NUCLEAR ENERGETICS IN THE CAPITALIST COUNTRIES OF WESTERN EUROPE

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The country that was first in constructing atomic power stations in large numbers was Great Britain.

Following the Soviet Union, the second country to install an atomic power station for the purpose of producing electric energy was Britain, where the Calder Hall atomic plant was put into operation at the town of the same name in 1956 (Fig. 1.). This atomic plant, built as a gas-cooled magnox type station, generated 4×55 MW* capacity by its full completion in 1959. This power plant is situated on the western shore of Britain and on the same latitude as that of the northern tip of the Isle of Man. This nuclear plant (Type MK – I) also supplies technological steam to the Windscale Nuclear Research Institute built a little north of here.

Two years later (in 1958) this was followed by the Chapel Cross Atomic Plant near the town of Annan, at the mouth of a stream with the same name, in the south of Scotland, some 70 km north of Calder Hall, furnished by four similar units in its full completion. To prove their good productivity some 3 thousand million kW-hours of electric energy is generated yearly in these two plants.

These power plants operate on carbon dioxide gas-cooled, graphite-moderated reactors, by heating elements made of natural uranium placed in grilled-surface magnesium alloy casings. The name "magnox" originates from this. No equipment is needed therefore to enrich uranium for their operation. Thus the British nuclear energy programme was able to run independently from the United States, and enabled the production of a certain amount of plutonium for military purposes. Production of plutonium in gas-cooled reactors is faster than in atomic plants of the water-water type. Some 500 – 600 kg of plutonium can be produced yearly in a 1000 MW capacity gas-cooled reactor (non-existent in reality), while output in a water-cooled reactor of similar size is about 300 kg.

* Nuclear reactors may be defined by their capacity of generated heat. 30 – 34% of it is transformed into electric energy by the electric blocks (turbines, generators). For the sake of simplicity and clarity electric capacities, that may be connected to reactors, are given as „ reactor capacities" in this study.

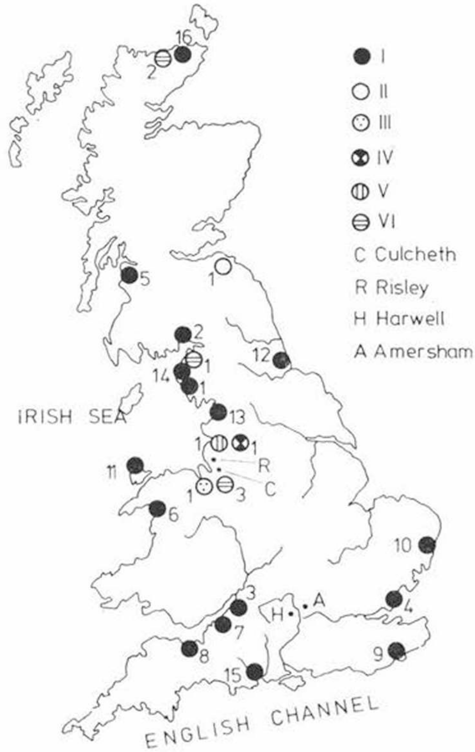

Figure 1. Location of nuclear power plants and other works connected with nuclear industry in the United Kingdom.

I. Working nuclear plants: 1 = Calder Hall; 2 = Chapel Cross; 3 = Berkeley; 4 = Bradwell; 5 = = Hunterston; 6 = Trawsfynydd; 7 = Oldbury; 8 = Hinkley Point; 9 = Dungeness; 10 = Sizewell; 11 = Wylfa; 12 = Hartlepool; 13 = Heysham; 14 = Windscale; 15 = Winfrith; 16 = Dounreay. II. Nuclear plants under construction: 1 = Torness. III. Uranium enrichment plant: 1 = Capenhurst. IV. Production of uranium metal: 1 = Springfields. V. Manufacture of hetaing elements: 1 = Springfields. VI. Reprocessing plants: 1 = Windscale; 2 = Dounreay; 3 = Capenhurst. Military plant: 1 = Aldermaston.
The category "working nuclear plants" (on figures 1—7) also include those planned for completion by the end of 1980.

The installation of these two plants was followed by a short interval for acquiring some operating experience that was to be put into use in later development works. From 1962 on production of reactor blocks of the same type, capacities now standing around 150 MW, began on a mass scale. Among these are included the reactor blocks of the Berkeley Atomic Plant (2×167 MW) near Gloucester, at the mouth of the Severn, completed in 1962, and the reactor blocks of the Bradwell Atomic Plant (2×187 MW) a little to the north of the Thames estuary. The town of Bradwell lies on the southern shore of Blackwater Bay. Two more reactor blocks of this kind were built during 1964—1965 in the town of West Kilbride, Scotland, as the first units of the Hunterston Atomic Plant (2×180 MW). They are located on the coast, slightly southwest of Glasgow.

From 1965 on unit capacities were increased significantly: a total of 10 gas-cooled reactor blocks of 250 – 300 MW each were built between 1965 – 1967. They are: Trawsfynydd Atomic Plant (2×292 MW), on the northeastern part of Wales, in the vicinity of a northern inlet of Cardigan Bay, named Tremadoc, on the shore of a lake with the same name. Oldbury Atomic Plant, slightly south of Berkeley Atomic Plant, in the Severn estuary (2×317 MW). Hinkley Point Atomic Plant, southwest of Bristol in Bay of Bristol, at the town of Somerset (2×332 MW). Dungeness Atomic Plant, in the southeastern part of England, some 30 km south of Dover on the coast (2×288 MW), near the town of the same name. Sizewell Atomic Plant, is southeastern England, about 40 km northeast of the town of Ipswich on the coast, next to the small town of the same name (2×325 MW).

Several years had passed until the setting up of the new reactor family and the years 1968 – 1971 saw no new atomic power station put into service. From 1972, however, unit capacity has again been doubled and the installation of AGR-type atomic plants equipped with 590 – 625 MW reactor blocks was started. 12 such reactor blocks have been constructed so far or are under construction. First to be completed was (1972) Wylfa Atomic Plant, in the northeastern part of Wales, on the island of Anglesey, (2×590 MW) but due to the risk of steel corrosion, it is operating at a lower temperature than had been originally planned, and supplies a total capacity of 900 MW, which was followed by the expansion of Hunterston and Hinkley Point plants in 1976 – 1977 (both are AGR-type and represent 2×625 MW capacity). After these work has started on the construction of the AGR-type Hartlepool Atomic Plant (2×625 MW) which is expected to be fully operational by 1980 – 81. The two AGR-type units of 625 MW capacity each of Dungeness B Atomic Plant (expansion) are planned for completion by 1979 – 80. The AGR-type reactor blocks of Heysham Atomic Power Plant (also with 2×625 MW capacity) are planned to be installed near the town of the same name, a little to the south of Calder Hall Atomic Plant, in 1980 – 81.

Despite the forced pace of construction Britain lost her place as leader in installed nuclear plant capacity, for in 1972 January built-in capacity was 6091 MW in Britain, wile 10 040 MW in the United States. At the same time Britain's nuclear industry has lost its hope of selling atomic plants abroad because gas-cooled reactors are unable to compete with those of water-water type in the phase of primary investment. This is a very serious loss for the branch of Britain's machine industry that specialize in the construction of gas-cooled atomic plants.

Efforts have been made to lessen or even put an end to this disadvantage and a determined attempt was made to improve the MK – I gas-cooled base reactor from different standpoints. It was enabled to replace fuel during running, and due to the crystallization of fuel the use of UO_2 as heating material was taken up. Moreover, planning of new, competitive reactor-types has been encouraged.

A 33 MW electric capacity AGR-type (Advanced Gas-cooled Reactor) unit was put into operation (mark MK – II) in the Windscale Research Institute as early as 1962, whose fuel was slightly enriched (1.5 – 1.7%) UO_2. Temperature of gas released from the reactor was raised to about 550 °C as against 410 °C of the MK – I type, consequently improving power engineering efficiency for the plant (from about 30% to about 40%).

This direction of research has led to the construction of a HTGR or "Dragon" type reactor in the Winfrieth Experimental Institute in 1964. Increased outcoming gas temperature for this reactor type was again the aim here, and it was constructed with the combined effort of scientists from several European capitalist countries. Essentially it uses rather expensive helium as cooling gas, while boron carbide (B_4C) serves as moderator. The 7 MW electric capacity reactor runs on uranium carbide (UC_2) concentrated to 93% and on thorium carbide (ThC_2) as fuel. Temperature of the outcoming gas is 750 °C.

The 100 MW reactor labelled SGHWR and completed in the Winfrith Experimental Site in 1967 represents an entirely new direction. It uses UO_2 as fuel concentrated to 2.28%, is cooled by light water, while heavy water serves as moderator. This pioneer reactor indicates the necessity of replacing gas-cooled reactors by more modern ones.

The experiments themselves cited above show the somewhat unconcentrated and uncertain state of development directions in Britain; a reactor type, able to compete with those of other countries and suitable for economical mass production has yet to be developed from the present thermal types. Construction programmes for atomic power stations have been altered several times. In the meantime production of plutonium for military purposes has also lost its original significance, as big-power position has from the mid-fifties been connected to ownership of hydrogen bomb and carrier rockets. In the field of developing these rockets with all their requisites Britain cannot compete with the Soviet Union and the United States, who have larger economic potentials.

In the second half of the 1970s the construction of atomic power plants has suffered a setback. The last development programme to be accepted by the British Government was in 1974, which called for the construction of SGHWR-type atomic plants. No orders were issued, however, and instead construction was later started on six AGR-type gas-cooled atomic power stations (with reactors) on the sites already mentioned. Construction of 4 new AGR-type reactor blocks was decided on in 1978, and work has already started in the Heysham Atomic Plant (Blocks Nos. 3. & 4.) and on a new site near Torness, in the vicinity of Dunbar, in SE Scotland.

For all these Britain will continue to lose her leading position in nuclear energetics. By 1990 some 20 000 MW nuclear plant capacity is planned for installation.

The United Kingdom is also a pioneer in the building of fast neutron reactors. The first "DFR"-mark, 15 MW breeder reactor was installed way back in 1959 in the Dounreay Experimental Institute in Northern Scotland, whose aim was to gain operation experience needed for bigger breeder reactors. The DFR breeder reactor was shut for good in 1978. Based on these a new "PFR" type, 250 MW breeder reactor was installed on the same site in 1975. Cooling material in a PFR is liquid sodium metal, while enriched uranium-plutonium dioxide is used as fuel. The latter serves the purpose of achieving experience for constructing large capacity breeder reactors suitable for serial production. A growing number of articles appearing in British technical journals express the view that in Britain concentration of development resources should be limited to the breeder reactor.

