for hard, brown coal and peat deposits, petroleum and natural gas deposits, metal ore and chemical deposits, solid rock and ceramic and refractory material deposits, it may be concluded that in the planned investment area, utility mineral deposits do not occur.

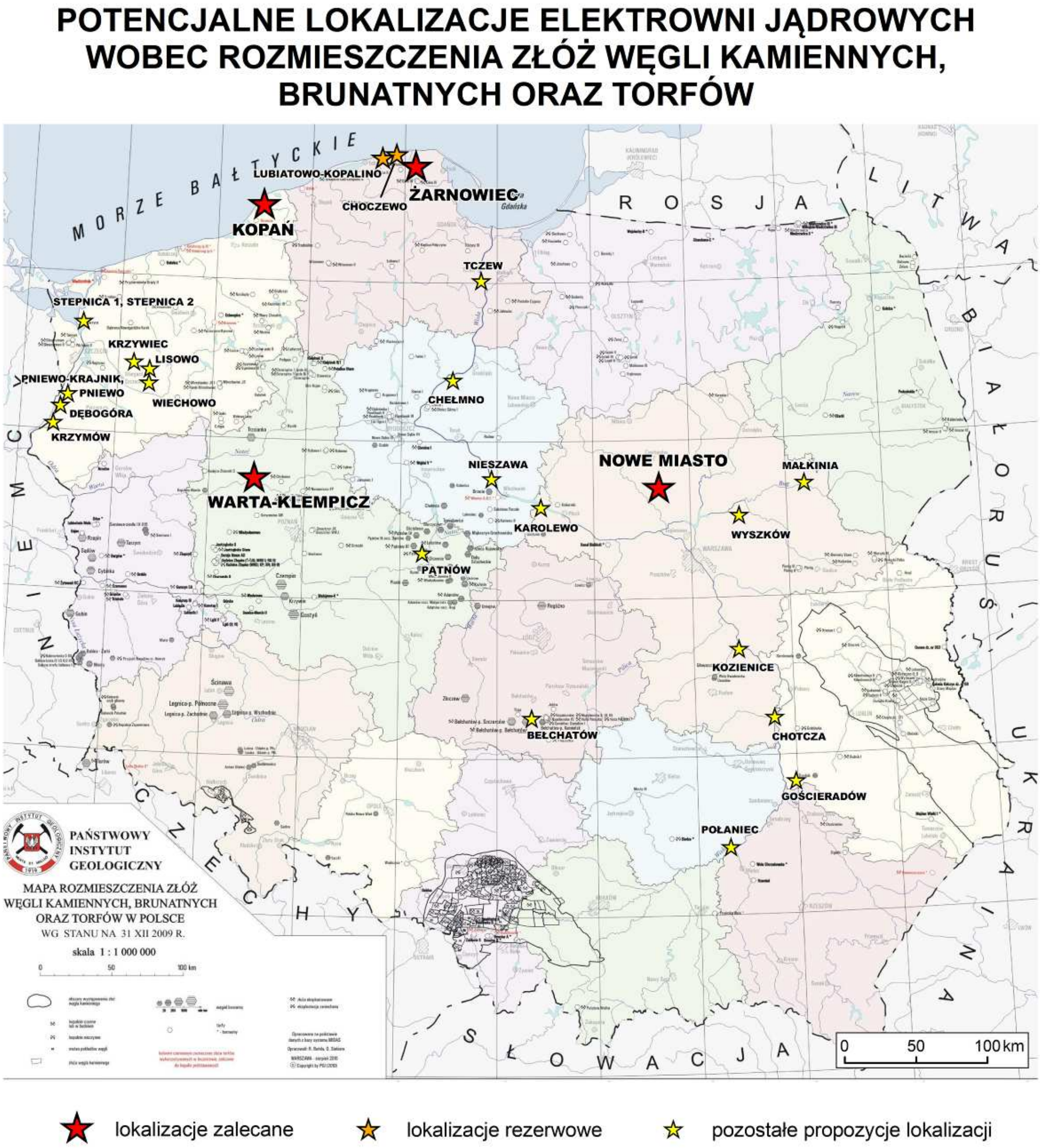


Fig. 4.3.45 Distribution map of hard coal, brown coal and peat deposits in terms of potential nuclear power plant sites (source: http://old.pgi.gov.pl/surowce_mineralne/).

[POTENTIAL NUCLEAR POWER PLANT SITES AGAINST DISTRIBUTION OF HARD COAL, BROWN COAL AND PEAT DEPOSITS
Recommended locations
Reserve locations
Other location proposals]

POTENCJALNE LOKALIZACJE ELEKTROWNI JĄDROWYCH WOBEC ROZMIESZCZENIA ZŁÓŻ ROPY NAFTOWEJ I GAZU ZIEMNEGO

lokalizacje zalecane
lokalizacje rezerwowe
pozostałe propozycje lokalizacji

Fig. 4.3.46 Distribution map of petroleum and natural gas deposits in terms of potential nuclear power plant sites (source: http://old.pgi.gov.pl/surowce_mineralne/).

[POTENTIAL NUCLEAR POWER PLANT SITES AGAINST DISTRIBUTION OF CRUDE OIL AND NATURAL GAS DEPOSITS
Recommended locations
Reserve locations
Other location proposals]

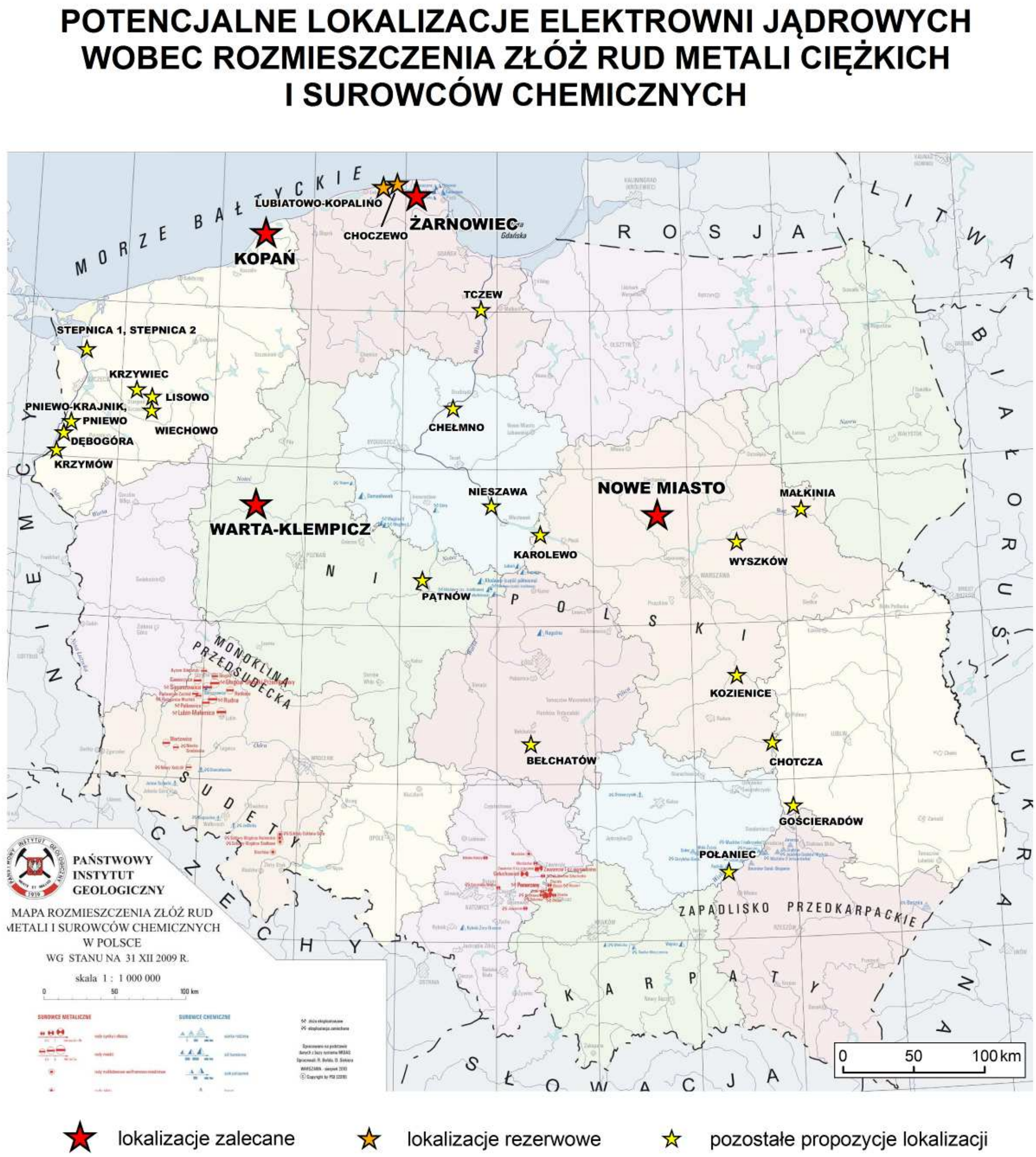


Fig. 4.3.47 Distribution map of metal and chemical deposits in terms of potential nuclear power plant sites (source: http://old.pgi.gov.pl/surowce_mineralne/).

[POTENTIAL NUCLEAR POWER PLANT SITES AGAINST DISTRIBUTION OF HEAVY METAL ORE AND CHEMICAL DEPOSITS
Recommended locations
Reserve locations
Other location proposals]

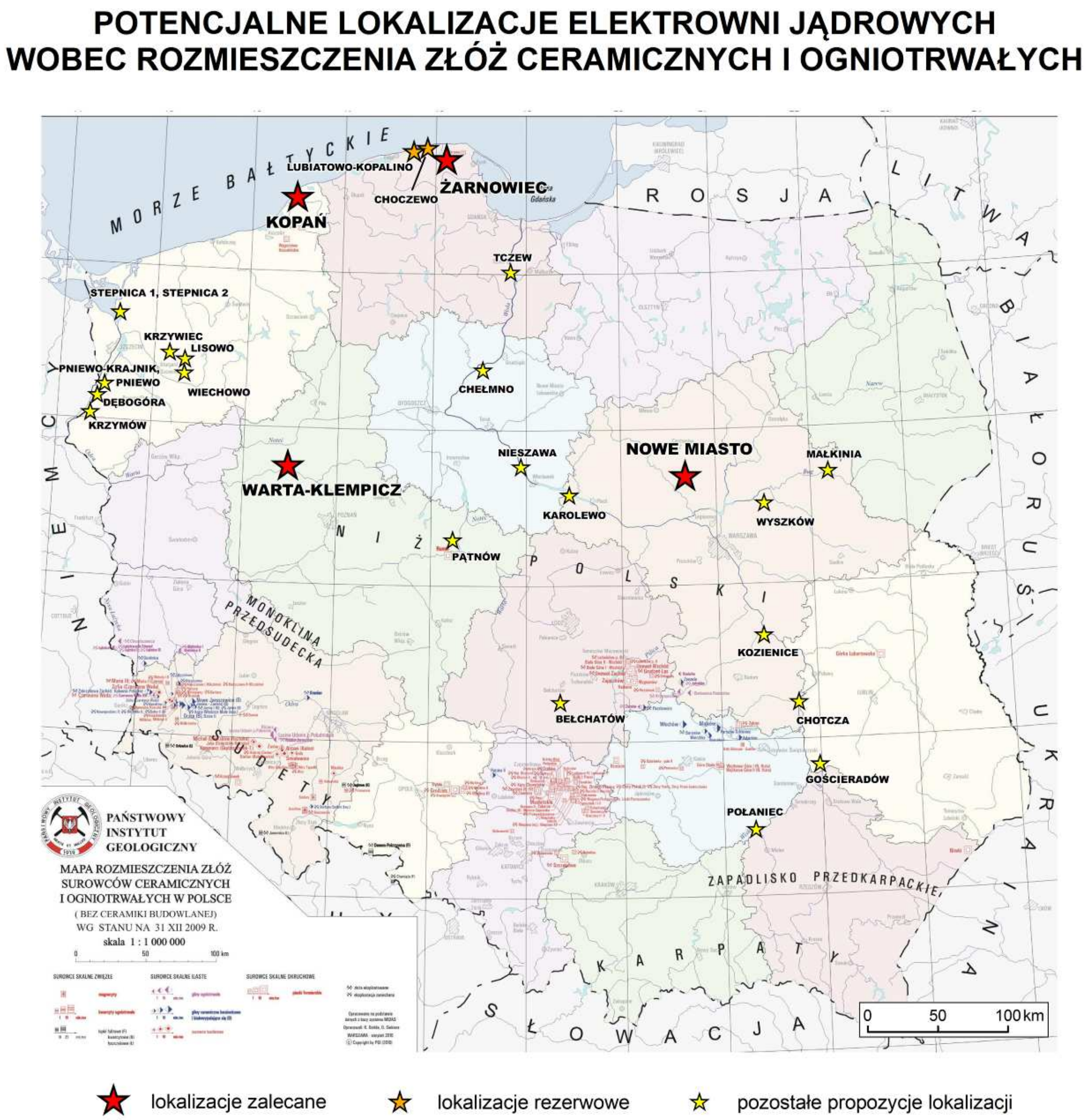


Fig. 4.3.48 Distribution map of ceramic and refractory deposits in terms of potential nuclear power plant sites (source: http://old.pgi.gov.pl/surowce_mineralne/).