Examining the development of British nuclear plant construction on a time scale one may distinguish periods resembling world trends, with important differences and specialities. Thus atomic energetics in that country so far may be given four periods:

- From 1956 through 1964 development was very rapid, buttressed by heavy state subsidies, and in the hope that British industry will take the lead in this new field, becoming the prime contractor in the construction of atomic power plants in other countries through the development of an economical and safe atomic plant type.
- During the period 1965–1972 it became clear, that with the unsatisfactory efficiency of the programme, especially considering the especially low fossil fuel prices of the time, the atomic plant construction programme could only be carried on by considerable amounts of further state subsidy. It became increasingly clear that the gas-cooled reator type developed in the United Kingdom cannot compete with the light-water types manufactured in the United States, although private companies constructing nuclear plants have also invested heavily in the development and building of plants which totals some 1500 million £.
- In the years between 1973–1978 nuclear plants already running became economical due to the high prices of conventional energy sources, but despite further development results and experiments all hopes in the competitiveness of gas-cooled reactors seem to lack foundation. With the now developed types British nuclear industry is in crisis, and they have turned to the use of slightly enriched uranium for the sake of greater operation safety and for gaining greater heat density. Part of the consumed uranium is enriched in the Soviet Union. No satisfactory long-term programme for further development has emerged so far but even official views now being expressed do not exclude the possibility of the use of light-water reactors. Due to the lack of new long-term plans the construction pace of nuclear power stations has kept slowing down in the 1970s, which may well have been caused by increased domestic petroleum and gas production, too, besides the reasons outlined above. 52 million tons of petroleum and 49 thousand million cu metres of natural gas were produced from below the North Sea in 1978.

The sole promising development at present appears to be the breeder reactor. The use of gas-cooled reactors with even higher temperatures of outcoming gas would only be justified if atomic energy were used for gaining technological heat at the same time. This practice, however, is yet to achieve worldwide recognition.

After sharp initial rises the development curve of British nuclear power industry took a more level course in the 1970s, at the same time when it gained new momentum in other advanced industrial states, like the United States, the German Federal Republic, France and Japan, in the second half of the '70s. Consequently – unless urgent steps for development are taken – British atomic energetics, initially taking the lead in this field, is bound to suffer its eclipse in the coming years. On the basis of its relatively early start and the significant nuclear plant capacity Britain still held second place, after the United States, in the output of electric energy that had been generated in its nuclear plants since the 1950s, by the end of 1979 (some 460 thousand million kW-hours).

Britain's atomic plants are all situated along the island's coast, ensuring the possibility of cold water supply for cooling – a factor of outstanding importance in the plant's economical operation. Apart from that concrete location is also influenced by the proximity of cities, industrial consuming centres and by certain aspects of regional development (e.g. development in Scotland). In view of the large densities of economy and population and of the given plant capacities, location of consumers is not a decisive factor. In selecting a site much more consideration is given to remote areas where heat pollution of future plants would not affect the population.

Britain is a leading world power in nuclear industry research works. During World War II a number of British nuclear scientists were working in the United States. Construction of nuclear plants was preceded by the setting up of research institutes with big staffs. The largest research centres perform producing, planning etc. functions as well.

One of the research centres was established at Harwell, where the first small, graphite-moderated reactor was completed as early as 1947, and a bigger (1.5 MW) research reactor named "Vero" was put into operation a year later at the same place, where the moderator was a graphite rod, with air taking the duty of coolant. Natural uranium was used as fuel here. Again here in 1956 the slightly larger "Dido" reactor was set up with heavy water both as moderator and cooling agent, whose heating elements were enriched to 80% in U_{235}. The following year a 6 MW reactor named "Pluto" was completed on similar functional principles to Dido's. With the research reactors of Harwell scientists aim at experimentally working out new fuel and heating element types, as well as at the production of isotopes (for industrial and medical purposes). A laboratory was also set up for the study of spent heating materials. The most important duty of the research centre, however, lies in the planning and constant improvement of reactor-systems generating electric energy. Apart from this they also specialize in the modernization of various particle accelerator types, and in the damage caused by radiation to the protecting shell of reactors. They also work out new elements of heating materials; other important sections carry out experiments for creating a sea water desalinizing device (fresh-water apparatus), and those for the recovery of uranium from sea water. Other applied research is also being carried on in Harwell; among others preservation and sterilization of foods by gamma rays, improvement of mechanical and electrical properties of various materials through irradiation by accelerators etc.

About 5500 persons work in the institute, with some 900 research engineers among them. This also serves to throw light on the size and significance of this research centre.

The second great nuclear research centre has grown up at Winfrith, in Southern England. Its primary aim is also the development of various reactor systems, evaluation of the running of the reactors from the viewpoint of economics and reactor physics, and the development of nuclear technology and instruments. The first "SGHWR" (Steam generating heavy water reactor) and "Dragon" reactors were constructed here.

The third large nuclear research centre has come into being at Dounreay, in the north of Scotland. Early research here was also concentrated on the development of thermal reactors. A reactor, marked 'DMTR', was put into service in 1958, with heavy water as cooling agent and moderator, and with the aim of putting reactor materials to trial. Fuel is concentrated to 93%, while the casing of fuel is made of uranium-aluminium alloy.

A big reprocessing plant was also installed in Dounreay processing spent heating elements of both thermal and breeder reactors. From the viewpoint of science Dounreay's significance stands first of all in the abovementioned fast-neutron breeder reactors, constructed and put into service here.

Apart from these three research institutes, numerous other larger and smaller ones have emerged with special research fields. Among them the reprocessing plant at Windscale (the largest in Britain) is outstanding, where spent heating elements of magnox, water-water and high-temperature reactors are being reprocessed. This reprocessing plant, built in 1952 and expanded in 1964, also receives for reprocessing spent heating elements from atomic power stations of Canada, Japan, Italy and other capitalist countries. The site has also got a section that separates plutonium. Spent heating elements from Japan and Italy are transported here by special ships. Some 1500 tons of fuel (calculated to 1% concentration) is reprocessed annually in this plant. Final product of the plant is UO_3, as well as plutonium metal. There is also a reprocessing plant in Capenhurst, and an experimental laboratory in Amersham. In addition to those described above major research institutes have been set up at Risley and Culcheth (both places specialize in the study of materials used in reactors), while a heating element factory is working in Springfield. A small uranium separating plant (gas diffusion) has been established at Capenhurst. Beyond these the atomic plants at Calder Hall and Chapel Cross are double-purpose facilities: they produce both electric energy and plutonium. The nuclear arms plant, the connected laboratories and experimental reactor are being run independently in the town of Aldermaston.

France was also among the first to use nuclear energy for peaceful purposes, although it was a few years late in starting its research and building the first commercial atomic plants compared to e.g. the United Kingdom and the Soviet Union. Nuclear research is on a very high level in the country. To achieve the aim of a nuclear arms industry based on its own resources and independent of the United States, early development of gas-cooled reactors fueled by natural uranium was promoted in France as well. This graphite-moderated reactor type, cooled by carbon dioxide, and which is different from the one developed by Britain only in its details of technological solutions, is still considered an independent French construction. Although important uranium deposits in France already became known in 1945, the possibility of building expensive uranium enrichment plants was then out of question.

France's first nuclear research institute at Fontenay-aux-Roses was founded in 1946 in connection with the discovery and opening of the country's uranium deposits in the years 1945 – 1952. Research was first concentrated on uranium chemistry, ranging from the primary enrichment of uranium to the production of heating elements. Research activity was later expanded to include other chemical experiments, e.g. separation of plutonium, study of irradiated materials and chemistry of liquid metal coolants. The institute's first small-capacity experimental reactor of heavy water – heavy water type (series mark EL – 1), with natural uranium heating elements, was installed at the end of 1948. More smaller reactors followed named Triton and Minerva, with experiments of reactor physics having been performed in them. And by the mid-fifties France completed her plant turning out metal uranium at Le Bouchet.

In 1951 a new nuclear physics research institute began operating in Saclay, a south-western suburb of Paris, which was to become the centre of basic research in the country. The small experimental heavy water – heavy water type reactor marked EL – 2 was put on stream here in 1952, which was followed by EL – 3, a 15 MW reactor of the same type in 1957. The latter uses uranium-molybdenum alloy as fuel, enriched to 1.35 per cent. Later two small experimental reactors, named Ulysse and Osiris were put into service in the institute. The facility at Saclay has developed into France's largest nuclear research institute, performing the complete cycle of basic research. Large cyclotron and synchrotron accelerators are being operated in the institute. A separate department specializes in the construction of nuclear powered ship engines. The optical department of the institute is also famous: "Mirabel", Europe's largest particle-photographing instrument was constructed here.

A new nuclear research centre was started in 1956 at Grenoble, where two experimental reactors, named "Melusine" and "Siloe" have been installed since. Numerous laboratories may be found in this institute, performing basic and applied research. They also do studies on irradiated materials and produce isotopes as well. A new research reactor was built in 1971, co-operating with scientists of the German Federal Republic from the outset.

To signify the extension of the atomic energy programme, a new nuclear research centre was built at Cadarache in 1963, whose chief duty is to work out new reactor types (mostly fast neutron ones fueled by plutonium). Apart from this its main duties include the building of nuclear powered ship engines, experiments on and construction of heating elements for atomic reactors, production of clean beryllium compounds, de-activization of liquid materials of medium radioactivity, reclamation of radioactive wastes and application of radioactive isotopes in agriculture. Successful experiments have been performed in the research centre on the development of fast neutron reactors. The breeder reactor named Rapsodie, with its initial capacity of 20 MW (later expanded to 24 MW), was installed as an experimental facility in 1967. Its capacity was eventually increased to 40 MW. Its heating material is made up of UO_2 and PuO_2, blended with ceramics, and concentrated first to 60%, later to 85%. Liquid sodium serves as coolant. Following the completion of the first succesful fast neutron reactor, decision was made in 1968 to construct a new, larger breeder reactor.

Several smaller thermal and fast neutron experimental reactors have been built at Cadarache. They include Cabri (light water), Cesar, Marius, Masurca and Hormonie (the last two are fast neutron reactors) and the reactor Peggy. Apart from these two, reactors for ship engines have also been constructed; they are named "Asur" and "Rat". Some larger-capacity reactors have also been built besides those listed above, like the 35 MW Pegase. The institute has acquired various types of accelerators and cooperates with the German Federal Republic in experiments on helium-cooled fast neutron reactors. Cadarache is situated on the river Durance, slightly north-east of Marseille.

In this country the first practical steps toward building atomic power plants were taken in 1952–1957. In 1956 the first, 5 MW experimental reactor, marked "GE–1" was built entirely on France's own resources, a graphite moderated, gas-cooled model, fueled by natural uranium. This was followed (also in Marcoule) by the 40 MW reactor marked GE–2 in 1959, and by the one marked GE–3 in 1960, also of 40 MW capacity, and similar to GE–1. They are double-purpose reactors: they produce both electric energy and plutonium. GE–2 was the first commercial reactor in the country; with its completion France has entered the ranks of countries operating nuclear plants (Fig. 2). Being provided by several laboratories Marcoule should also be considered a research site. Marcoule is in southern France, on the river Cèze, a small tributary of the Rhône, some 100 km north-west of Marseille.