[POTENTIAL NUCLEAR POWER PLANT SITES AGAINST DISTRIBUTION OF CERAMIC AND REFRACTORY DEPOSITS
Recommended locations
Reserve locations
Other location proposals]

Fig. 4.3.49 Distribution map of firm rock deposits in terms of potential nuclear power plant sites (source: http://old.pgi.gov.pl/surowce_mineralne/).

[POTENTIAL NUCLEAR POWER PLANT SITES AGAINST DISTRIBUTION OF FIRM ROCK DEPOSITS
Recommended locations
Reserve locations
Other location proposals]

4.3.7 Impact of the infrastructure development

4.3.7.1 Condition of Polish infrastructure and necessary directions of changes (specified in PSE strategy)

Polish high-voltage power supply grid is made up by grid infrastructure (Fig. 4.3.50 state as of 2009), including the following facilities:

- 236 lines with total length of 13053 km, including one 750 kV, 114 km long, 68 lines with 400 kV voltage of total length 5031 km and 167 lines with 220 kV voltage, of total length 7908 km,
- 106 high voltage stations; 174 LV/110 and LV/LV kV transformers with total capacity of 38 450 MVA.

Fig. 4.3.50 Power supply grid in Poland

[POTENTIAL NUCLEAR POWER PLANT SITES AGAINST EXISTING HIGH VOLTAGE POWER SUPPLY GRID
Recommended locations
Reserve locations
Other location proposals]

Territorial scope of power supply transmission system covers entire Poland. The greatest grid density occurs in southern part, and the lowest - in north-eastern part.

Needs in terms of transmission grid expansion result from forecasts of increase of power demand, requirements of recipients in terms of power supply reliability and investments necessary for power connection and output from new production units. Needs in terms of transmission grid expansion also result from EU directives concerning RES share in power production and requirements related with expansion of cross-border connections. The future costs of transmission system operation in market conditions will be highly affected by decisions made today, concerning the expenditures on its development. The aim should be to minimize total power production and transmission costs.

Difficulties in expansion of transmission grid caused that grid density in the North and in relation from The North to central part of the country is insufficient. Electric power market based on the concept of trading "above actual grid", implemented at a later time, introduced price competition disturbances and lack of stimuli for rebuilding and diversification of generation sources. To reduce the effects of this situation, transmission grid operator initiates and performs works aiming at improvement and development of market mechanisms. In long-tem perspective, the most significant directions of development of market mechanisms should include sending multi-component economic signals to production source investors and implementation of principles of power trade consistent with actual, physical character of power supply system.

Taking into account:

- total length of 220 kV line - 7908 km,
- plans of voltage change on those lines to 400 kV,
- commonly known regulatory obstacles,

actions are necessary aiming at acceleration of rebuilding and retrofitting 220 kV line and simplification of formal and legal procedures in the investment process.

In large sets of lines, facilities and devices, decreasing technical condition takes place gradually with their age. Also, age of facilities is related to materials and technologies used in their construction (affecting ability to perform functions in the predicted life cycle of a facility). Therefore, the basic parameter in synthetic assessment of technical condition is age of a line, facility or device, including its ability to operate.

400 kV transmission lines.

Most lines were built in the 1970s and 1980s. Some grids exceeding the age of 40 require urgent modernization. Modernization is difficult due to lack of option of line shutdown.

220 kV transmission lines.

Age structure of 220 kV lines indicates necessity of modernization. Expansion and modernization programmes prepared by PSE Operator SA are based on the concept of 400 kV grid development along the routes of existing 220 kV lines. After their execution, structure of line length according to voltage will be changed.

Transformers

In age structure o transformers, 30, 40-year old units have large part. In previous years, a stage programme of transformer units replacement was executed. Further replacement is being planned, together with the programme of adding transformer units and purchase of new generation transformers. this is necessary in order to renew the transformer population, to cover the demand and increase reliability of power supply to recipients.

The analyses show that most facilities may be operated for another several years. This expected useful life is safe in the case of network facilities such as transformer stations, switches, and 400 kV line components. However, it is too short for 220 kV lines.

Implementation of power network investments, including (but not limited to) the connection of nuclear power plants, needs several years to complete the preparation and implementation phase. According to regulations currently in force, this period is about 7 years.[239]

4.3.7.2 Infrastructure necessary for proper operation of nuclear power plants

4.3.7.2.1 Power supply grid

Power outlet

In construction of a nuclear power plant we must include necessity of incurring significant grid investments related to expansion, modernization and construction of new 400 kV lines and construction of appropriate 400 kV power plant stations.

New grid investments for the purposes of power outlet from nuclear power plants require several years of preparation and execution. In view of current legal regulations, about 7 years will be needed to conduct the entire process.

To lead out 1600 MW from a nuclear power plant, the following are needed:

1) construction of 400 kV station

2) construction of two 400 kV lines

Internal load supply during construction and regular operation

During nuclear power plant construction and regular operation, power supply at the proper level is necessary by means of local power supply grid and from emergency power supply systems (*"Ultimate Emergency Diesel Generators"*). Substations are needed to provide required voltage during construction and operation stages.

4.3.7.2.2 Analysis of environmental impact due to expansion of power supply infrastructure

Power supply infrastructure of a NPP mainly consists of 400/110 kV power stations and 400kV lines (power outlet) and 110 kV lines (emergency internal load supply). With 1600 MW unit, to provide power supply safety and power outlet, the following are necessary:

- construction of 400/110 kV station,
- construction of at least two transmission lines 400 kV and a 110 kV line.

Apart from that, feeding fail proof power supply from MV grid (1o kV) is also necessary, as well as construction of proper power supply grid at construction site.

Positive impacts of these investments include the creation of favourable conditions for electricity transmission.

Negative impacts in the implementation phase will include an increase in the level of noise, exhaust gases and dusts generated by construction machinery and equipment, as well as the removal of trees and shrubs along the route of the power line and in sections of construction sites.

In the operation phase, 400kV and 110 kV equipment may generate the following environmental impacts:

- permanent area occupation for construction of power poles and stations 400kV and 110kV,
- creation of limited use zones,
- constant electromagnetic field emission,
- disruptions of radio and TV reception,

- generation of acoustic noise (maximum measured noise for 400 kV line is 48 dB).
- permanent and significant changes in the landscape (the poles will be 35-60 m tall, and the smallest possible distance of working cables from the ground is 7.67 m),
- permanent hazard to birds and bats.

Acceptable levels of electromagnetic fields and manners of observing them are specified by Ordinance of Minister of Environment of 30th October 2003 on acceptable electromagnetic levels in environment and manners of verification of observance of the same (Journal of Laws No. 192 item 1883).

The alternative could be to apply 400 kV cable lines, laid in special channels and properly insulated. This is however very costly and thus unrealistic at a larger scale. Sometimes at small distances cables are used - between unit transformers and power plant power station, when it is necessary due to specific spatial arrangement of a line (e.g. crossing). In cable technology, we eliminate the electric shock hazard or negative impact of lines on the landscape, but at the same time we increase exposure to electromagnetic fields and potential disruptions in operation of electronic devices.

Necessary expansion of 400 kV grid is described in other chapters of the Forecast and mentioned in Chapter IX of Polish Nuclear Programme; it tackles the issues of preparation and required changes in domestic transmission system. Due to the scope of changes, a document must be updated titled "Development Plan in terms of covering current and future power demand for the years 2010-2025".

The document will be subject to strategic assessment of environmental impact, in terms of which environmental impacts of infrastructure expansion will be evaluated. This approach also arises from Article 5.2 of SEA Directive:

„Report[…], made according to excerpt 1, contains information which may be rationally required, including […] content and level of specification of a plan or programme, its stage in decision-making process and scope in which certain issues may be more appropriately evaluated at various process stages, <u>in order to avoid multiplication of assessment</u>"

In environmental impact forecast for development plan in terms of meeting current and future power demand, particular attention must be paid to collision with Natura 2000 areas and analysis of potential alternatives.

Moreover, during the investment process procedure of environmental impact assessment will be performed, including N2000 areas. This multi-stage procedure should guarantee minimising potential significant impacts. The procedure should examine both effects of grid expansion and effects of nuclear power plant construction.

4.3.7.3 Other infrastructure

4.3.7.3.1 Water intake

Construction of a power plant (not only nuclear) requires providing sufficient amount of cooling water.(**For a nuclear power** unit with net capacity of **1000 MW_e** expenditure of cooling water, with 10 K heating, is ca. **50.2 m^3/s** (with 12 K: ca. 41.8 m^3/s).

4.3.7.3.2 Transport

Expansion of local road grid and railway transport to a power plant.

Technical transport for NPP. During investment process, significant intensification of heavy road and railway transport will occur in the NPP area. After the power plant commissioning, traffic intensity will decrease. Transport of utility parts and periodical transport of spent fuel to a processing plant or deep geological repository will continue (3rd generation reactor of nuclear power unit with capacity of ca. 1000 MW_e uses less than **20 tonnes** of nuclear fuel **-** i.e. one train car per year).

Passenger transport. Operation of one unit will employ ca. 800 people. Therefore, if we choose French reactors with capacity 1600 MW, the employment will include ca. 1500 people in one power plant. If we decide to use American reactors with capacity 1000 MW, the employment will include ca. 2500 people.

The construction will also stimulate the economy. Construction of a nuclear unit in Olkiluoto, Finland employs 1500 companies and 4000 people, many of them from the nearby commune.

In case of NPP sites near big rivers and sea coasts, there is an option of building harbours capable of reception and unloading large-size and heavy devices and structural elements.

4.3.7.3.3 Social facilities.

During construction and regular operation, construction of facilities providing proper operation of the entire site back-up facilities will be necessary, also at the further stage of regular power plant operation.

4.3.7.3.4 Analysis of environmental impact due to expansion of other infrastructure

Development of the infrastructure will require the use of certain environmental resources (especially water and energy), just as for any other large industrial plant. Passenger and technical transport vehicles will generate additional emissions of exhaust gases to the environment. However, these amounts will not be considerable. We should note that passenger traffic will be more intensive than traffic of technical vehicles, given the low demand for raw materials but high demand for workforce (high number of employees on site).