Following the completion of the experimental reactor G–1 large-scale reactor-development works were started in France and – as it was already seen above – a total of 13 different experimental reactors have been constructed in the various research institutes. In 1960 a small capacity gas diffusion plant was built in Pierrelatte to ensure the supply to the reactors

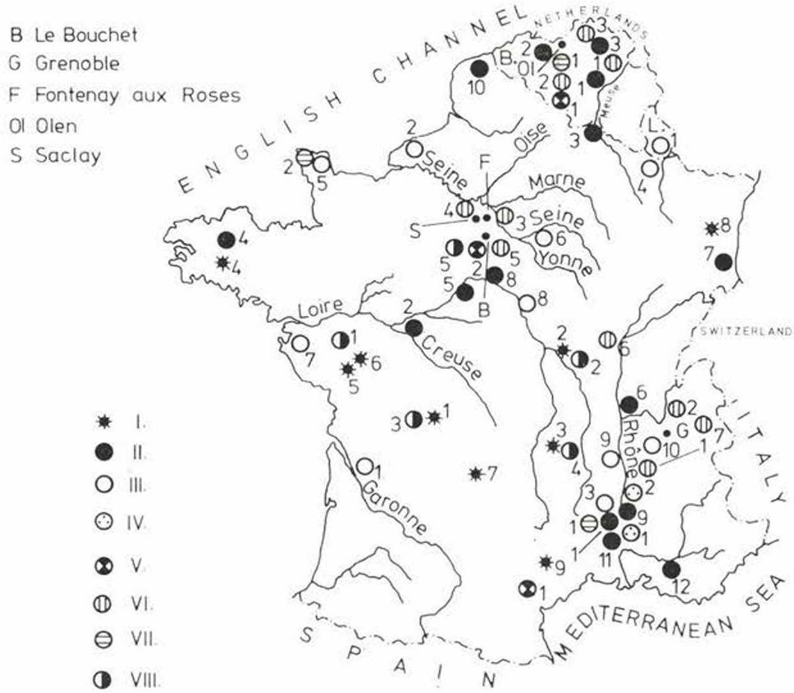

Figure 2. Location of nuclear power plants and other works connected with nuclear industry in France, Belgium and Luxembourg

France. I. Uranium ore deposits: 1 = La Crouzille (three different mines, they are: Fanay, Brugeaud, Margnac); 2 = Grury (Monts du Morvan); 3 = Saint-Priest, La Prugne (Monts du Forez); 4 = Pontivy (Bretagne); 5 = La Chapelle, Largeau; 6 = Vendée (Gatine Heights); 7 = Saint Pierre (Central); 8 = Saint Hippolyte; 9 = Lodéve. II. Working nuclear plants: 1 = Marcoule; 2 = Chinon; 3 = Chooz; 4 = Brennilis; 5 = St. Laurent; 6 = Bugey; 7 = Fessenheim; 8 = Dampierre; 9 = Tricastin; 10 = Gravelines; 11 = Phénix (Marcoule); 12 = Cadarache (experimental). III. Nuclear plants under construction: 1 = Le Blayais; 2 = Paluel; 3 = Cruas; 4 = Cattenom; 5 = Flamanville; 6 = = Nogent-sur-Seine; 7 = Le Pellerin; 8 = Belleville; 9 = St. Maurice; 10 = Malville (Super Phénix). IV. Uranium enrichment plants: 1 = Pierrelatte; 2 = Eurodif. V. Uranium metal producing plants: 1 = Malvési; 2 = Le Bouchet. VI. Manufacture of heating elements: 1 = Romans; 2 = Annecy; 3 = Bonneuil-sur-Marne; 4 = Corbeville; 5 = Bouchet; 6 = Chalon-sur-Saone; 7 = Chedde. VII. Reprocessing plants: 1 = Marcoule, 2 = Le Hague. VIII. Production of uranium concrete: 1 = = L'Ecarpiere; 2 = Guegnon; 3 = Bessines; 4 = Bois-Noirs; 5 = Le Bouchet.
Belgium. II. Working nuclear plants: 1 = Tihange; 2 = Doel; 3 = Mol (experimental). V. Production of uranium metal: 1 = Olen. VI. Manufacture of heating elements: 1 = Herstal; 2 = Olen; 3 = Mol. Reprocessing plant: 1 = Olen.
Luxembourg. III. Nuclear plant under construction: 1 = Remerschen.

running on enriched uranium. The Pierrelatte uranium enrichment plant serves mainly military purposes. Serial construction of nuclear plants was started after experiences at Marcoule had been taken into account.

The first to be built was "Chinon", a 70 MW commercial plant marked EDF – 1 near the town of this name. It was followed by the reactor marked EDF – 2 (with 240 MW capacity) also at Chinon in 1965, and the 500 MW reactor block marked EDF – 3 in 1967. Chinon is situated in central France in the triangle at the confluence of the rivers Loire and Creuse, on the bank of the latter. The first large-capacity graphite-moderated, gas-cooled nuclear plants of this country were installed here. The obsolete EDF – 1 plant was recently closed for good. Extension of the Chinon Atomic Plant by two pressurized water reactors of 905 MW each is planned for 1981 – 1982.

At almost the same time with these the first pressurized water reactor (325 MW) was completed in 1966, as a joint venture of France and Belgium, at Chooz, near the small town of Givet, on the river Maas, on French territory (Chooz SENA). Output of the station, built near the border of the two country as a common investment, is diverted on a 1/3 – 2/3 basis into the Belgian and French electric grid.

The next nuclear plant in line (marked EL – 4) was built on the fields of the village of Brennilis, with a capacity of 80 MW (Monts d'Arrée Atomic Plant). The plant, completed in 1970, is moderated by heavy water, uses CO_2 as coolant and U_{235} (enriched to 1.4 – 1.65%) as fuel. Enrichment is being carried out at the Pierrelatte plant, whose construction was completed in 1967.

Construction of gas-cooled reactors was continued at Saint Laurent des Eaux, on the river Loire, with the 500 and 530 MW reactor blocks of the Saint Laurent Atomic Plant, completed in 1969 and 1971 respectively. The site of the plant is located some 25 km SW of Orléans.

The last major gas-cooled nuclear plant (Bugey – 1) was built in central France with a capacity of 560 MW, on the right bank of the river Rhône, at Saint Vulbas, some 20 km NE of Lyon.

Experiences gained during the operation of gas-cooled reactors were not favourable, especially considering the economy of the nuclear plants. Similarly to those explained above in connection with British nuclear plants these atomic plants were not economical, considering the low fossil fuel prices prior to the oil price increases of 1973. Cost of primary investment of light water nuclear plants already being operated in other countries was only half of that of the gas-cooled plants, when calculated to similar capacity.

Accordingly, France has revised its nuclear energy programme, and on the basis of various decisions adopted in 1969 – 1970, it has turned to the better-proved pressurized water type nuclear plants developed by the United States. Their design and construction was carried out in co-operation with the U.S. The mixed company "Framatome" was founded with the participation of the Westinghouse firm and with the aim of building nuclear plants. The majority of the subsequent numerous atomic plants were built by this company.

The explosion of energy prices in 1973 has accelerated the new atomic plant construction programme that had already started, and from 1975 on large capacity pressurized water reactor blocks, based on the new concept, have been installed in large numbers. In 1975 the first such reactor block of 900 MW capacity was put into service in the Fessenheim Atomic Plant on the French – West German border on the left bank of the Rhine, east of Mulhouse. The second 900 MW unit was connected into the grid in 1977. The French are bent on building additional pressurized water reactors of 900 and 1300 MW capacity. Since 1978 90% of the net increase in electric energy production in France have originated from nuclear plants. The

Bugey Atomic Plant was expanded by four such units of 900 MW each in 1978 – 1979 (Bugey 2 – 5). Construction has started on additional large pressurized water power plants in this series. Work on the first reactor of the Paluel Atomic Plant, a seawater cooled model with a planned capacity of 2 × 1300 MW, was started in 1977 NE of the Seine estuary, on the coast near the town of Fecamp. The first block is expected to be operational by 1983. The Tricastin plant, being built slightly north of Marcoule Atomic Plant, with an eventual capacity of 4 × 900 MW, is already generating energy at the order of 3 × 900 MW from 1979. The fourth unit was put into service in 1980. Tricastin, built at the village of Trois Chateaux, will also supply energy to the neighbouring "Eurodif" enrichment plant. The sea-water cooled Le Blayais Atomic Plant, with its planned capacity of 4 × 900 MW, at the mouth of the river Garonne in the vicinity of Bordeaux, will have its first two units completed in 1981, and plans to have its two additional blocks operational by 1982 and 1983 respectively. The Dampierre-en-Burey Atomic Plant (planned capacity: 4 × 900 MW), located on the river Loire slightly SE of Orléans, generated electricity by its first two units in 1979. The other two will be completed in 1980 – 1981. The sea-water cooled Gravelines Atomic Plant, which is planned to contribute 4 × 900 MW capacity to the national grid, had its first two units completed in 1979. The two blocks of the second stage of this plant, situated close to the northernmost point of the country on the coast between Calais and Dunquerque, will be operational in 1980. The Flamanville Atomic Plant is also under construction on the coast of the English Channel near Cherbourg, in Normandy, with two pressurized water reactors of 1300 MW capacity each. Deadline for completion is set for 1984 – 1985. Expansion of the Saint Laurent is also planned to be carried out by two pressurized water reactors of 925 MW capacity each, with their expected installation in 1980 and 1981 respectively. Completion of the 4 × 900 MW, pressurized water Cruas Atomic Plant is expected by 1983 – 1984. It is located slightly east of Marcoule in the vicinity of the Tricastin Atomic Plant. Of the future locations of additional nuclear plants already announced construction on the following sites will already start in the mid-'80s: Cattenom 1 – 2, on the river Moselle near Metz; Nogent-sur-Seine 1 – 2, on the river of the same name, south-east of Paris; Le Pellerin, on the Atlantic coast south of the Loire estuary; Golfech, on the river Garonne, north of Toulouse; and finally St. Maurice, in the Rhône Valley, south of Lyon. These plants will largely exhaust the fresh-water cooling capacity of French rivers and additional larger nuclear plants will be located on the coasts of the Atlantic Ocean and the Mediterranean.

Apart from the nuclear plant construction programme outlined above and which supplies a significant share of France's electric energy production (nearly 17% in 1978), the country performs important research and development activities to work out fast breeder and other reactors. Within the framework of this programme Phénix, the first fast neutron reactor block, with a capacity of 250 MW, was built and installed in the Marcoule Atomic Plant in 1973. Experiences gained in the running of Rapsodie breeder reactor at Cadarache were utilized during the construction. Phénix also uses UO_2 and PuO_2 as fuel enriched to 17 and 28% respectively. On the basis of experience acquired during the operation of Phénix plans have been drawn up for the 1200 MW Super Phénix. Completion of Super Phénix is planned for 1983. This puts France to the second place after the Soviet Union in the development of fast breeder reactors. Design of Super Phénix is a joint venture of several European firms: EDF of France, Italy's ENEL and West Germany's RWE. French experts also regard fast neutron reactors as the basic nuclear plant type to be applied in the near future. The next stage in research and development will be the plant Hyper Phénix. This fast neutron nuclear facility is envisaged for construction at Chalon-sur-Saône, on the river Saône.

Following the termination of the construction of gas-cooled reactors French industry has effectively turned to the manufacture and installation of pressurized water nuclear plants, employing to some extent the technology of the United States. With its conversion to operating atomic plants running on enriched uranium France's independence in supplying fuel to its nuclear plants has come to an end, as the Pierrelatte plant works chiefly for military orders and has only limited capacity. This was the reason for the urgent construction of a new uranium enrichment plant. On France's initiative a new gas diffusion plant with French technology is being built on French soil by several countries on the following capital sharing basis: France: 57.5%, Italy: 22.5%, Spain and Belgium: 10% each. According to plans the first unit of this plant – "Eurodif" – will start production in 1980 with one third capacity. The enrichment plant is expected to run on full capacity by 1990, until then France will send its needed uranium for enrichment to the United States and the Soviet Union.

According to plans released France's nuclear plant construction programme is a very ambitious one. It calls for the installation of 120 thousand MW nuclear plant capacity until the turn of the millennium, of which 30–40 thousand MW would be generated by fast neutron reactors. Thus in a rather short time nuclear energy has got to hold a dominant share in France's electric energy production. The setting up of an adequate uranium industry is a precondition for this large-scale programme. Larger uranium deposits available for French use are shown in the following table, showing deposits in France and those secured in long-term production contracts with various African countries.

The deposits of uranium ore in the African countries (see table, next page) were explored by French equipment and experts, and France has also built large-capacity mines in two of the countries. In 1978 uranium mined in France and Niger was 2200 t each, while in Gabon it was 1200 t. Of the sites mentioned above production in Niger may be increased to 4–9000 t/year; in Gabon the aim is to keep the present level of mining, while in France itself output may be raised to 3–3.5 thousand tons/year.

Following primary uranium enrichment five large concentrating plants produce uranium oxide. They are: Bessines, L'Ecarpiere, Bois-Noirs, Gueugnon, and Le Bouchet.

France	60 200 t**	African countries***	78 000 t
from this:		from this:	
Forez and Morvan Hills	7 000 t (0.21)*	Gabon	20 000 t
La Crouzille	17 000 t (0.20)*	Niger	50 000 t
Vendée	8 000 t (0.19)*	Central African Republic	8 000 t
Largeau	12 000 t		
Pontivy (Bretagne)	1 200 t (0.54)*		
Saint Pierre (Central Massif)	15 000 t (0.29)*		

* uranium content
** positive findings and scarcely explored deposits combined
*** deposits of contracted areas only

Two other plants turn out uranium metal: the one at Le Bouchet (cap.: 800 t/year) and the other at Malvési (Cap.: 1500 t/year).

The sites producing heating elements are: Annecy, Romans, Le Bouchet, Chedde, Chalon, and Corbeville.

Having turned to light water reactors it was now necessary for France to shift to the production of UO_2 heating elements. A new plant had to be biuilt at Pierrelatte to produce the new fuel enriched to $3-4\%$, where enrichment sections of low (to 2%), medium (to $6-10\%$), high (to $25-30\%$) and very high degree (to 90%) had already been working.

Among other plants the Marcoule reprocessing and plutonium separation plant is significant that processes spent heating elements of local gas-cooled reactors. Spent heating elements from other gas-cooled, light-water, fast-neutron and other reactors are transported by rail to Normandy, to the la Hague peninsula slightly north-west of Cherbourg, on whose tip a reprocessing and plutonium separating plant is run by the French state. The plant processes 900 tons of spent uranium as its yearly capacity. During routine work – like in other reprocessing plants – neptunium$_{237}$ cesium$_{137}$ and strontium$_{90}$ are also obtained as by-products. The plant was expanded in 1976 and was adapted to reprocess UO_2 spent fuels as well. Capacity of the new plant is about 1400 t/year.

The German Federal Republic had not been permitted to decide its own nuclear policy following World War II. It had been doubtful for a long time whether the country would be allowed to join the ranks of those that used atomic energy for peaceful purposes in the near future. The government of the country began to subsidize nuclear research in 1956, while some industrial firms had already started nuclear research for peaceful purposes somewhat earlier. From this position of disadvantage the federal government has organized several new institutes for nuclear research, whose task – like that of the laboratories of private firms – was to come close to and catch up with countries leading in atomic energetics in the foreseeable future.

The government of the German Federal Republic (GFR) founded two large state nuclear research institutes at Karlsruhe and Jülich in 1957 that have stood out from among the state nuclear research institutes to our days.

The remarkably well equipped Karlsruhe research centre consists of 12 institutes whose field of work practically embraces the full cycle of basic and applied research pertaining to nuclear power plants. The research workers dispose of 8 different reactors (for thermal and fast neutron research), among them a larger commercial-experimental reactor (marked MZFR). Besides these a cyclotron of 50 million electron volts capacity, and a 40 ton/year capacity experimental reprocessing device operate in the institute. Among the activities of the institute research on fast neutron reactors, separation of isotopes, and development of heating element production are worth mentioning. They also do research on the chemical and physical processes brought about by nuclear radiation in living organisms.

The similarly large Jülich research centre has 18 research institutes that also comprise the major fields of basic and applied research. A special task of the Jülich research institute is to develop an MHD generator with the help of plasma physics and the generated heat of atomic reactors. For this purpose a special reactor has been built in which critical state of matter was successfully achieved as far back as 1971. Applied medical, botanical, zoological, agricultural and microbiological research is also being carried on in the institute. Three experimental reactors are operated in the Jülich institute: a 5 MW sunk basin type, a 15 MW heavy water model, and a 15 MW high-temperature, gas-cooled reactor (AVR). The latter runs on globular heating elements, and in 1975 outcoming temperature of 950°C was achieved. This institute also disposes of a large-capacity isochronal cyclotron and a linear accelerator.

The basic tasks of the Karlsruhe and Jülich institutes are the development of nuclear plant reactors, the working out of technologies, instruments, materials needed for these reactors, and environmental research.

The Nuclear Research Institute set up in West Berlin in 1957 is mostly financed by the federal government. It was formed from the chair of Nuclear Chemistry of the Technical University. The institute, which is smaller and has a limited programme compared to the two other institutes, was given an experimental reactor in 1958. A Van de Graaf accelerator was also installed here.

Among the larger nuclear research institutes the Max Planck Physics Institute, set up at Garching in 1960, has a place. Parallel to this the Scientific Research Centre on Radiation was founded in Neugerberg, also in the vicinity of Munich. This latter research institute also included in its programme the study of topical questions of environmental pollution in 1970.

A new research institute was organized in Darmstadt in the late 1960s that runs a heavy ion accelerating device. The "Desy" Electron-Synchrotron Institute was set up as an independent establishment near Hamburg, where Europe's largest-capacity electron synchrotron was constructed. The positron-electron tandem accelerator "PETRA" is also working here.

A large institute has been founded as an independent unit of the Justus Liebig University of Giessen, named Radioactive Research Centre on Radiation. A fairly wide range of basic and applied research on nuclear physics is being performed in the institute. The work of scientists is also helped by a cobalt gun, a large-capacity linear accelerator, twin ion accelerators and a neutron generator in this well-equipped research establishment.

The state nuclear research institute established at Geesthacht, slightly south-east of Hamburg, has the same rank as have the Karlsruhe and Jülich research facilities, and its chief aim is the design and building of atomic reactors that power ocean-going vessels. Reactors of both light water (water-water), and high-temperature, gas-cooled types are being built at the research site. Among the activities of the institute the design and construction of sea-water desalinizing devices using heat generated by atomic reactors, and the recovery of various minerals found in sea-water are important. Six reactors of various types work in the institute; among these three have 5, 15 and 25 MW capacities respectively. The Geesthacht research site has various other equipment necessary for its research duties.

In the GFR the Max Planck Society has six further important research sites, entirely or in part doing research in atomic physics. They are as follows: Institute of Nuclear Physics (Heidelberg), Institute of Physics and Astrophysics (Munich), Institute of Biophysics (Frankfurt an Main), Chemical Institute (Mainz), Metallurgical Research Institute (Stuttgart), Coal Analysing Institute (Mülheim).

The federal government and the provincial governments of the GFR have spent some 20 thousand million marks for the setting up and maintenance of the described research establishments between 1956 – 1979, which sum again shows the efforts made for closing up with the leading countries.

Like in other countries important nuclear physics research is being carried on in the technical universities of the Federal Republic and on the science faculties of others. Apart from the above institutes research on nuclear physics is also being performed in some 35 university department laboratory teams, mainly under contract with industrial firms. Some of these research ventures are of considerable size.

The picture thus drawn would not be complete if we didn't give an outline on the activities of the Federal Republic's major companies on nuclear physics research as in a number of cases the research laboratories of the great private enterprisses are larger than the biggest government research centres. Some 5 thousand scientists are employed near Frankfurt am Main at the AEG reactor research and development centre, but less than 3500 in the Karlsruhe institute. The Siemens firm maintains two large research laboratories: one at its headquarters in Erlangen, the other in the town of Garching. The firm Brown Boveri – with its largest steam turbine construction site at Mannheim – has set up its scientific experimental laboratory at Heidelberg, where research is concentrated at the direct transformation of atomic energy into electric energy The "Uranerzbergbau" enterprise runs a well-equipped laboratory in Bonn, where problems of production and processing of uranium are dealt with. No official figures are available on the financing expenditures of these private enterprises, but some West German sources put them on the same level as that of the state subsidies. To these should be added the research investiments of foreign (mainly US) firms into West Germany which are not covered by reliable data.

The creation of this large research network has had its results: the GFR has achieved world standard in the field of nuclear energetics and now even has leading position in some areas.

In the initial stage of the construction of commercial reactors foreign companies have also participated besides those of the Federal Republic, chiefly from the United States. The first small reactor of 16 MW capacity (named VAK) was completed near the settlement of Kahl, on the river Main, in 1962. (Fig. 3.) This reactor is of the boiling water type, with pressurized cooling water. Light water serves both as moderator and coolant. It uses UO_2 enriched to 2.3% as fuel. Construction of this nuclear plant has been carried out by the American General Electric and the West German AEG companies as prime contractors. In this period the atomic plant constructing firms of the GFR (mostly major well-known enterprises and their subsidiaries) have bought a lot of licences in the United Kingdom, France and the Unites States. This has significantly shortened the time from start of research to the building of reactors, and repetition of mistakes usual with beginners was possible to avoid. The '60s saw the construction of commercial thermal reactors of varied type and of chiefly smaller size, with the purpose of selecting suitable types for serial production and of gaining further experience. The boiling water type, 25 MW capacity atomic plant, marked HDR and built in the nearby village of Grosswelzheim, was meanwhile closed for ever.

The second commercial-experimental atomic plant (marked MZFR), with a capacity of 58 MW, was completed at Leopoldshafen, near Karlsruhe, in 1966. The reactor is of the heavy water type, uses D_2O as moderator and pressurized light water as coolant. Its fuel is non-enriched UO_2.