Operation of the infrastructure will also produce waste. Annual amount of conventional waste for PWR unit with net capacity **1000 MW_e** were specified on the basis of estimates for EPR unit [UK EPR: PCER, Chapter 3]. They are:

- 294 Mg of chemically neutral and municipal waste,
- 63 Mg of hazardous (non-radioactive) waste.

4.3.8 Impacts on the landscape

Operation of a nuclear power plant must be examined in terms of its impact on the landscape. Definition of a landscape seems intuitively clear for everyone, however specialists debate the proper specification of this basic notion. According to Ostaszewska[240], in Polish the word "landscape" has two meanings: firstly, it denotes the earth surface as seen from a certain point (surrounding view), secondly - presentation of real (or fantastic) world in any technique. The quoted author reviewed several functioning definitions of landscape, suggesting referring to landscape as a system of connected natural components occurring on and near Earth's surface. In this concept, examining landscape issues should involve both its abiotic components (geological structure, relief, soils, water) and biotic components (flora, fauna), creating a certain local geocomplex. Since in the Report on nuclear power industry impact on individual environment components they are subject to separate evaluation, the landscape will be treated as a whole, in compliance with older views, rather as a subjective impression of an observer. In such an approach, landscape was referred to by Jermołajew (cf.: Kalesnik[241]) as geographical space or geosphere.

Impact of the nuclear power plant on landscape is closely related to the location of the project and type of land use in the neighbouring areas. Therefore, it depends on the scale of the investment, cubage of buildings and facilities, and the associated infrastructure, as well as the urban layout and components of the natural environment in the area. Therefore, the expected impacts cannot be precisely defined at this stage. Still, we may analyse impacts recorded for the adopted reference projects.

We may venture a statement that impact of nuclear power plants on landscape is somehow an individual matter for a recipient, depending on their aesthetic notions and preferences. It is believed that the so-called beauty models are not constant, they remain specific for specific cultural cycles and period of creation. Also historical changes of the notion of ugliness are closely related to analogous changes in perceiving the notion of beauty. Here however, we enter the sphere of unresolved philosophical reflections. The notion of supremacy of natural beauty over manmade creations is also popular and perhaps true. However, the situation of actual shaping natural elements by humans, since historical times, poses further questions concerning the meaning of this statement. Polish legislation formulates the definition of landscape values. Pursuant to Environment Protection Act of 16 April 2004[242] these are ecological, aesthetic or cultural values of the area and related relief, formations and components of nature, shaped by natural forces or human activity.

It seems beyond any doubt that all large investments in the power sector change the existing spatial arrangement. These changes include single point, surface, and linear objects (such as roads or transmission lines). Their vertical range (and thus visibility from a distance) is also diversified. Given that a qualitative evaluation of this interference is difficult, we could use quantitative data for a project with a comparable or generally high electricity production capacity (e.g. in terms of the area occupied by the project or the area where raw materials are extracted). The following examples (Fig. 4.3.51) illustrate different methods of presentation of various projects and how it influences the way we perceive these projects. Supporters and opponents of various types of investments often use quite different images – photographs of landscapes.

In Poland, some areas with high landscape values are protected as landscape parks and, to a lesser extent, natural and landscape complexes[243]. Landscape parks serve not only protection of natural values (including landscape values - maintaining their characteristics), but also historical and cultural values. In those places, economic activity is allowed, although limited, e.g. enterprises of significant environmental impact are prohibited, as well as ground works permanently distorting the area or building new structures in the 10m wide area from the river banks, lake shores and other water reservoirs (except facilities for water tourism, water management or fishery). The domestic landscape parks created so far are not directly adjacent to the recommended and reserve nuclear power plant sites (see site variant analysis). Those structures should not therefore result in deterioration of quality of those areas. Another section of the Report also discusses landscape parks and forms of environment protection in Poland.

POWER PLANTS FIRED WITH BROWN COAL

Fig. 4.3.51 Landscapes in the area of various types of power plants – examples of one-sided presentation[244].

To some extent, operation of a nuclear power plant depends on good communication – including transport by road or rail and power lines. The first two problems seem marginal, given that fuel deliveries and removal of spent fuel are not too frequent, and the number of people who come to work at the power plant is not too high. However, high-capacity transmission lines and the associated infrastructure will definitely change the original spatial arrangement. Still, this effect is observed for all large electricity-generating facilities, irrespective of the technology, and in all places where transmission lines are installed – even if there is no power plant in the area. The following photographs illustrate examples of the siting of large facilities (nuclear power plants) in the surrounding landscape, in accordance with the principle of keeping the negative impacts on the landscape at a minimum.

Fig. 4.3.52 Nuclear power plant in Neckarwestheim (Germany)

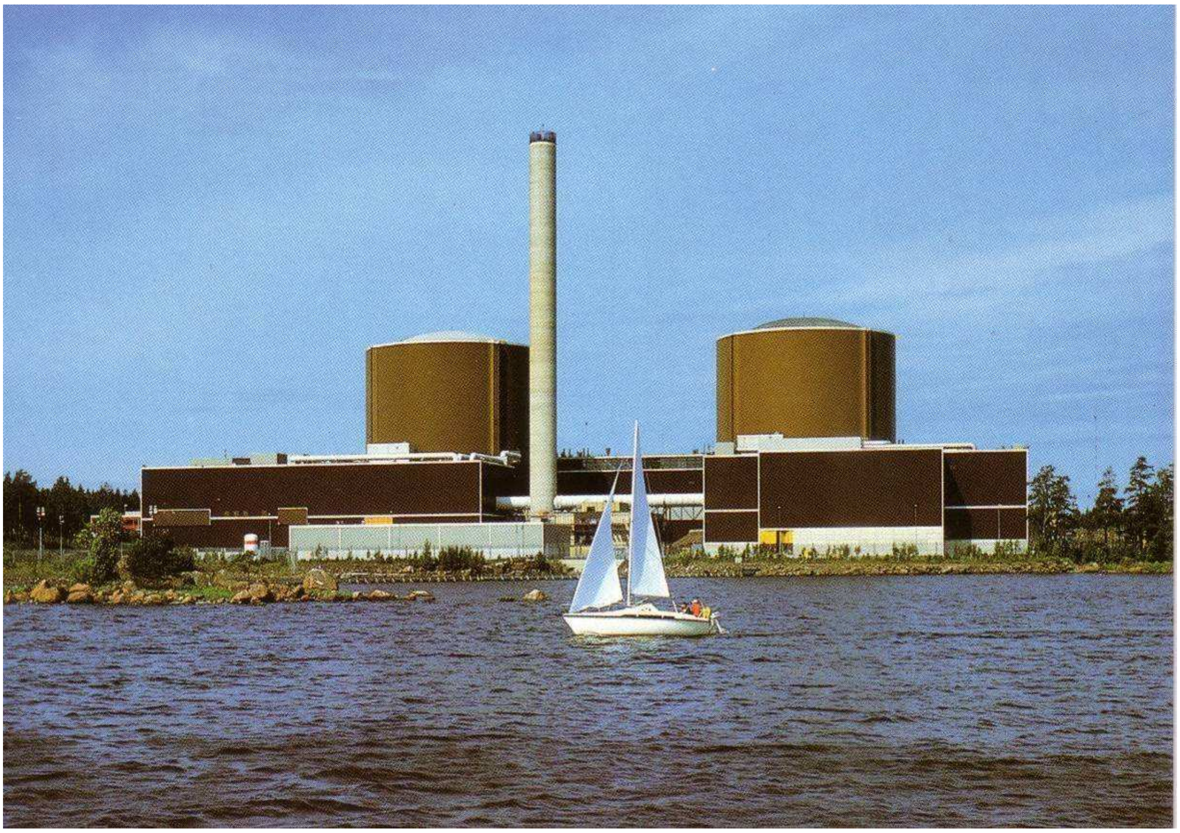


Fig. 4.3.53 Nuclear power plant in Loviisa (Finland)

Experience of other countries indicates that construction of nuclear power plants, even in attractive, historically significant regions, does not have to decrease the value of those areas, on the contrary, it may increase tourism, and due to improvement of road infrastructure it may improve access to those areas. An example can be the power plant in Belgium, erected in the vicinity of historical town of Huy, on the opposite bank of the river Meuse. According to town authorities, adverse effect on tourism was not observed. In fact, it was just the opposite. Trips organised by the power plant authorities attract new category of people to the town, which affects development of trade and services. It was also shown that those people come to the region as holidaymakers[245]. Also in France, country where main source of power in nuclear power, may power plants are situated in culturally valuable regions, e.g. in the valley of the river Loire with historical castles and nearby power plants in the towns of Chinon, Saint-Laurent, Dampierre and Belleville.

Fig. 4.3.54 Belleville power plant situated in the valley of the river Loire (source: Areva)

4.3.9 Socio-economic effects

The impact of a nuclear power plant must be also analysed in terms of its operation as a very important production facility. Certainly, its construction will have high economic significance for the commune where it is located and for adjacent communes, in terms of:

- higher value of land in the area,
- increased income of the municipality,
- improved infrastructure,
- lower unemployment rate,
- economic revival in the region,
- increased safety of power supply in the region.

4.3.9.1 Higher value of land in the area

At first, location of a nuclear power plant may cause decrease in land value - people, fearing harmful effects of the power plant will not settle in the neighbouring villages and municipalities. However, taking onto account that construction of a power plant involves employment of large numbers of workers, both at the construction and operation stage, and that the residents will not be able to satisfy the employment demand, inflow of population is expected and, what follows, increase demand for land and residence. This will increase value of real estate. Furthermore we may assume that increasing awareness of Polish society in terms of actual threats of nuclear power plant operation will bring about increase perception of advantages of living in the area.

The power plant in the Belgian town of Huy may serve as an example. In October 2009, the Senate Office conducted a questionnaire directed to the parliaments of the European Council member states and Canada, USA and Israel, concerning the attitudes of local communities to location of nuclear power plants in their area.

Authorities of Huy stated in response that in this area, value of real estate, including apartments and land, increased due to economic boost caused by location of the power plant.[245].

4.3.9.2 Increased income of the municipality

Construction of the power plant will greatly improve financial condition of the municipality. Even the Polish example shows that mining and power industry affect income of the municipalities. In 2007, the richest commune in Poland was Kleszczów in Łódzkie province. Its income was three times higher than the commune in the second place. Kleszczów receives high income due to its brown coal mines and the power plant located there.[246]

There are many examples of increasing income of administrative units where a nuclear power plant was located. In Europe, the Belgian town of Huy may serve as an example, with its significant increase of income on tax, related to increase in population, increase in salaries of the power plant employees, development in building engineering and fees paid by the power plant, which annually pays ca. 30 million Euros of national and regional taxes, half of which goes to municipal budget. Operator of nuclear power plant in Olkiluoto (Finland) paid more than 4.2 million Euros in tax in 2007 on real estate title, the nuclear power plant in Flammanville (France) pays 25 million Euros every year in local taxes.

The situation is similar in the USA. Until 2002, budgets of the counties located near Indian Point NPP and state budget received more than 49 million dollars on taxes paid by the power plant and taxes paid by other companies related with power plant commissions and investments.[247]

4.3.9.3 Improved infrastructure

Construction of a nuclear power plant involves expansion of necessary infrastructure, such as roads, water and sewage system, power supply grid. These investments are necessary for the power plant operation, but at the same time they increase comfort of life for the residents. Temelin, Czech Republic may serve as an example. Two waste treatment plants were built there on the river Vltava for the needs of the nuclear power plant.