The third commercial-experimental nuclear plant (marked KRB) was put into service at the settlement of Gundremmingen, some 30 km north-east of Ulm on the river Danube, at the end of 1966. Its reactor is of the boiling water tape; cooling water is pressurized. It has an electric capacity of 250 MW. Both moderator and coolant is light water, while its fuel is slightly enriched UO_2. Prime contractors for this construction were the firms that had built the reactor at Kahl.

The fourth commercial-experimental atomic plant (Marked AVR) was installed at Jülich in 1967. It is a gas-cooled, high-temperature nuclear plant of 15 MW capacity, with globular heating elements. This reactor was planned and built by the firms Brown Boveri and Kruppreaktorbau.

The fifth commercial-experimental atomic power plant (marked KWL) was completed at Lingen on the river Ems, near the starting point of the Mittelland Canal, in 1968. This 250 MW reactor is of the boiling water type with steam superheated by oil burning. UO_2 enriched to 2.4% is used here as fuel. The reactor has a capacity of 216 MW including oil burning.

The sixth commercial-experimental nuclear plant (marked KWO) was built at Obrigheim on the river Neckar, east of Heidelberg, near the town of Mosbach. This pressurized water reactor of 340 MW capacity is fuelled by UO_2 enriched to 2.5–3.1%. The plant reached its planned capacity in 1970. The Siemens firm has been prime contractor in this venture.

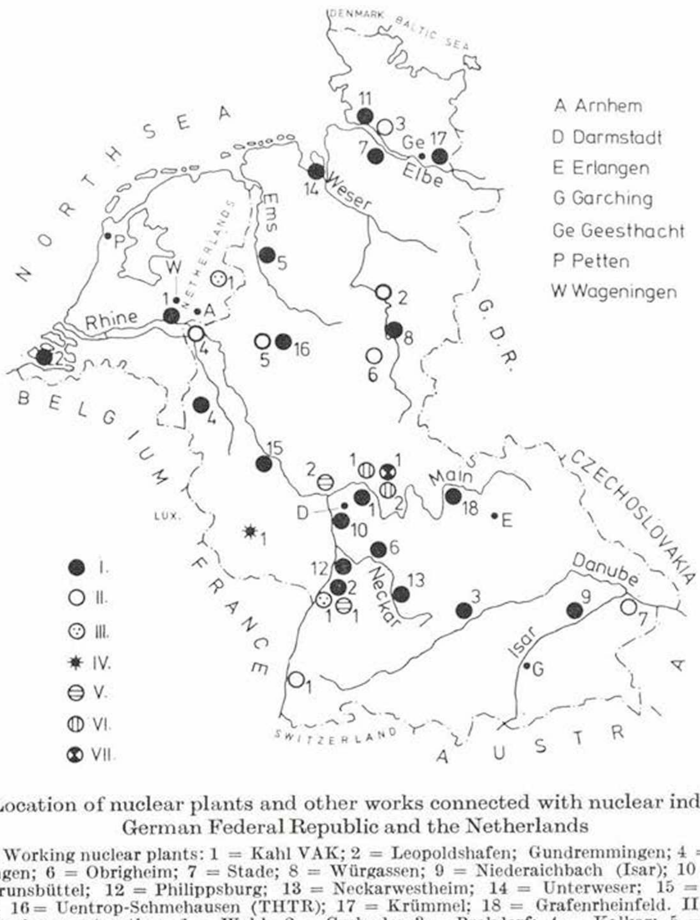

Figure 3. Location of nuclear plants and other works connected with nuclear industry in the German Federal Republic and the Netherlands

GFR. I. Working nuclear plants: 1 = Kahl VAK; 2 = Leopoldshafen; Gundremmingen; 4 = Jülich; 5 = Lingen; 6 = Obrigheim; 7 = Stade; 8 = Würgassen; 9 = Niederaichbach (Isar); 10 = Biblis; 11 = Brunsbüttel; 12 = Philippsburg; 13 = Neckarwestheim; 14 = Unterweser; 15 = Mülheim Kärlich; 16 = Uentrop-Schmehausen (THTR); 17 = Krümmel; 18 = Grafenrheinfeld. II. Nuclear plants under construction: 1 = Wyhl; 2 = Grohnde; 3 = Brokdorf; 4 = Kalkar; 5 = Hamm; 6 = Borken; 7 = Pleinting. III. Uranium einrichment plant: Karlsruhe (experimental). IV. Uranium ore deposit: 1 = Ellweiler. V. Reprocessing plants: 1 = Karlsruhe (experimental); 2 = Frankfurt am Main (under construction). VI. Manufacture of heating elements: 1 = Hanau; 2 = Wolfgang. VII. Production of uranium metal: 1 = Wolfgang.
The Netherlands. I. Working nuclear plants: 1 = Dodewaard; 2 = Borssele. III. Uranium enrichment plant: 1 = Almelo.

The seventh commercial-experimental reactor of 20 MW capacity (marked KNK – 1) was put into operation with special technological solutions at Leopoldshafen, in 1971. The reactor used sodium for thermal extraction; zirconium hydride (ZrH) served as moderator. Its fuel was UO_2 enriched to 6.8%. This nuclear plant was shut in 1974, rebuilt into a fast reactor cooled by sodium in 1975, and was put into service under the code-name KNK – 2 in 1977.

The eighth and ninth commercial-experimental atomic plants were completed in 1972, near the town of Stade at the estuary section of the river Elbe, and at the small town of Würgassen, south-west of Hannover on the river Weser. The 660 MW Stade Atomic Plant (marked KKS) is of the pressurized water type, while the 670 MW capacity Würgassen Atomic Plant is powered by a boiling water reactor. Both reactors are fueled by UO_2; their degree of enrichment are 3% and 2.6% respectively.

The tenth commercial-experimental atomic plant (marked KKN) – built at Niederaichbach on the river Isar – first generated electricity in 1973. This 100 MW gas-cooled reactor is of the heavy water type (its moderator is heavy water). Its fuel is 1.15% enriched uranium.

With these reactors listed above the study of thermal reactor types in the Federal Republic – for the purpose of selecting the best suited types – has come to a close. Certainly water-water type reactors (boiling water and pressurized water) have proved to be the best, consequently the large commercial reactors afterwards were constructed solely on this pattern. Following that large-scale nuclear plant construction in the GFR has begun in full force.

Both boiling water and pressurized water reactors have been built from the outset. Looking back one may establish the trend that early construction of mostly boiling water reactors was later replaced by the building of pressurized water models as the dominating type. Light water commercial reactors, built in the GFR, represent three development levels, excluding the Karlsruhe (VAK) and other experimental facilities.

The first development level is represented by the Gundremmingen, Lingen and Obrigheim Atomic Plants, installed between 1966 – 1969, with capacities ranging between 250 – 340 MW.

The next development level is marked by the installation in 1972 of the Stade and Würgassen nuclear plants with capacities of 660 and 670 MW respectively.

From 1974 on some truly large-capacity reactors have been put into operation, representing the third development level. The year 1974 saw the completion of two big atomic plants. One of them, coded RW – 1 (also called Biblis – 1), was built with a capacity of 1204 MW between Ludwigshafen and Frankfurt, on the Rhine north of Worms. This reactor is of the pressurized water type. Another atomic plant (marked KKB), equipped by a boiling water reactor with a capacity of 805 MW, was put into service near the town of Brunsbüttel, not far from the starting point of the Nord-Ostsee Canal, at the end of the Elbe estuary.

The Neckarwestheim Atomic Plant (marked GKN) on the river Neckar was completed in the following year, in 1975. It has a pressurized water reactor of 885 MW capacity. The 1300 MW pressurized water reactor "Biblis – 2" was connected on the national grid in 1977.

The Unterweser Atomic Plant was installed at the town of Nordenham, on the Weser estuary to the North Sea, in 1978. This pressurized water plant has a capacity of 1300 MW. The same year witnessed the completion of the nuclear plant "KPK – 1", with its 900 MW capacity boiling water reactor, near the town of Philippsburg, on the Rhine slightly north of Mannheim.

The following nuclear plants are under construction: Krümmel (marked KKK), cap.: 1300 MW, boiling wazer; Grafenrheinfeld (KKG), cap.: 1300 MW, pressurized water; Mülheim-Kärlich (Koblenz Nord), cap: 1300 MW, pressurized water; Uentrop (THTR), cap: 300 MW, high-temperature, gas-cooled. Completion of the last four atomic plants is expected for 1980 after considerable delay (regarding the original plans). With the completion of these constructions the Federal Republic will have a total built-in nuclear plant capacity of about 12 800 MW by 1980, and this will put it to the 4th place among capitalist countries. The building of the reactor THTR near the settlement of Uentrop-Schmehausen, on the north-eastern edge of the Ruhr Region, is remarkable. Besides its favourable conversion efficiency, its sparing of the environment, which is even better compared to the water-water type reactors, will facilitate the spread of this reactor type.

The nuclear plant programme of the GFR will continue in the first half of the '80s chiefly by expanding existing plants. Blocks No. 2. and 3. at Gundremmingen are set for installation with boiling water reactors of 1300 MW capacity each by 1981 – 1982. The 1300 MW pressurized water reactor of Philippsburg – 2 is planned for completion by 1982. The pressurized water reactors of Biblis – 3 (1300 MW) and Neckarwestheim – 2 (855 MW) should generate electricity by 1983 and 1984 respectively. Construction of Isar – 2 (Ohu) with a 900 MW boiling water reactor is set for completion by 1985. Apart from these several new atomic plants are expected to supply additional energy, among them: Grohnde, cap.: 1300 MW, pressurized water, in 1982; Wyhl, Brokdorf and Hamm Atomic Plants, cap.: 1300 MW each, pressurized water, in 1983; and the fast neutron reactor of the Kalkar Atomic Plant, cap.: 327 MW, also in 1983. They are planned to be followed by the nuclear plants Neupotz, Vahnum, Pleinting and Borken through the end of 1986.

Dutch, Belgian and Luxemburgian firms will also take part in the building of the Kalkar fast reactor. The firm "Belganuklear" will manufacture heating elements, while the Na/H_2O steam generator and the sodium pumps will be the responsibility of the Dutch firm "Niratom". The Federal Republic will continue to rely on foreign help in future development and construction of large capacity fast neutron reactors. Construction of its first large-capacity fast neutron reactor is planned in

France, while the second (with a capacity of around 1000 MW) is expected to be installed in the GFR, both with French cooperation.

Earlier forecasts in the Federal Republic had envisaged dynamic growth for the '80s, but according to later plans the pace of development will decline, and nuclear plant capacity will thus reach about 25 – 27 thousand MW by 1985.

Looking at the present situation the heating material mined in the GFR is not sufficient and the country has to buy some two-thirds of its consumed UO_2 abroad. There are some uranium deposits in north-eastern Bavaria in the Oberpfälzer Wald and in the province of Rheinland-Pfalz (Rhineland-Palatinate). Deposits of the latter occurrence are put at a few thousand tons, and mining of the ore is going on. There is a smaller occurrence in the Schwarzwald (Black Forest). In this situation uranium mining firms of the Federal Republic, namely the "Uranerzbergbau Gesellschaft" and the "Urangesellschaft", with headquarters at Bonn and Frankfurt am Main respectively, buy uranium ore for stockpiles in France, Canada and elsewhere. The federal government also backs financially the activities of these firms abroad, that are directed at acquiring prospecting and mining rights and at purchasing shares of foreign mining companies and uranium enrichment plants. The enterprise "Urangesellschaft" holds 10% of the shares of the Niger mining and enrichment company "Somair", while the firm "Uranerzbergbau" participates in Canadian mining. Since 1974 the GFR has been receiving 150 tons of U_3O_8 a year from the Republic of Niger, and this will be doubled in the future. Uranium supply coming from Canadian production, however, is more substantial.

Heating element factories of the Federal Republic almost entirely satisfy domestic demands. Two such great works have been constructed: one of them at the town of Hanau, the other at closeby Wolfgang. These works are managed by the firms "Kernreaktorteile" and "Reaktorbrennelemente"*. Plutonium heating elements for the fast neutron atomic plants are manufactured by the Alkem* Company. Zirconium pipes for the heating elements are produced by the following firms: "VDM" (Duisburg), "SUT" (Sprendlingen) and MRW (Düsseldorf). Sprendlingen is situated at the southern fringes of Frankfurt am Main.

At present the GFR does not have its own uranium enrichment facilities; enrichment for the country's plants is performed chiefly in the United States and, to a lesser degree, in the Soviet Union. Effective research is being carried on, however, for the construction of such plants. In 1970 three countries: the United Kingdom, the Netherlands and the GFR signed a contract for the establishment of 'Urenco', a joint company that builds common experimental ultracentrifugal enrichment works at Capenhurst (Britain), Almelo (The Netherlands), and Gronau (GFR). The experimental plants will be built on these three sites for the purpose of gaining experience and creating suitable prototypes. By 1982 output of the Capenhurst and Almelo works will have reached 400 t/year and 600 t/year respectively,

* subsidiaries of Siemens

while the Gronau plant will produce 400 t/year from 1985 on. Almelo had its first enrichment unit installed back in 1974. The centrifugal equipment was produced by the West German firm MAN, that had already designed and constructed generations of centrifugals. The Karlsruhe research institute has worked out a further method of uranium separation, namely the sprinkler method, and an experimental device was also created there.

At present reprocessing of spent heating elements is done at the only existing, small capacity Karlsruhe plant. Spent heating elements are therefore shipped to the United States, Britain and Belgium for reprocessing. To construct a reprocessing plant of commercial size in the country a joint enterprise (URG) was established at Frankfurt am Main, with French and British participation. The plant will carry out reprocessing for all three countries, and has a planned capacity to process 1500 t/year of oxide heating elements.

Nuclear plant construction companies of the Federal Republic also work on orders from abroad. The first such venture was completed in Argentina in 1968, where a 340 MW, PHWR type nuclear plant (with D_2O moderator and pressurized light water coolant) was built at the town of Atucha, somewhat north-west of Buenos Aires on the southern river arm of the Paraná delta.

The second nuclear plant built by West German firms was a 477 MW capacity pressurized water reactor. It is situated at the town of Borssele, in the Netherlands.

The Austrian boiling water type atomic plant, which is still uncompleted as a result of the negative outcome of the referendum, has also been built by West German firms.

Amid fierce international competition (by American and Swedish companies) KWU has won the tender for the construction of the 960 MW pressurized water Gössgen Atomic Plant in Switzerland. West German firms have also held talks on nuclear plants to be built in other countries, like Iran, Brazil, the People's Republic of China etc. These examples demonstrate the efforts of West German industry to gain international positions in this new branch of economy.

On the basis of constructions carried out up to the present we may give a short summary of the types of nuclear plants the major companies have specialized in. The Siemens firm has specialized in the construction of pressurized water and heavy water atomic plants. The firm AEG Telefunken (headquarters in Frankfurt am Main) did so in boiling water reactors. Brown Boveri builds high-temperature, gas-cooled reactors jointly with the firm Kruppreaktorbau. Interatom (headquarters in Bensberg) has specialized in sodium-cooled (both thermal and fast neutron) reactors and in those for ship engines. Recently this enterprise has been working busily on the creation of an MHD-generator power plant (plasma-plant) connected to a nuclear plant. 60% of the company's shares are held by Siemens, while 20% by the firm Demag.

The firm Kraftwerkunion (headquarters on Mülheim) an der Ruhr supplies equipment to both pressurized water, boiling water and heavy water reactor types. At present this company produces the world's largest nuclear reactors in terms of capacity. Since January 1st, 1977, the shares of this enterprise have been owned 100% by the firm Siemens. KWU's reactor and turbine constructing plants are located in the town of Mülheim itself.

Apart from those listed above the following firms have specialized in the supply of certain types of nuclear plant equipment: West (headquarters in Frankfurt am Main), Gutehoffnungshütte (headq.: Sterkrade), Demag (headq.: Duisburg), and Krupp (headq.: Essen).

When looking at the map of the Federal Republic one may state the fact that the country now has a fairly dense pattern of nuclear plants. Their greatest concentration, however, is found along the Rhine and on the Elbe estuary. Intentional location of nuclear plants in the south of the country, along the rivers Danube, Isar and Rhine, may be perceived, for the purpose of easing the area's shortage in primary energy sources. Although the network of nuclear plants is rather dense, proximity of cities and other large consuming centres clearly have had significant impact on the decisions on locating the plants. In such conditions finding suitable sites for new plants in the GFR is not an easy task. Consequently the idea has been raised that would locate nuclear plants on artificial islands in the North Sea. As a matter of fact, at present construction of some of the new plants is carried out in heavily populated, built-up areas. An increasingly large share of future electric energy needs of the advanced West German industry will have to be provided by nuclear plants. In selecting the location of plants the danger of radiation is practically out of question; the reason why these water-cooled stations are built still a little farther from populated areas is that the thermal pollution of the environment (air and water) should not affect the population.

Spain was generally regarded as an industrially backward, slowly developing country until the early 1960s. However, during the 1960s rapid industrialization started to take place in the country and, for one thing, it now produces more than 11 million tons of steel each year. Development of industry has rapidly increased the demand for energy, but apart from the country's small coal deposits and its hydroelectric potential of limited importance it does not possess significant sources of energy. The major part of the country's energy needs has to be met by imported petroleum (60 million t/year).

It seemed therefore expedient for the country to start a nuclear plant construction programme in order to meet the rapidly growing demand for electric energy. Spain essentially also voted in favour of the two nuclear plant types developed by the United States.

Similarly to other countries a small capacity atomic plant was installed at first, primarily for the purpose of gaining experience. This power plant, named José Cabrera (Fig. 4.), was put to service with a pressurized water reactor of 153 MW capacity, near the village of Almonacid de Zorita, on the river Tajo, in 1969. The small capacity did not raise any special demands on location, for it uses a moderate amount of cooling water. The plant was built somewhat to the north-east of Madrid.

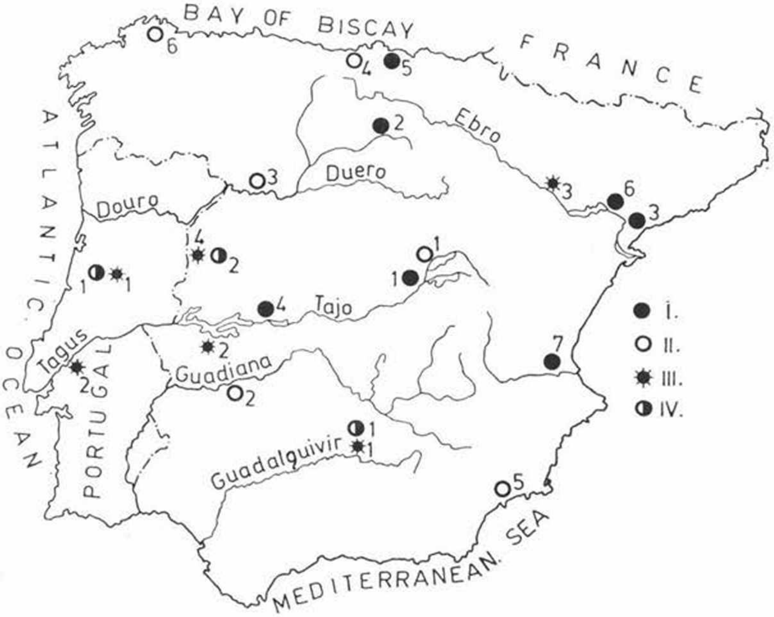

Figure 4. Location of nuclear plants and other works connected with nuclear industry in Spain and Portugal

Spain. I. Working nuclear plants: 1 = Jose Cabrera; 2 = Santa Maria de Garonna; 3 = Vandellos; 4 = Almaraz; 5 = Lemoniz; 6 = Asco; 7 = Conferentes. II. Nuclear plants under construction: 1 = Trillo; 2 = Valdecaballeros; 3 = Sayago; 4 = Santillan; 5 = Cabo Cope; 6 = Regodola. III. Uranium ore deposits: 1 = Andujar; 2 = Caceres; 3 = Zaragoza; 4 = Ciudad Rodrigo. IV. Production of uranium oxide: 1 = Andujar; 2 = Ciudad Rodrigo. *Portugal.* III. Uranium ore deposit: 1 = = Urgeiriça. IV. Production of uranium oxide: 1 = Urgeiriça.

The second Spanish atomic plant, called Santa Maria de Garonna, was constructed with a capacity of 440 MW near the town of Burgos, on the river Arlanzón. It was installed with a boiling water reactor in 1971.

The following year saw the completion of the third nuclear plant, named Vandellos, which had been built in French–Spanish co-operation. This plant is different from other Spanish nuclear plants, for it was constructed with a French made gas-cooled reactor. Its capacity is 480 MW. It is located near the village of Hospitalet del Infante, slightly south of Tarragona, on the coast of the Mediterranean. Plans call for its expansion by two pressurized water reactors of 1000 MW capacity each, of which the first is expected to be completed by 1982.

The fourth, truly large-capacity Spanish nuclear plant, called Almaraz, was put to service with a 930 MW pressurized water reactor, in 1979. The site of the power plant is north of the town of Caseres, on a dammed river branch of the Tajo, close to the Portuguese frontier. Completion of the similar second block is planned for 1980.

The Lemoniz Atomic Plant, located on the fringes of the small town of Arminza, near Bilbao, will also run with two pressurized water reactors of 930 MW capacity each. The first block was completed in 1979, while the second is expected to be installed in 1981. The Asco power plant has been built on the same design, with two pressurized water reactors of 930 MW capacity each, between Barcelona and Tarragona on the Mediterranean coast. It has been supplying electricity since 1979.

In addition to those listed above Spain has several plants under construction.

The Cofrentes Atomic Plant, planned for completion in 1980, was built with a boiling water reactor of 974 MW capacity near Valencia, on the Mediterranean coast.