4.3.9.4 Lower unemployment rate

Construction of a nuclear power plant will largely contribute to an increase in employment in the local labour market and lower unemployment rate. The population may be permanently employed in the power plant and subcontracting companies, and temporarily employed during maintenance works. The previously discussed Kleszczów commune may be referred to as an example of employment growth due to industry development. In 1977, there were 81 work places in the municipality. Construction of a mine, power plant and associated companies expanded the labour market to 17,600 work places in 2009. this is 4 times more than residents of the municipality.[248]

Preliminary estimates show that in the USA, 800 employees of various levels are employed in one unit with net capacity of 1000 MWe.

Table 4.3.15 List of job positions in a nuclear power plant [249]

TYPES OF POSITIONS	NUMBER OF EMPLOYEES
Civil engineers	5
IT engineers, electricians, electronics engineers	20
Mechanical engineers	15
Nuclear engineers	25
Design and maintenance engineers	30
Control system and equipment operators	75
Chemical technicians	20
Maintenance technicians	135

Radiological protection and radioactive waste management technicians	35
Physical security staff	70
Training staff	35
Other staff	335
Total	800 (+/-300)

Additionally, project execution stage will require employment of 3000-4000 people for construction works, plus employment in construction of associated investments, such as: Power lines, access roads etc.[249]

In Europe, nuclear power plants are main employers in their locations. Belgian power plant Huy employs 950 own employees and additionally 500 subcontractors. Additionally, town authorities state that the number of people whose employment is related to the power plant is three times bigger than the power plant staff. The next example is French nuclear power plant Flammanville, employing directly 680 staff and ca. 2000 outside people, employed during scheduled overhauls and maintenance. Most of them (especially permanent workers) live in the neighbouring municipalities.

American power plant Indian point employs more than 1600 workers (as of 2002), of which 80% live in the area of five neighbouring counties.

4.3.9.5 Economic revival in the region

The power plant will directly and indirectly affect economic revival in the region. Orders placed with surrounding companies by the power plant will greatly affect their activity and development. Additionally, influx of well-earning new residents and increase in life standard of present ones will contribute to development of local trade. Huy power plant purchases various goods and services for 100 million Euros per year, Flammanville power plant annually places orders for 37 million Euros with local suppliers, Indian Point power plant (new York state, operator: Entergy company) executes 30% of their orders in neighbouring counties - by 2002 their value was almost 450 million $.[247]

To sum up: analysis of impact of nuclear power plant construction on the aforementioned aspects indicates, that location of a nuclear power plant may largely and positively affect material situation of its municipality and neighbouring municipalities.

4.3.9.6 Improved energy security of the country

Introduction of nuclear power engineering in Poland will constitute a new method of power production. It will diversify domestic power sources, presently mostly based on coal (see chapter **Błąd! Nie można odnaleźć źródła odwołania.**). Dependence of the entire power sector on only one primary material cannot provide permanent power engineering security or sustainable state development. Introduction of uranium as additional primary power source has significant potential for long-term stabilisation of power prices at low level and providing reliable power supplies (see chapter 4.3.1.1 and 6.1). Providing cheap and reliable power supply is an inherent condition of economic progress and improvement of the nation’s quality of living. Introducing an additional power production source will therefore positively affect population and material goods.

4.3.9.7 . Development of modern technologies

Introduction of new power production technologies in Poland will give an impulse for development of scientific and technological base. Due to technological advancement of solutions and necessity of installation of state-of-the-art security systems, power engineering is the most demanding power production sector. Therefore it forces dynamic development in various related and accompanying domains. Certainly, introduction of power engineering in Poland will have an inspiring impact on development of modern technologies at the highest level.

4.3.10 Natural threats to the operation of a nuclear power plant

Natural threats are understood as the impact of nature's forces that poses a threat to human life and health or to human-made infrastructure. As a rule, these are extreme or abnormal phenomena. They include extreme weather conditions (storms, tornados, droughts, etc.), hydrological phenomena (storms, floods, low water, etc.), seismic events (earthquakes, rock bursts), mass movements (avalanches, landslides, mud and debris flows), as well as events in the biotic world (such as locust swarms etc.). They are rather unpredictable, occur suddenly, and have serious consequences for the economy. However secular, slow-operating processes, although uninterrupted, may also pose a threat to environment. Among them are for instance land creep or atmospheric pollution. It must be emphasised that even the events at exceptionally large scale or occurring extremely rarely are completely normal from the perspective of natural environment, excluding those caused directly by human activity. Also, threats are not equivalent with the notion of risk. Usually risk is specified with the formula[250]:

$R = H \cdot V$, where *R* – risk, *H* – hazard, *V* – vulnerability. It means that with application of proper protections (increasing resistance to damage or decreasing vulnerability), risk does not necessarily grow with increase of hazard.

Natural hazards, which must be included due to development of nuclear power engineering are specified in the draft of Ordinance of Council of Ministers on requirements for a nuclear power engineering project. The list includes:

1. Earthquakes and active tectonic faults.
2. Geotechnical and hydro geological hazards,
   - instability of slopes or embankments,
   - collapse, settlement or elevation of the surface,
   - Liquefaction of ground materials,
   - behaviour of ground materials with static and seismic loads,
   - condition and chemical properties of ground water (potential aggressiveness towards concrete and reinforcing steel).
3. Weather events,
   - extreme weather phenomena (maximum wind velocity, maximum daily precipitation of rain and snow, extreme air temperature, storm swelling of a water reservoir),
   - rare weather phenomena (atmospheric discharges, tornadoes).
4. Floods and floodings due to precipitation and other natural causes.
5. Other external events or hazards: extreme temperatures of cooling water, depletion of reservoir water resources (natural causes), drought, blocking the flow in the river, the excessive growth of aquatic organisms, ice phenomena which may cause blocking the water intake or distort the functioning of a closed cooling cycle (including the cooling tower due to icing).

It should be noted that these project hazards include both natural aspects, and engineering solutions for potential investments. At the stage of development of the Forecast and with no concrete data on the adopted engineering solutions and the selected location, we are not able to refer directly to all the points of the presented list. Still, the key factors connected with natural hazards to nuclear power facilities and the associated infrastructure are described.

4.3.10.1 Seismic hazards

Comprehensive discussion of seismic factors in Poland and therefore issues related with tectonic movements and earthquakes can be found in another chapter of the Forecast. As Poland is not a seismically active area (although it is not fully aseismic, as some studies state), it may be assumed that the seismic factor will not be of key significance for conditions of power plant operation. The largest perceptible earthquakes recorded in the last millennium did not exceed the magnitude of 6. It means that no strong, large or extreme earthquakes have been recorded in Poland – only moderate earthquakes that can affect only buildings in a bad technical condition, and only to a limited extent.

Maintaining the construction standards prescribed by the International Atomic Energy Agency (IAEA), selection of proper building materials, and technical control and proper maintenance of nuclear power facilities under operation should guarantee absolute safety of nuclear power plants in Poland as regards their resistance to seismic shock.

4.3.10.2 Geotechnical and hydro geological hazards

Geotechnical and hydro geological threats should be eliminated by the proper analysis of ground conditions during preparatory works for the project and by using top-quality building materials and techniques. In Poland, young Quaternary sediments display high lithological diversity even at the small area, which results in various usability of the land for founding buildings. The so-called quicksand is an extreme obstacle, in engineering geology construed as fine loose sediment, e.g. sand or sludge mixed with water, poorly bound with land, behaving like thick liquid. Also frost susceptible soil, susceptible to cryogenic processes (water freezing and changes in volume) also is not favourable for construction of buildings. Therefore, detailed analyses of the geology of sub-surface layers and the system of groundwater are of key importance. Accurate determination of the existing hydro geological and geological conditions and application of the proper building technologies will guarantee stability of the nuclear power plant when its operation starts.

4.3.10.3 Meteorological threats

For Poland, there is an abundant collection of data concerning exceptional weather events, presented in many scientific studies. Weather conditions that may pose a threat to safety in a nuclear power plant include mainly snowfalls and rainfalls (and also hail) – their intensity, frequency, and time; wind – its speed and gustiness; atmospheric discharges; extreme temperatures; and other phenomena, such as tornados.

Despite Poland's location in moderate climate, the specifics of the region where masses of continental and oceanic air come into contact causes significant contrasts and amplitudes of weather factors. According to the information provided by Institute of Meteorology and Water Management (IMGW) the highest temperatures in Poland were 40.2°C (Prószków near Opole, 29 July 1921) and 39.5°C (Słubice, 30 July 1994). Heat waves and drought periods also occurred several times, e.g. in July 1994 or July 2010. The lowest recorded temperatures are −41.0°C (Siedlce, 11 January 1940) and −40.6°C (Żywiec, 10–12 February 1929). The most intense rains were recorded in Szychowice near Hrubieszów (35.3 mm in 2 minutes, 13 June 1956), Ryczów near Zawiercie (80.0 mm in 10 minutes, 19 June 1956) and in Sułoszów near Olkusz (180 mm in 60 minutes, 18 May 1996). Recorded wind speed may exceed 288 km/h in the mountains (Kasprowy Wierch) and 162 km/h in the lowlands (Gdańsk, 25 November 1993). Besides gales, for instance hurricane Cyryl in southern Poland in 2007, also tornados and waterspouts are observed in Poland. Tornados, although their scale is incomparably smaller than famous tornados in the USA, may damage poorly secured buildings. This happened on 20 July 1931 near Lublin, m20 August 1946 near Kłodzko, 25 August 1956 near Szczecin, 20 May 1960, 20 August 2006 in Kraśnik District (Lubelskie). Recently, records of such events have increases significantly, also due to development of communication techniques. In terms of number of days with atmospheric discharges, records are from mountain regions (Kasprowy Wierch - up to 54 stormy days a year). The values given should be deemed measured extremes. Slight exceeding of extremes could have occurred, but they were not recorded in measurement grid points.

Adverse weather conditions will affect mainly the safety of the associated infrastructure of a nuclear power plant during its operation, including electricity transmission lines. They can be expected especially in winter months. In the winter of 2009–2010, HV power lines would break down under the weight of ice. However, the problem concerned mainly old lines that had not been properly maintained. It may be expected that a properly designed, constructed, and managed nuclear power plant will be resistant to extreme weather conditions. The same applies to the related associated services, including proper organisation of transport of fuel and spent fuel.

4.3.10.4 Hydrological threats

Hydrological threats are important for all potential nuclear power plants, which will be located t the bottoms of river valleys and in direct vicinity of rivers and water reservoirs. The specificity of the technological process that requires water for cooling eliminates the possibility to move a nuclear power plant at a large distance from water intake points.

High water is one of hydrological threats that require special attention. The increase in water level due to oversupply of water or a blockage along the river course is generally considered the highest risk in Central Europe. In Poland, floods – defined as high water that affects people's lives – occur in various rivers each year and practically during all seasons. The most serious floods affecting a large part of major river basins occur in the warmer seasons of the year. Floods are also a problem in the melting season – in spring and mid-winter. There is one another category – floods that are caused by the build-up of ice or slush-ice, affecting mainly rivers in lowlands (such as the annual ice build-up in the Włocławek part of the Vistula). Issues related to floods are discussed in the subchapter on condition of environment in Poland.

In hydrological literature, high water is divided into regular - reaching the shore water level (full-bed state, without water overflow to flood plane) or low high water (with overflow to flood plane) and catastrophic high water, exceeding medium high water. Punzet[251], when studying the Vistula river basin, divided high water into catastrophic (with culmination flow $Q_{kulm}>Q_{5\%}$), large ($Q_{5\%}>Q_{kulm}>Q_{10\%}$), medium-large ($Q_{10\%}>Q_{kulm}>Q_{50\%}$) and regular ($Q_{50\%}>Q_{kulm}>(Q_{śr}+Q_{50\%})/2$). There is also standard high water, referred to as maximum probable flood . This term means the largest flood which may occur during simultaneous occurrence of adverse factors responsible for water supply and wave culmination[252]. Estimation of probability of maximum water levels and flows is burdened with an error and is reviewed during greatest floods, which was proven by events of July 1997 in the Odra river basin or spring 2010 in the Vistula river basin. Specification of actual flood risk is also made difficult by incompleteness of studies on flood threats for all river basins, which is Polish obligation imposed by the European Union[253] according to *Directive 2007/60/WE of the European Parliament and the Council of 23 October 2007 on assessment and management of flood risk*.

Hydrological threats must be included during designing nuclear power plants and analyses in proper amount of detail. With the currently available building technologies and engineering solutions, it would be possible to protect a nuclear power facility against the negative effects of even the highest water levels. A well-designed nuclear power plant and the associated infrastructure should not be affected by floods.

Another issue concerns low water, i.e. decrease in level of surface and underground water, also treated as hydrological extremes. A nuclear power plant must have access to sufficient water resources. If this water comes from surface water courses, its level must not drop below the minimum flow limit that is required by organisms living in that water course[254].

4.4 Non-radiological impacts at the nuclear decommissioning stage

Non-radiological impacts related to NPP decommissioning will not deviate from the impacts of decommissioning of other facilities of similar area. Demolition works will certainly produce higher emissions of dusts into the atmosphere and higher noise levels. These emissions may be considered a nuisance by inhabitants of the surrounding area. However, they will be only temporary and should not be particularly problematic, given that nuclear power plants are located away from residential areas. Designation of access route to demolition site is also important, as this is the transport route of obtained materials for land reclamation, and transport of heavy machinery and workforce.

Increased noise emission and air pollution emission will also take place on this route. Its course should be designated at a maximum possible distance from residential development areas.

Decommissioning of a nuclear power plant will produce large amounts of waste that should be reused or recovered to the highest degree possible or neutralised. Providing high degree of recovery of demolition materials will reduce adverse effect on natural resources (in form of using raw materials) and ground surface (in form of its occupation by waste storage).

NPP buildings should be completely demolished, and the area must be cleaned and recultivated. If these works are successfully completed, the impact of the decommissioning stage is considered positive – it removes 'foreign' elements from the landscape. Removal of the large hardened surface will also have a positive impact on soils and waters in the area, leading to the restoration of biologically active surfaces and the natural circulation of water by allowing its infiltration into the ground. Those impacts will be possible in case of choosing a natural reclamation direction (forest, meadow, agriculture). Selection of recultivation method may however be different - industrial, allowing for using the hardened area, possibly also some buildings for industrial purposes, if such demand exists in a given area. This recultivation method would not have positive impact on soils and water. Depending on the manner of area use, the impacts may be neutral or negative.

4.5 Impact on biodiversity, including biological resources protected under the Natura 2000 network

4.5.1 Impact on biodiversity, including biological resources protected under Natura 2000 network

Individual identified impacts on plants, animals, biological diversity and Natura 2000 areas generated by construction of a nuclear power plant according to the Programme mostly have broad spectrum and overlap. To avoid multiplication of impacts regarding animals, plants etc., the impacts are described collectively for all level environmentally significant levels, dividing them into individual stages of investment:

- construction stage,
- operation stage,
- decommissioning stage.

4.5.1.1 Impacts at construction stage.

Construction stage is a part of investment process generating the most adverse impacts. For this stage, the following actions were diagnosed which have negative impacts on environment:

- Area occupation for permanent and temporary construction facilities, machines and devices used in construction, area occupation for construction backup facilities, access roads, construction material storage, resulting in:
  - damaging integrity of the areas or their properties.
  - loss or decrease in population of protected plant and animal species due to destruction of feeding grounds, breeding grounds etc.
  - direct lethality of animal species due to collision with buildings and machinery (birds, bats)
  - loss of plant communities

- Waste storage from ground works and the site, resulting in:
    - destruction of natural communities (e.g.: sand dunes, haughs, river valley habitats)
    - animals settling on temporarily stored soil masses (sand martins and other burrow-dwelling species) and resulting species endangerment
- Dust generation during construction activities, such as: transport of soil, reloading sediments and soil, construction of facilities and road foundations etc., resulting in:
    - dust settlement, adversely affecting plants and animals
- Construction of buildings, access roads and parking spaces (with hardened surface), resulting in:
    - soil erosion and water quality changes - possible sediment emission to water and disruption of aquatic ecosystem balance
- Drainage and surface run-off due to ground works and displacement of soil, resulting in:
    - possible destruction of plant communities by contaminants running-off with water (e.g. machine oils)
    - soil erosion and water quality changes - possible sediment emission to water and disruption of aquatic ecosystem balance
- Application of natural surface water for production of concrete, washing machines and equipment, resulting in:
    - impact on quality of surface and ground water and on habitats, plant and animal species and Natura 2000 areas
    - possibility of contamination of local water courses and related endangerment of plant and animal species and protected Natura 2000 areas
    - impact on amount of surface water due to decreasing the level of ground water locally
- Drainages for excavation works, resulting in:
    - disruption of local water relations and impact on neighbouring ecosystems, including plants, animals and entire communities and their protective areas
    - impact on quality of surface and ground water and on habitats, plant and animal species and Natura 2000 areas
- Installing cooling water intake and discharge infrastructure, resulting in:
    - direct interference in aquatic ecosystems due to violation of bottom structure in water reservoirs
    - worsening living conditions of aquatic organisms due to stirring and dislocation of sediments onto plant and animal organisms
- Accidental fuel, petroleum, chemicals, concrete, cement spills etc., resulting in:
    - contamination of ground water, surface water (deterioration of water quality), contamination of natural plant communities and poisoning animals or worsening their living conditions by deterioration of habitats

- Vehicle traffic, resulting in:
    - direct lethality of animals due to collision (birds) or road kills
    - scaring animals
- Noise and vibrations from explosive works, piling, foundation drilling and tunnelling or laying pipeline for cooling water intake as well as from construction machines, means of transport and other vehicles, resulting in:
    - decreasing the values of breeding grounds, feeding grounds, rest areas (birds) or migration routes for several species of animals
    - disturbing fish and aqueous and semi-aquatic mammals
    - disturbing land animals dwelling in the neighbouring areas
- Light emission during construction works (area, machine and vehicle illumination), resulting in:
    - disruption of animal environment (preying bats, resting birds etc.)

4.5.1.2 Impacts at operation stage

Operation stage, being relatively stable in terms of executed tasks and their scope, generates relatively few negative impacts. For this stage, the following actions were diagnosed which have negative impacts on environment:

- Area occupation for power plant building and associated buildings and devices, resulting in:
    - direct lethality of animal species due to collision with buildings and machinery (birds, bats)
- Vehicle traffic, resulting in:
    - direct lethality of animals due to collision (birds) or road kills
    - scaring animals
- Area occupation for access roads and parking spaces (with hardened surface), resulting in:
    - soil erosion and water quality changes - possible sediment emission to water and disruption of aquatic ecosystem balance
    - contamination run-off (oil, lubricants etc.) to ground and surface water, resulting in deterioration of plant communities and living conditions of animals
- Area occupation for aerial contact line, resulting in:
    - direct lethality of birds and bats due to collisions
    - possibility of changing bird migration route due to barrier effect (numerous, dense and landscape-crossing power lines)
- Noise and vibrations from transport and vehicle traffic, resulting in:
    - decreasing the values of breeding grounds, feeding grounds, rest areas (birds) or migration routes for several species of animals

  - disturbing fish and aqueous and semi-aquatic mammals
  - disturbing land animals dwelling in the neighbouring areas
- Light emission (area, machine and vehicle illumination), resulting in:
  - disruption of animal environment (preying bats, resting birds etc.)
- Water intake to the cooling system, resulting in:
  - direct animal lethality due to suction
  - disruption of aquatic ecosystem balance
  - underwashing and local substrate changes causing indirect impacts on flora and fauna
- Warm water discharge from cooling systems, resulting in:
  - disruption of balance in aquatic ecosystems (change in population of various species depending on environmental preferences)
  - impact on bird migration habits (possibility of wintering of water fowl and risk of increase lethality in case of rapid weather changes)

4.5.1.3 Impacts at decommissioning stage

This stage implies necessity of repeated ground works, although due to environmental values already decreased at construction stage, the impacts are smaller.

For this stage, the following actions were diagnosed which have negative impacts on environment:

- Area occupation for permanent and temporary construction facilities, machines and devices used in decommissioning, area occupation for decommissioning backup facilities, access roads, demolition material storage, resulting in:
  - direct lethality of animal species due to collision with buildings and machinery (birds, bats)
- Waste storage from ground works and demolition, resulting in:
  - animals settling on temporarily stored soil masses (sand martins and other burrow-dwelling species) and resulting species endangerment
- Dust generation during demolition activities, such as: transport of soil, reloading sediments and soil, demolition of facilities and roads etc., resulting in:
  - dust settlement, adversely affecting plants and animals
- Drainage and surface run-off due to ground works and displacement of soil, resulting in:
  - possible destruction of plant communities by contaminants running-off with water (e.g. machine oils)
  - soil erosion and water quality changes - possible sediment emission to water and disruption of aquatic ecosystem balance

- Application of natural surface water for washing machines and equipment, resulting in:
  - impact on quality of surface and ground water and on habitats, plant and animal species and Natura 2000 areas
  - possibility of contamination of local water courses and related endangerment of plant and animal species and protected Natura 2000 areas
  - impact on amount of surface water due to decreasing the level of ground water locally
- Disassembly of cooling water intake and discharge infrastructure, resulting in:
  - direct interference in aquatic ecosystems due to violation of bottom structure in water reservoirs
  - worsening living conditions of aquatic organisms due to stirring and dislocation of sediments onto plant and animal organisms
- Accidental fuel, petroleum, chemical spills, resulting in:
  - contamination of ground water, surface water (deterioration of water quality), contamination of natural plant communities and poisoning animals or worsening their living conditions by deterioration of habitats
- Vehicle traffic, resulting in:
  - direct lethality of animals due to collision (birds) or road kills
  - scaring animals
- Noise and vibrations from explosive works, demolition of buildings, pipeline for cooling water intake as well as from construction machines, means of transport and other vehicles, resulting in:
  - decreasing the values of breeding grounds, feeding grounds, rest areas (birds) or migration routes for several species of animals
  - disturbing fish and aqueous and semi-aquatic mammals
  - disturbing land animals dwelling in the neighbouring areas
- Light emission during demolition works (area, machine and vehicle illumination), resulting in:
  - disruption of animal environment (preying bats, resting birds etc.)

4.5.2 **Impact on protected areas, including Natura 2000 areas**

Implementation of the Programme involves construction of two nuclear power plants and related infrastructure in Poland, in form of aerial transmission grids, roads etc. These actions may adversely affect Natura 2000 network in Poland, depending on selected sites. Degree of environmental impact of specific final locations will be assessed at the stage of EIA. This document analyses, solely on the basis of literature, potential impacts on Natura 2000 areas of power plant location in proposed sites, divided into two groups - i.e. recommended and reserve sites and other proposed sites. One of the criteria of site assessment was adherence of location within the area created pursuant to Birds Directive or Habitat Directive. The diagrams below present possible collisions with SAC and SPA areas in case of power plant construction in one of the analysed locations.