The Sayago Atomic Plant is under construction with a 1000 MW pressurized water reactor, on the shores of the reservoir created by damming the river Duero, near the town of Zamora (at the village of Moral de Sayago), close to the Portuguese border. Its completion is expected for 1986. Another atomic plant, named Trillo, is being built east of Madrid, near a reservoir of the the Tajo, with pressurized water reactors of 2×1000 MW capacity. Completion of the first block is expected for 1982. The Valdecaballeros Atomic Plant is under construction with two boiling water reactors of 1000 MW capacity each, east of the town of Badajoz, on the shores of a reservoir on the Guadiana river. Their expected dates for completion are 1981 and 1983 respectively.

Beyond these, construction of the atomic plant "Santillan", near the village of San Vicente, west of Bilbao on the coast of the Bay of Vizcaya, and of another one named "Cabo Cope" , south-west of Cartagena on the Mediterranean coast are also planned (with boiling water reactors of 1000 and 930 MW capacities respectively). The latest site for the location of a new plant is at Regodola, where a pressurized water nuclear plant of around 1100 MW capacity is envisaged.

With its built-in nuclear plant capacity of roughly 6500 MW and an additional 6000 MW under construction Spain holds a fair place among nations applying nuclear technology. This has been achieved by the concentration of resources and by selecting the most suitable types. Supposing an unbroken development Spain, with its nuclear energy output, for some time may take a place near the top in the rank of countries with high nuclear plant capacities.

Italy joined the ranks of countries operating nuclear plants at the rather early date of 1963. In that year its first atomic plant, named "Latina", was installed with assistance from British firms. The plant was built with a gas-cooled (magnox) reactor of 160 MW capacity, near the town of Latina, south of Rome, close to the Tyrrhenian sea-coast. The second plant in line started to generate electricity also near the coast in 1964, but with a boiling water reactor of 160 MW capacity. This atomic plant, named "Garigliano", is situated on the stream of the same name, on the fringes of the small town of Sessa Aurunca. The power plant was built with the American General Electric Company taking part. The third nuclear plant, equipped with a 257 MW pressurized water reactor, was built with assistance from the American firm Westinghouse. The facility, called "Trino Vercellese", was constructed near the town of Vercelli, on the river Sesia.

For the purpose of manufacturing some of the equipment of the said nuclear plants Italian industry has bought several licences.

Apart from hydroelectric power, and disregarding the small deposits of natural gas, Italy does not actually possess domestic reserves of energy sources. Two-thirds of the country's production of electric energy comes from imported petroleum, which now runs at some 180 million t/year. Consequently its early participation in harnessing nuclear energy was justified indeed. Apart from already existing hydroelectic power plants and thermal power stations burning imported oil, even at this time only nuclear power plants seemed economically capable of supplying the growing amounts of electric energy demanded by the advanced Italian industry. The Italian atomic plant construction programme has started accordingly, on a wide base.

After a promising start, however, construction of Italian nuclear plants came to a halt, which was to last for about 10 years. This break was probably caused by the extremely low world market prices of petroleum, lasting up to 1973. The first large-capacity atomic plant, named Caorso, was installed as late as 1975, with a 822 MW boiling water reactor, east of Milan, on the river Po, between the towns of Piacenza and Cremona.

Meanwhile a decision was passed that called for the future development of Italian nuclear plants by the construction of pressurized water and boiling water reactors of 950 and 980 MW capacities respectively. Construction on the nuclear plant powered by two pressurized water reactors of 950 MW capacity each was started, with the participation of the Westinghouse firm, near the settlement of Montalto di Castro, at the mouth of the stream Fiora, north-west of Rome on the Mediterranean coast. Completion of the power plant is expected for 1984. Work on the other facility, the Termoli Atomic Plant, eventually equipped by two boiling water reactors of 980 MW capacity each, began with the participation of the General Electric firm, near the small town of Termoli, south-east of Pescara on the Adriatic coast. Much equipment for these plants was supplied by the Italian industry producing under licences.

Italian use of the British gas-cooled reactor type was abandoned earlier. The start of building experimental reactors of its own design should be seen as one sign of ending Italy's dependence on American licences. Such a nuclear plant is e.g. the one, named Cirene, under construction slightly south of Latina, which is powered by a natural uranium fueled, heavy water moderated reactor of 40 MW capacity, and cooled by a mixture of light water and steam.

Among heavy water moderated, larger-capacity experimental reactors the 8 MW ESSOR, run by the nuclear research institute at the town of Ispra on Lake Maggiore, should be included. The Ispra research institute runs a total of 5 experimental reactors.

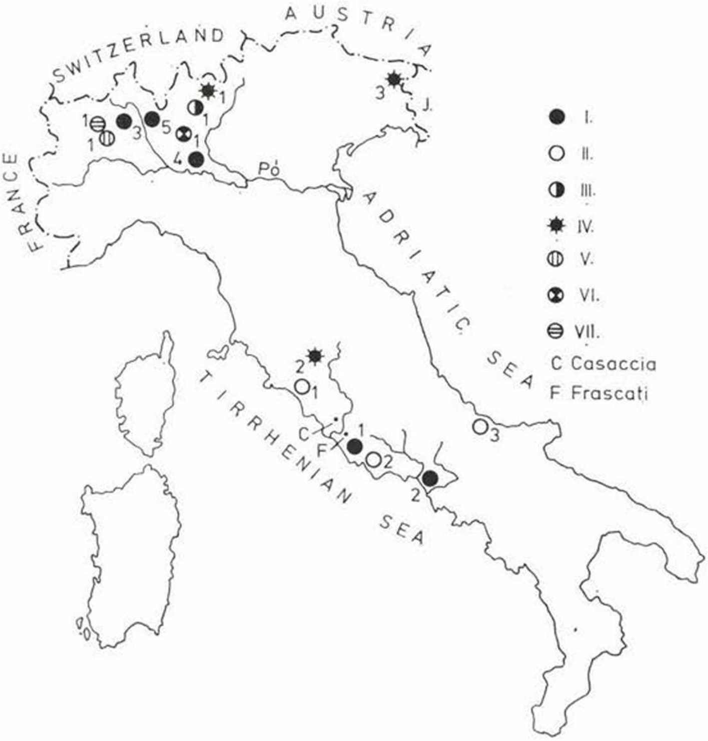

Figure 5. Location of nuclear plants and other works connected with nuclear industry in Italy

I. Working nuclear plants: 1 =Latina; 2 = Garigliano; 3 = Trino Vercellese; 4 = Caorso; 5 = = Ispra (experimental). II. Nuclear plants under construction: 1 = Montalto di Castro; 2 = Cirene (Latina); 3 = Termoli (Molise). IV. Uranium ore deposits: 1 = Novazi (Clusone near Bergamo); 2 = Vitterio (near Viterbo)· 3 = Trento. III. Production of uranium oxide: 1 =Novazi. VI. Production of uranium metal: 1 = Milan. V. Manufacture of heating elements: 1 = Saluggia. VII Reprocessing plant (experimental): 1 = Saluggia.

Apart from the already mentioned Ispra institute, Italy has an impressive network of nuclear research institutes. The institute, founded in the town of Frascati, some 20 – 25 km south-east of Rome, was created with the aim of basic research. Another large institute for applied reactor research was established in the small town of Casaccia, at a similar distance, to the north-west of Rome, where 6 experimental reactors of different functions are worked on. One of the reactors serves the purpose of fast reactor research. Activities of the Bologna computer centre are also connected with these reactor research works. Two smaller research reactors also work in the outskirts of Bologna. In addition to these two larger research institutes have also been set up, that do actual production as well. A heating element manufacture-assembly plant has been built at Saluggia for the purpose of assembling the elements shipped by the Westinghouse firm. For the time being the plant manufactures heating elements of chiefly experimental reactors (uranium metal and ceramics heating elements etc.), while to a lesser extent, it also works for pressurized water reactors. An experimental plant has also been set up here to reprocess spent heating elements. This institute also specializes in developing a nuclear powered ship engine and in fast neutron reactor experiments. Preliminary experiments connected with the operational running of the Cirene reactor were also performed here. In Milan a special laboratory group has been formed with the participation of numerous large firms, where production of heavy water, enrichment of uranium and construction of reactors are carried on. Plans for the Cirene reactor have also been worked out here. The long-term aim of the construction of the latter reactor is to end the country's reliance on imported enriched uranium.

Plans have surfaced on the setting up of a plant by a possible American – Italian joint company that would manufacture heating elements for boiling water reactors. For the same purpose another British – Italian joint enterprise is planned for the reactors fueled by natural uranium. Considering all these it should be clear, that Italy is interested in the construction of the uranium enrichment plant "Eurodif", which is being planned by several advanced European capitalist countries. At the same time the country gives high priority for the domestic research on the separation of uranium. Two research ultracentrifugal types are operated in Florence, and research is also directed on the development of highly productive diffusion membranes. Until the country's enrichment plant is completed, enriched uranium for its reactors will be bought chiefly from the United States and, to a lesser degree, from the Soviet Union. Under the agreement, signed in the Soviet Union in 1973, Italy will receive from the Soviet Union enriched uranium for the manufacture of heating elements, between 1975 – 83.

A look at the spatial pattern of Italian research institutes will confirm at once the concentration of locations around centres of learning, universities and sites of big companies. Spatial distribution of nuclear power plants, on the other hand, reflect the special features of the Italian energy system. During the present period atomic plants were constructed in the economically advanced northern part of the country, as well as in the vicinity of larger central Italian industrial agglomerations.

Among Italian companies that have participated in the development of the country's nuclear industry the firm "Breda" is outstanding: its important engineering works in the town of Sesto San Giovanni manufacture main components of pressurized water and other reactors. Based on licence purchases Italian machine industry is now capable of turning out the full cycle of nuclear plant equipment almost independently. Most of its production capacity is working for export orders into the GFR.

Italy's uranium reserves, considering high-grade ores, stand at the rather modest figure of 1000 tons. Uranium deposits, that are exploitable at higher costs, however, are approximately 30 000 tons. The best quality ores are found near Bergamo, where a small uranium enrichment plant was also set up. Apart from these there are positive thorium findings in

Calabria, with relatively high ore concentration, and there are some low-grade thorium deposits in the province of Lazio, too. The latter region has a promising site for mining north of the settlement of Vitterio, with deposits of U_3O_8 put at about 10 000 tons. Most of the described deposits consist of low-grade ores; mining stands at 150 t/year with actual work going on only near Bergamo. In these conditions the country is forced, even at present, to import significant amounts of uranium from Canada, France etc. To improve the supply of uranium Italian firms contribute financially to prospecting and exploiting by Canadian and American firms. Bi-lateral agreements with Somalia and Gambia for uranium prospecting on their territories also aim at guaranteed uranium supply. Italy has also concluded an agreement with the Republic of Niger, through the French–Niger company, for mining uranium ore.

Although after its relatively early start, which was followed by a 10 year halt, Italy launched its nuclear programme in the 1970s, it will be hard put to make up for its lag, compared to countries following more consequent nuclear policies.