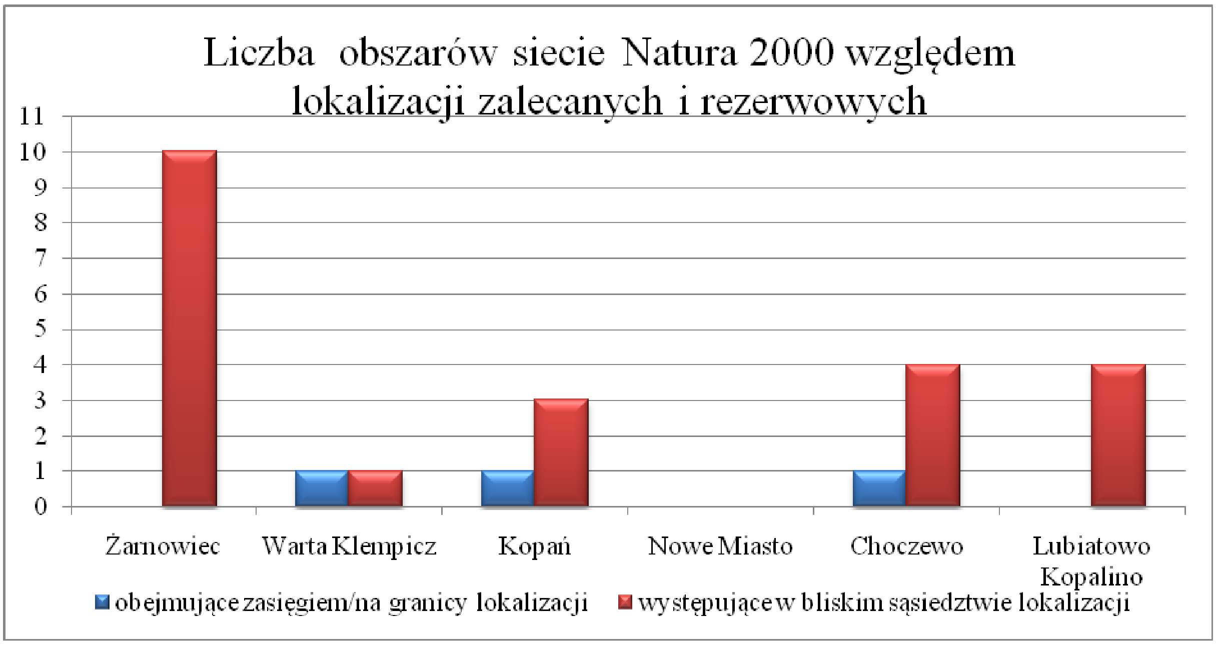


Fig. 4.5.1 Location and number of Natura 2000 areas in relation to the assessed recommended and reserve locations

[Number of Natura 2000 sites with regard to recommended and reserve locations
In their range/bordering
In the close proximity of the site]

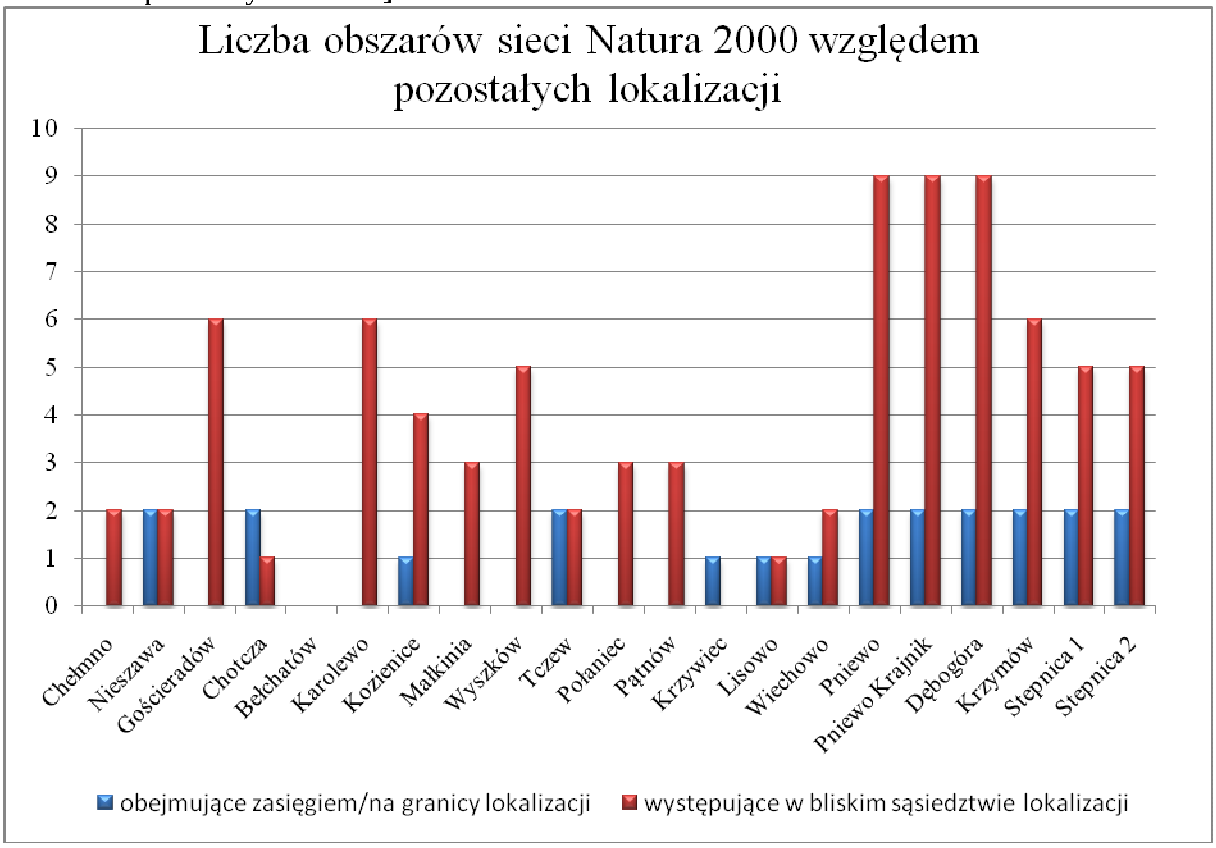
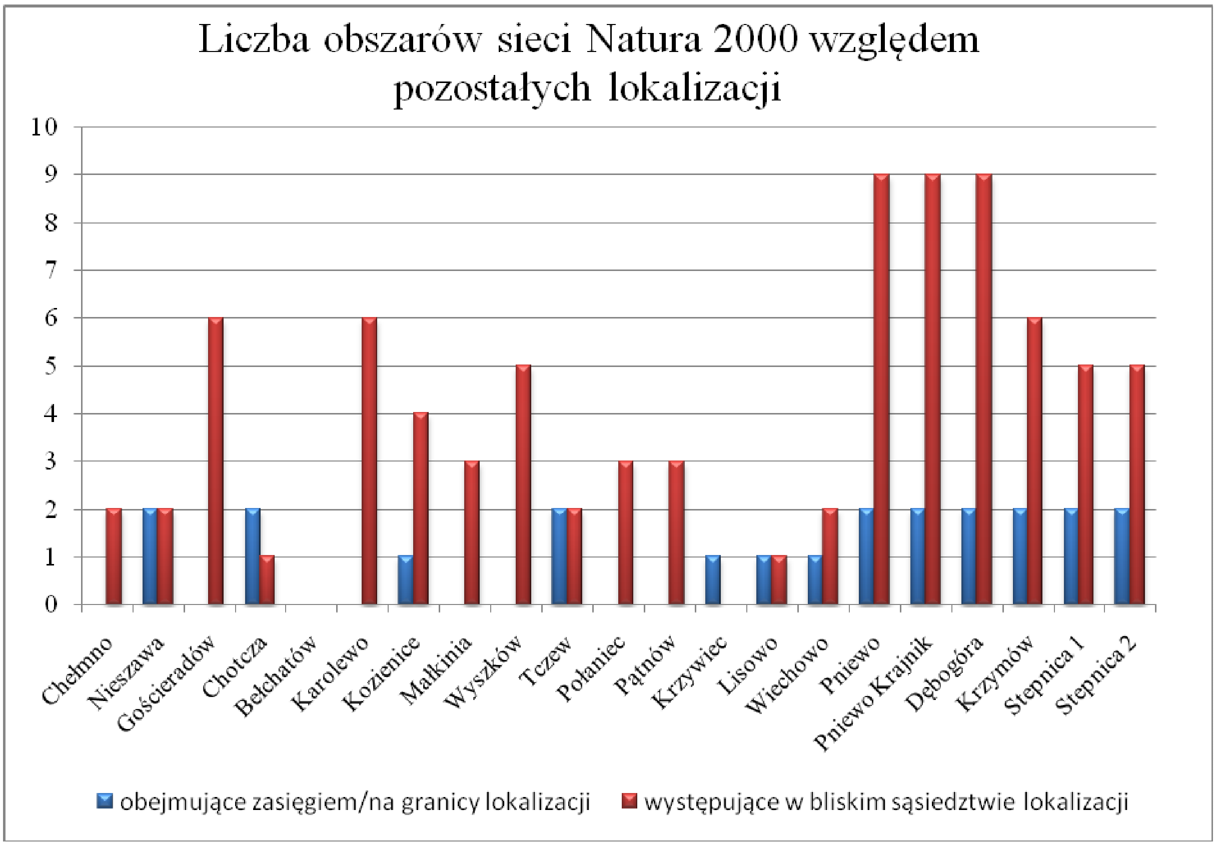


Fig. 4.5.2 Location and number of Natura 2000 areas in relation to the assessed recommended and reserve locations

[Number of Natura 2000 sites with regard to other locations
In their range/bordering
In the close proximity of the site]



As it can be seen, most analysed locations are in or in the neighbourhood of Natura 2000 areas - except for sites in Nowe Miasto and Bełchatów. In other cases, more or less apparent collisions may occur. In case of selection of sites in sensitive areas, integrity of Natura 2000 area may be violated and execution of objectives may be threatened. EIA procedure, conducted properly and according to good practice at the subsequent Programme stages should prevent such negative impacts.

Also, expansion of contact line grid resulting from the Programme may impact Natura 2000 areas due to deforestation, ground works at construction stage and increased bird mortality in its course areas at operation stage.

4.5.3 Impacts on biodiversity

Biodiversity may be examined according to various criteria and on various precision levels.

From the perspective of nature organisation, biodiversity is examined on three basic levels:

- intraspecific diversity - or genetic diversity, including i.a. diversity of subspecies, varieties, forms, in order to increase (or not decrease) diversity on intraspecific level, a grid of wildlife corridors was created (particularly for migrating animals).
- species diversity - includes diversity of species, but in a broader sense this is also taxonomic diversity, including supraspecific diversity of higher-rank taxa, to which individual species belong - i.e. genera, families etc.
- supraspecific diversity - diversity of species groups and their habitats but not in taxonomic aspects, but as communities,, sets created by species. Such diversity is best recognised and commonly analysed and included in the aspect of nature protection with regard to plants. In contrast to plant species diversity including flora, plant diversity is also analysed in terms of plant

communities, i.e. syntaxonomic units distinguished in this aspects, i.e. associations, relations, orders and classes of vegetation. Plant types currently are protected similarly to species. Plant communities occur in landscape complexes involving various communities related in spatial and dynamic aspects and they form a basic landscape component. Thus, landscape is the highest level of biological diversity.

Analysis of potential impact of nuclear power plants in Poland in the context of biodiversity was performed on species and supraspecific level. Analysis for intraspecific level in relation to the preliminary assessment stage (of strategic character) and to lack of proper and sufficiently precise data was not performed.

Analysis on species level may be conducted for various groups of organisms, and analyses for plants and animals were performed in this aspect. Analysis of supraspecific impact was performed for plant communities, and more precisely for types of protected habitats specified in Annex 1 to Natura 2000 Habitat Directive. Precise data were included in location analysis for individual potential sites. Synthetic discussion of results for animals, plant species and their community was presented in separate, dedicated chapters.

Undoubtedly, programme execution may impact biodiversity, though mainly in local aspect. Level of impact on biodiversity will depend on selected nuclear power plant location.

4.5.4 **Impact on animals**

Significant impact of the Programme on environmental components may refer to selected animal species. Programme execution may directly affect the species or may affect them indirectly due to changes of habitats.

Nuclear power plant construction in Poland as the main environmentally burdensome effect of the Programme is related to possible increased direct mortality of animals due to collisions with facilities such as buildings, devices and vehicles, mortality due to construction works (particularly ground-dwelling and aquatic invertebrates). Moreover, necessary expansion of aerial transmission grids threatens migrating birds and bats, both in terms of increase mortality due to collisions and due to the barrier effect (transmission lines concentrated in the vicinity of power plant may affect correction of established migration routes).

In power plants taking cooling water from reservoirs and rivers, there is a hazard of animal mortality due to suction into cooling systems. Also discharge of heated water to natural reservoirs may lead to deterioration or improvement (depending on species requirements) of environmental conditions and related species population.

Deterioration of the functions of a wildlife corridor is also possible due to location of a nuclear power plant within. As a result, migration may be reduced (mainly for mammals), which increases the risk of isolation of animal population.

Depending on a selected site (and its natural values) impacts may vary in terms of their specifics, intensity and duration, therefore it is important to properly select a site and diagnose hazards at the EIA stage.

4.5.5 **Impact on plants**

The basic aspect of analysis of potential impact of nuclear power plant construction on plants was analysis of potential negative impact on biodiversity of plants on species and community level. Rare and endangered taxa and syntaxa, legally protected, were selected as potentially most susceptible to negative impacts and most valuable for impact assessment in methodological sense. From the syntaxonomic perspective, analysis was performed according to types of habitats specified in Annex

1 of Habitat Directive, being in different rank, i.e. not only plant associations, but also higher units, including classes.

The preliminary biodiversity analysis on the basis of available literature shows that individual sites are highly diverse in this regard. Basic data collected in the tables allow for numerous analyses in various variants, however in general it can be stated that although differences between sites are significant, diversity analysed with various selected criteria gives mutually correlated results. It is understandable, as in locations with large diversity of habitats, greater diversity of species also occurs, and what follows - greater probability of rare species. With regard to the above, basic analyses for selected criteria are presented below, allowing for assessment of potential significant impacts on biodiversity of plants and flora. Plant species from Annex 2 to Habitat Directive, usually very rare, are an exception. There are no more than 5 of them in a given location, so that form a non-representative group. Therefore, despite occurrence of those species, biodiversity of a much broader group of rare and protected species was analysed. A group of frequent species was excluded from protected plants, as they appear in most locations, have larger populations and usually appear with more frequency and coverage. Therefore they have much less value differentiating sites with respect to their negative impact on plants, and they are less susceptible to such impacts. The results for plants and habitat types are presented in Fig. 4.5.3 - Fig. 4.5.5.

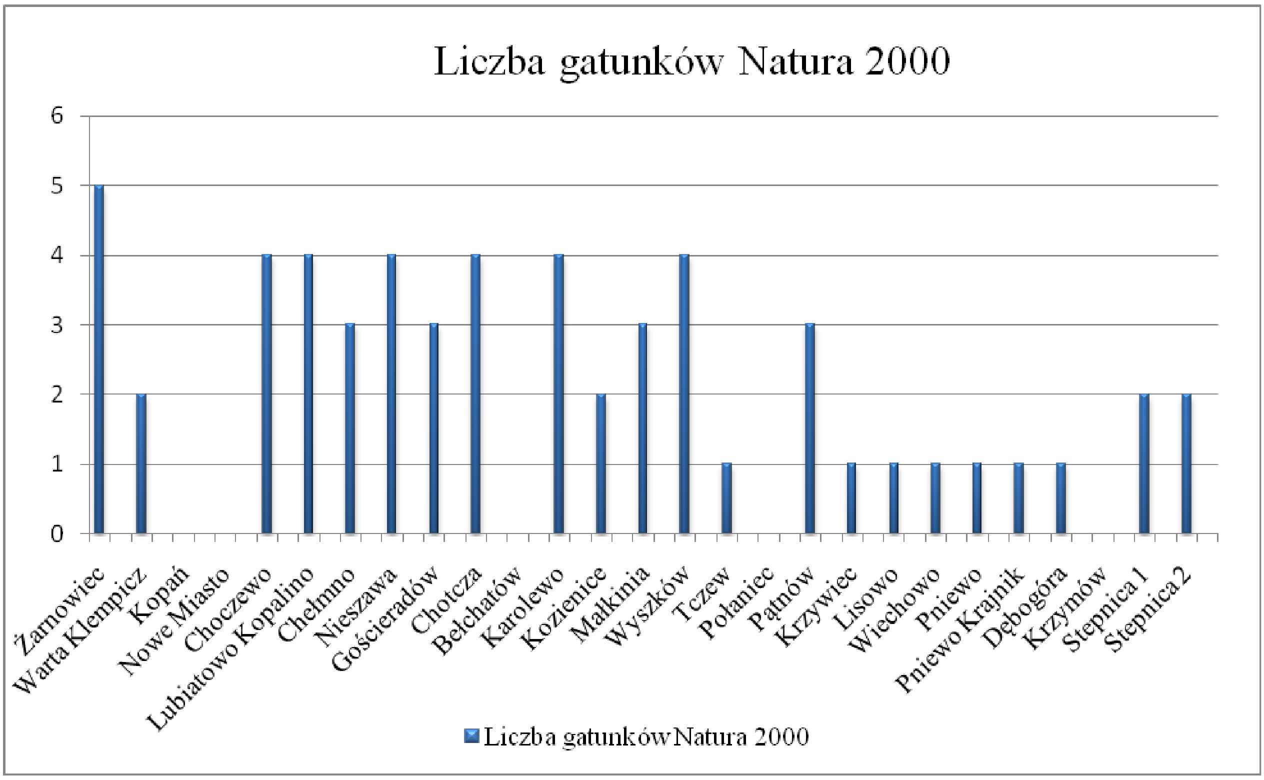


Fig. 4.5.3 Occurrence of the species from Annex 2 to Habitat Directive in the area of proposed site and in the area of surface environment protection forms in its vicinity.

Fig. 4.5.4 Occurrence of the rare and endangered species under strict protection in the area of proposed site and in the area of surface environment protection forms in its vicinity.

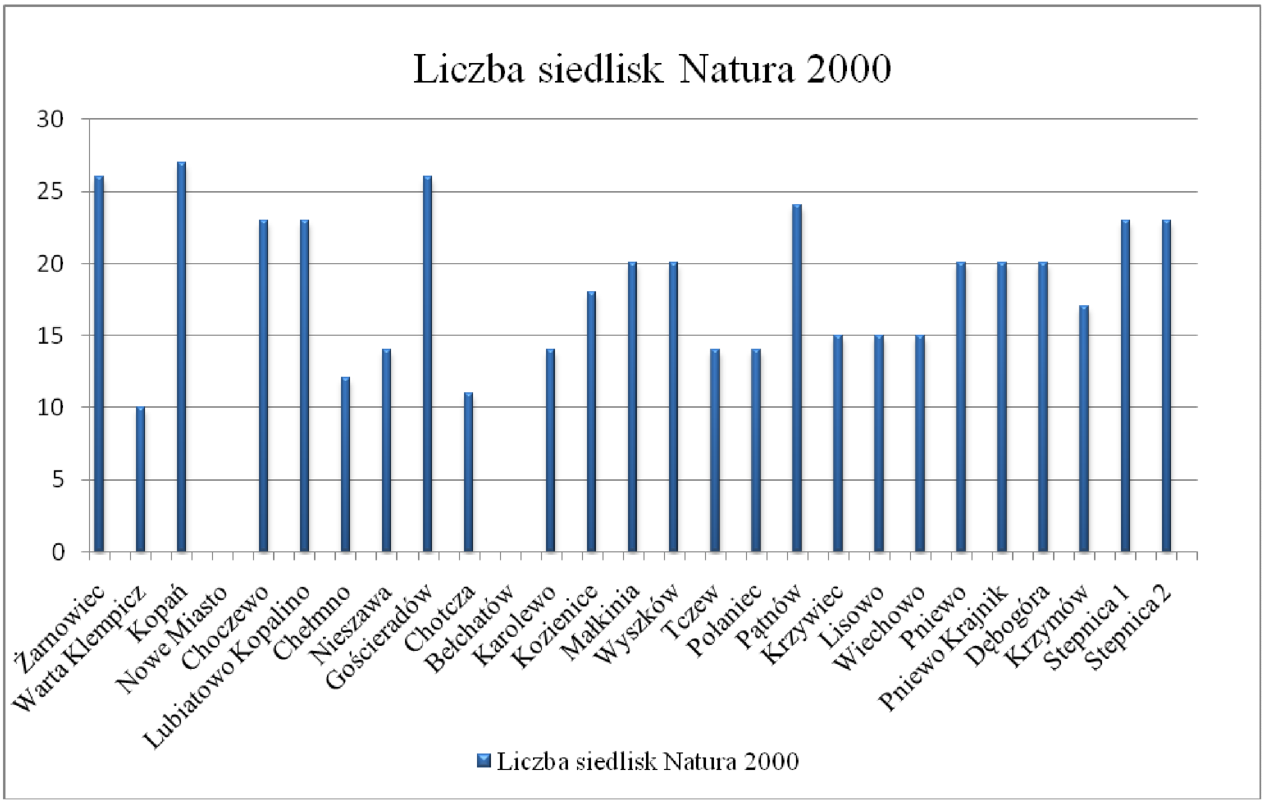


Fig. 4.5.5 Occurrence of habitats from Annex 1 to Habitat Directive in protected areas within potential sites

In case of plant species and plant communities, one of the basic factors which may potentially adversely affect their diversity is their direct destruction due to construction of a power plant and related infrastructure. Therefore, intensification of predicted impacts at the current stage of analysis is assessed on the basis of number of protected and rare species and habitats in a given site area. Therefore, the greater the diversity of vegetation in all aspects, the greater the power plant impact may be. Negative impact to a smallest extent may be expected in places where diversity and occurrence of rare and protected taxa is the lowest. As the differences in this regard, according to the analyses, are significant, from the perspective of impact on plants, it may be clearly indicated that potentially smallest risk of impacts occurs in Nowe Miasto site among recommended sites and in Bełchatów among reserve sites; however, it must be emphasised that new sites will probably be added to the assessed ones, not included in this analysis.

4.5.6 Analysis of premises mentioned in art. 34 of the Environment Protection Act of 16 April 2004

The forecast for the draft of Nuclear Power Engineering Programme includes a habitat assessment, concluded with a statement of **possibility of potential** impact of the drafted document on Natura 2000 areas. Thus, pursuant to art. 55 of the Act on environmental information and protection, participation of society in environmental protection and assessment of environmental impact (EIA Act), the draft of the document cannot be accepted, unless premises occur from art. 34 of the Environment Protection Act of 16 April 2004 (Journal of Laws 2009 Nr 151, item 1220 as amended), pursuant to which

1. If justified by requirements of overriding public interest, including requirements of social or economic nature, and the absence of alternatives, the competent local regional director of environmental protection, and in marine areas - the director of the competent maritime authority may authorize the implementation of the plan or action that could significantly adversely affect the conservation objectives of Natura 2000 area or areas on the list referred to in art. 27, excerpt 3 point

1, ensuring implementation of environmental compensation necessary to ensure consistency and proper functioning of the Natura 2000 network.

2. Where a predicted significant impact relates to the priority habitats and species, a permit referred to in excerpt 1, may be granted only for the purpose of:

1) protection of human life and health;

2) providing common safety;

3) obtaining beneficial results of primary significance for

environment;

4) resulting from requirements of overriding public interest, upon obtaining the opinion of the European Commission.

The premises are as follows:

1) Lack of alternatives and 2) necessary requirements of public interest, which, pursuant to the Act, include social or economic requirements.

In case of impact of the draft of Nuclear Power Engineering Programme on priority species protected in terms of Natura 2000 network, the premises were limited to objectives related to:

1. protection of human life and health;
2. providing common safety;
3. obtaining beneficial results of primary significance for environment;
4. and other objectives resulting from requirements of overriding public interest, upon obtaining the opinion of the European Commission.

In order to assess whether the premises occur in the discussed case and whether they will enable approval of the document pursuant to art. 34 of the Environment Protection Act, they must be semantically and legally analysed in detail,

The key premise for initiation of the assessment of occurrence of a category of objectives from art. 34 of the Environment Protection Act is the premise of "lack of alternatives".

Alternatives described in the EIA procedure should include alternative sites or trails (routes in case of line investments), different scales and sizes of investment or project design solutions, and the timetable or the organization of construction work, construction methods, as well as decommissioning method and alternative processes[255]. Assessment of alternative solutions should always be through the prism of the conservation objectives of a given Natura 2000 area, its integrity and contribution to the overall coherence of Natura 2000 network. Zero option also must be considered[256]. The term "non-existence of alternatives" means that there are not any solutions that enable the achievement of the objective in a different, less environmentally damaging way, although the choice of one of the selected opportunities does not have to be based on the ones which have the least negative impact on the area.

The impact forecast analyzes the potential sites from a list of the Ministry of Economy with the proviso that none of those locations is determined (see Chapter 10.3) and possible technological and structural solutions, as well as examines the possibility of securing its energy needs through other sources, including renewable energy (see chapter 10.1). In the analysed case, also assessment analysis of zero option was performed, i.e. effects of failure to execute the drafted document, although it should be emphasised that the political decision on introducing nuclear power engineering in Poland was made on the basis of another document, i.e. State Energy Policy until 2030 with the strategic environmental impact assessment (see chapter 2). Pursuant to art. 5.2. of SEA directive, work schedule was not included in the forecast (both in terms of logistics and construction) due to the fact that the term was "given" in State Energy Policy until 2030.

It should also be noted that due to the need to carry out the procedure to obtain a decision on the environmental conditions for the three possible equivalent locations guarantees proper approach to variant analysis guarantee that the chosen location will have the minimum possible impact on the environment and that the variant analysis performed at the environmental decision stage will allow assessment of the existence or nonexistence of alternatives.

The following remarks - without prejudging in any way on recognition of the existence/nonexistence of alternative solutions focus only on the premise of the necessary requirements of overriding public interest.

In order to assess what is or could be regarded as such a premise, one needs to indicate interpretation of the term "legal interest" in doctrine and judicature.

The concept of public interest is subject to constant interpretation in the doctrine and judicature, mainly due to the fact that there is no general definition of interest as a normative category[257]. (In legal language there is the category of "private interest" (individual), "public interest", "general interest" or "social interest" (general social), "state interests" (of the state)).

For the purposes of this paper it is worth quoting only the selected views, which may contribute to the subsequent interpretation of the concept of "overriding" public interest[258].

Judicature accepts that the public interest relates "essentially to matters related to the functioning of the state and other public bodies as a whole, especially with the functioning of the basic structure of the state. Effective action in the public interest is associated with the possibility of real influence on the functioning of certain state institutions in a broad sense"[259], and that the interpretation of the term "public interest" should take into account the values shared by society as a whole, this particularly refers to justice, security, citizens' trust in public authority[259]. Moreover, according to the ruling of the Constitutional Tribunal, public interest (common good) to be upheld, should have an established axiological base in the consciousness of individuals, which implies a particular normative imperative. The concept of public interest cannot be treated as the notion that gives the legislature an opportunity to treat it randomly, because it has no blanket character. Therefore, it is legislature's obligation to identify its content with regard to constitutionally protected standards.[260]

In summary, the concept of legal interest is a classic legally indeterminate phrase, which does not have a precisely defined content, and therefore it does not have a precisely defined legal meaning. Therefore, we should agree with the view of M. Wyrzykowski that it is most favourable to present the public interest in descriptive terms, i.e. **as the best response to the situation in the conditions of existence of all interests and in a way that respects the values generally accepted in the society**[261]**.**

In this context, the question arises whether, and if - in what extent - the concept of public interest includes protection of the environment on the one hand and energy security - on the other. The answer can be found in the provisions of the Polish Constitution[262], more precisely art. 31, excerpt 3, which mentions specific manifestations of public interest, including environmental protection and safety[263]. Similarly, art. 5 of the Constitution indicating functions of the state, i.e. fundamental directions and objectives of its activity. The elements expressed therein comprise interest of the state[264].

Similarly, art. 3 p. 13 of Environment Protection Law (i.e. Journal of Laws 2008 No. 25, item 150 as amended), which construes the notion of environment protection as *taking or failure to take action to preserve or restore the natural balance; this protection is, in particular:*

a) rational shaping the environment and management of environmental resources in accordance with the principle of sustainable development,

b) preventing pollution,

c) restoration of the natural elements to the proper state.

Thus, it should be assumed that management of resources (including non-renewable energy resources) is not opposed to the popular meaning of "protection" of the environment but - if it is compliant with the principle of sustainable development and takes place in a rational way - is a component of the concept. This means that the objectives of environmental protection and resource management are not contradictory. The question is, however, how one may reconcile them with satisfying needs for energy supply. The answer can be found in art. 1 of the Energy Law[265], pursuant to which

1. The Act defines the rules of the state energy policy, terms and conditions of supply and use of fuels and energy, including heat, and the activities of energy companies, and also defines the competent authorities in matters of fuel and energy.

2. The purpose of the Act is to create conditions for sustainable development of the country,

energy security, economical and rational use of fuels and energy, the development of competition, counteracting negative effects of natural monopolies, integrating environmental protection requirements, the obligations arising from international agreements and balancing the interests of energy companies and consumers of fuels and energy.

The concept of energy security should be understood as the possibility of ensuring stable supplies of fuels and energy at a level guaranteeing meeting national needs at the prices accepted by the economy and society, assuming optimal use of domestic energy resources, and through diversification of sources and lines of supply of crude oil, liquid and gaseous fuels . Energy security is also the security of technology, guarantee of sector investment profitability and continuity of supply.[266]

According to the jurisprudence of the Constitutional Court, ensuring **energy security** of the country, in other words striving to meet both existing and projected energy needs, is the duty of public authorities[267]. Ensuring energy security should take place in conditions specified in art. 74, excerpt 1 of the Constitution, taking into account the ecological security of current and future generations

In light of the definition of "energy security" and "public interest" understood as the best response to the situation in the conditions of existence of all interests in a way that respects the values generally accepted in the society[268] it must be recognized that energy security is in the public interest. Such a position is also confirmed by the doctrine[269] and case law, in particular the judgment of Regional Administrative Court in Warsaw VI SA/Wa 1893/07 of 2008-04-07 recognising energy (including fuel) security as public interest.

Since energy security can be considered as public interest, one should consider whether it constitutes a category of "overriding" public interest. Environment Protection Act, nor the Habitats Directive, nor the Court of Justice of the European Union [270] define "necessary requirements of overriding public interest". However, art. 34, excerpt 2, p. 1-3 Environment Protection Act lists the human health, public safety and beneficial consequences of primary importance for the environment[271], as examples of the necessary requirements of overriding public interest. Undoubtedly, however, the term "necessary requirements of overriding public interest" also includes other than the above mentioned types of social or economic interest. Surely this "overriding public interest" is an interest of a social or economic nature, but "qualified" in relation to the interests specified in art. 34, excerpt 2, p. 1-3 Environment Protection Act. According to the Court of Justice judgment in case of *Leybucht Dykes*, it must include interest exceeding the value of natural resources, for the protection of which a given area was created[272].

The overriding public interest can be regarded as strengthening the competitiveness of the region, better conditions for trade development, ensuring adequate quality of transport, the beneficial social effects in the short-and long-term scale, environmentally friendly alternative transport[273]. It results from the examples discussed in the amended version of the study "Managing Natura 2000 sites" that **potential overriding requirement for the necessary public interest can also be: prevention/minimization of unemployment, reducing greenhouse gas emissions, air pollution** and new jobs (all these arguments can be taken into consideration in connection with the planned nuclear power plant**)**, and the competitiveness of specific European industry and region, the demand for drinking water, etc.[273] Examples taken from the Commission's opinion indicate that the requirements of the overriding public interest may also be included in the area of priority infrastructure projects, approved by the EU itself[274]. Necessary public interest requirements also apply to situations in which it can be proved that the planned projects are necessary to protect human life and property[275].

Public interest should be deemed overriding, if it is a **long-term interest,** both economic and other interests bringing only short-term benefits to society, do not seem to be sufficient to dominate the natural long-term interests protected by the Directive.[276] Ensuring national energy security by building a nuclear power plant should certainly be treated as long-term interest.

For these reasons it should be considered that energy security can be regarded as an overriding public interest.

Another premise is the recognition whether conditions arising from an overriding public interest are **„necessary requirements**”. Due to the lack of interpretation of this concept in EU law and national law, the jurisprudence of the Court of Justice and the Commission communication relating to the concept of "service provided in general economic interest" may be applied in auxiliary capacity.

Primary EU law uses the term "service of general economic interest" cited in art. 106 TFEU (former art. 86, excerpt 2 TEC) as an exception to the competition rules laid down for companies providing such services. In its Communication on services of general interest in Europe the Commission, taking into account the case law on this matter, gave the following definition of services of general economic interest: *"These include commercial services of public utility, based on specific principles of public services specified by the member states. This applies in particular to services provided in transport, energy sector and communication networks"* [277] This clearly demonstrates the recognition by EU institutions of the services in the energy sector as services of general economic interest, which can render them explicitly as falling within the premise of the necessary requirements of overriding public interest.

In practice, the assessment of the premise of necessary requirements of overriding public interest is made by the administrative body which according to the ruling of the Regional Administrative Court in Warsaw IV SA / Wa 2319/06 "must consider the existence of alternatives *in concreto*, also taking into account the environmental or social costs of implementing alternatives. The existence of alternative solutions should be considered, bearing in mind the particular need for protection of goods subject to special forms of environment protection (e.g. areas of international importance under the Natura 2000 network), not forgetting at the same time the need for balancing the issues of reasonable protection of these areas with other considerations (such as social considerations or conservation of natural resources not covered by specific forms of protection), without neglecting the principles of sustainable development"[278].

This means that it is possible to adopt a document on the basis of art. 34, excerpt 1 of the Nature Conservation Act - as falling within the premise of the objective arising from the necessary requirements of overriding public interest. At the same time, if the competent authority selects the location of a nuclear power plant, the assessment of the impact on specific Natura 2000 areas (including perhaps - priority species) will be carried out *in concreto* as environmental impact assessment for the planned project. Then, if necessary, the implementation of the project will be possible on the basis of art. 34, excerpt 2 p. 4 of the Nature Conservation Act - as falling within the premise of the objective arising from the necessary requirements of overriding public interest, after obtaining the opinion of the European Commission. At the same time, it seems, a positive opinion in this regard would be the obvious consequence of the adoption of EU law documents such as climate and energy package, 6 action program for environmental protection along with the thematic strategy on air pollution and the Thematic Strategy on the sustainable use of natural resources for 2006-2013 as well as secondary legislation.