Among western European countries *Sweden* has developed an impressive nuclear technological base, and it now ranks first in this respect in the group of the Scandinavian countries. The extensive application of nuclear power in Sweden may be traced to the almost complete utilization of ist hydroelectric resources, and its lack of any other energy sources (apart from very little coal deposits and production). To satisfy demands, considerable amounts of electric energy were imported in the early '70s, mainly from Norway. Existence of the advanced Swedish industry was a factor of advantage for the construction of nuclear plants. Sweden is the only capitalist country, that was able to construct light-water, boiling-water reactors very much on its own resources, with the purchase of very few American licences.

The first Swedish nuclear plant, named "Ogesta", was put to service in the outskirts of Stockholm with an electric capacity of 12 MW, in 1964. "Ogesta" was one of those rare types of plants that had three cycles: production of heat (first cycle), twofold utilization of hot water, with part of it driving the turbines in the vaporizer by its steam (second cycle), and the rest used as communal hot water (third cycle). Heavy water served both as moderator and coolant. The basic function of the power station was communal heat supply; its total heat generating output reached 80 MW. The nuclear plant has proved the safety of reactors to the population both inside and outside the plant area. Because the plant, that had been working since 1963, was technologically obsolete, operated at a high cost and was unable to supply all hot water needs of the surrounding residential area, it has been dismantled and its marketable components sold. (During a study tour of Sweden by a group of geography undergraduates from the Roland Eötvös University of Budapest, in 1966, the students had the opportunity to learn the functions and location of the "Ogesta" reactor.)

The first large nuclear plant, with a boiling water reactor, was installed in 1971 near the town of Oskarshamn ("Oskarshamn–I"), and the reactor reached its 460 MW capacity in 1972 (Fig. 6.). The power plant was located at the Kalmar-sund strait, on the Baltic sea-coast, in the south-eastern part of the country, at almost the same latitude with the northern tip of the island of Öland. Equipment was supplied by the Swedish firm "Asea-atom". The first reactor was followed by the installation of a 600 MW boiling water reactor two years later, at the same site (Oskarshamn – II). Uranium for these two plants was bought in France and enriched in the United States. These nuclear plants were constructed with virtually no foreign help, consequently they may be regarded as Swedish national designs. The boiling water reactor of "Oskarshamn – III", with a capacity of 110 MW, is envisaged for completion by 1984.

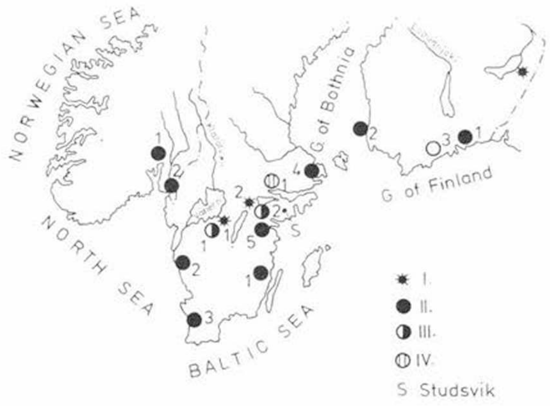

Figure 6. Location of nuclear plants and other works connected with nuclear industry in the Scandinavian countries

Sweden. I. Uranium ore deposits: 1 = Billingen; 2 = Kvarntorp. II. Working nuclear plants: 1 = Oskarshamn; 2 = Ringhals; 3 = Barsebäck; 4 = Forsmark (Estahammer); 5 = Marviken (experimental). III. Production of uranium oxide: 1 = Ranstad; 2 = Kvarntorp. IV. Manufacture of heating elements: 1 = Västerás.
Finland. I. Uranium ore deposit: 1 = Eno. II. Working nuclear plants: 1 = Loviisa; 2 = Olkiluoto. Nuclear plant under construction: 1=Helsinki. *Norway.* II. Working nuclear plants: 1 = Oslo (experimental); 2 = Halden (experimental).

The next step was the installation of the first unit of the Ringhals Atomic Plant in 1973, with a boiling water reactor of 780 MW capacity, also with components manufactured by the firm "Asea-atom". Fuel for this reactor has been supplied by the heating element factory of the firm "Asea-atom", built in the town of Västeras. The power plant is located near Varberg, at the Kattegat Sound on the south-western coast of Sweden. At present the Ringhals plant is Sweden's largest nuclear power station, where a 860 MW pressurized water reactor has since been built, which was followed by two reactor blocks of the same type, each with 900 MW capacity, in 1974 and 1978 – 1979 respectively. Equipment for the last three reactors have been supplied by the firm Westinghouse.

Construction of the Barsebäck Atomic Plant, named after a small nearby settlement, was simultaneous with that of the Ringhals nuclear facility. This plant was located 20 km to the north of Malmö on the Öresund coast, near the town of Löddeköpinge, and has two Swedish-made reactor blocks of 580 MW capacity each. The blocks have been generating electricity since 1975 and 1978 respectively.

Depending on the favourable outcome of the referendum planned for March, 1980, the first two units of Forsmark, the next large Swedish nuclear plant, is expected to be installed in 1980, with boiling water reactors of 2×900 MW capacity. The plant is located near the settlement of Estahammar, north of Uppsala, at an inlet of the Baltic Sea. Installation of the third unit, named Forsmark – 3, is planned for 1984.

The Marviken Atomic Plant was built between 1965 – 1970, with heavy water serving both as moderator and coolant. Due to unsatisfactory economical indices, this nuclear plant of 140 MW electric capacity was finally built for experimental purposes. Its site is on the southern side of the canal mouth draining Lake Vättern, at the Baltic coast. Sweden has some 5500 MW built-in nuclear plant capacity in 1980. According to earlier plans capacity was to have been raised to 9400 MW by 1985, with a further ambitious nuclear plant construction programme up to 1990.

After the fall of the social democratic government in 1976 construction pace of nuclear plants was slowed down, and was eventually planned to stop altogether. This plan was later abandoned, and because of problems in energy supply, coalition partners of the anti-nucler Centrum Party have even broken the alliance in this question with their decision to back further construction of nuclear plants.

Sweden ranks near the top among countries with outstanding deposits of uranium, which is a favourable condition for its long-term nuclear programme. Huge reserves were found in the country in the vicinity of Kvarntorp and Billingen, in Cambrian bituminous shale formation, – although with few exceptions they are of very low grade. Uranium content of the bituminous shale is very low: 0.023%, (mean value) i.e. one ton of ore holds 230 grammes of uranium. Uranium content of better quality ores hardly exceed 0.03%, and these reserves amount to about 150 000 tons around Billingen. Total uranium content of lower grade ore deposits is several times higher, some sources put it at around 1 million tons.

For the purpose of directing the development of Sweden's nuclear industry, the state company "AB Atomenergi" had been established with wide powers, that set up a small-capacity (5 – 10 t/year) experimental uranium oxide producing plant at Kvarntorp (Nerke province), in 1953. Uranium ore mined aruond Billingen in modest quantities is enriched in the small town of Ranstad, where the company later (in 1965) built a new uranium oxide plant of 120 t/year capacity. Output of uranium ore mined at Billingen is about 15 000 t/year, which means that domestic production can only supply a fraction of the demand of Swedish nuclear plants. At present prices purchase of uranium in the USA, France etc. is seen economically more sensible than mining domestic ores of very low grades.

Industrial investments into nuclear energetics and the major part of scientific research are mostly financed and carried out by the mixed company "Asea-atom" (50% of its stocks are held by the state, while the other half is owned by Sweden's largest electrical engineering firm "Asea".) "Asea-atom" has created an entire plant-complex in the town of Västerås (100 km west of Stockholm) for the manufacture of all kinds of nuclear plant equipment. Thanks to its plants in the country "Asea-atom" has gained monopoly over the manufacture of heating elements for reactors in Sweden. The plants at Västerås also produce radioactive sources of electricity (up to 1 kW), and a large number of laboratories are performing research. Also participating in the construction of nuclear plants on the basis of orders by "Asea-atom" are "Axel Jonson grupp" by supplying special steel, "Stal – Laval turbin AB" by undertaking deliveries of turbines, among a number of other firms. In addition to these several American – Swedish mixed companies have been founded for taking part in nuclear plant programmes.

The state firm "AB Atomenergi" has developed the centre of Swedish nuclear research in the small town of Studsvik, for the purpose of basic and applied research. Among the constructed experimental reactors the 50 MW R – 2 is suitable for operation simulation of pressurized water, as well as boiling water reactors. Since the mid-'60s Sweden has been co-operating with Britain in the development of fast neutron breeder reactors. Similar co-operation has been established later with American and West German firms. Construction in Sweden of an experimental fast neutron reactor is planned for the mid-'80s.

One of the characteristic features of Swedish nuclear plant construction is that some of the reactors are built immediately next to large towns to supply them electric energy and communal heat.

Switzerland's conditions greatly resemble those of Sweden. Apart from its impressive hydroelectric capacity the industrially advanced small country disposes of no other source of energy. On the other hand the advanced industry and the highly electrified Swiss households need rapidly increasing amounts of electric energy. Hydroelectric reserves of the country have now largely been put to use. Consequently Switzerland has planned to generate its additional required electric energy in nuclear plants. The country has also alternately built American-developed boiling water and pressurized water reactors, following the failure of the 10.5 MW experimental Lucens Atomic Plant of its own design, that was installed back in 1968. The small town of Lucens is situated in the valley of the Broye river, north-east of Lausanne. The reactor of the plant was moderated by heavy water, while gas served as coolant. In 1969 it broke down and repair did not seem worth the trouble. At a time, when light water reactors were working well in western and socialist countries, further costly experiments were pointless.

The first nuclear plant to be installed in Switzerland was Beznau – I, with a pressurized water reactor of 365 MW capacity (Fig. 7.). The plant was expanded by an identical reactor block in 1973. The Beznau nuclear facility was located near the small town of Doetingen in northern Switzerland.

Simultaneous with the building of the second block of the Beznau power station was the construction and installation in 1971 of the Mühleberg Atomic Plant, with a boiling water reactor of 320 MW capacity, slightly to the west of Bern on the river Aare. Mühleberg lies about 20 km west of Bern, near a dam on the river Aare.

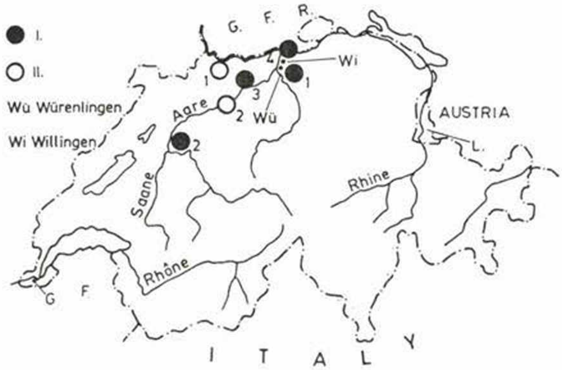

Figure 7. Location of nuclear plants in Switzerland

I. Working nuclear plants: 1 = Beznau; 2 = Mühleberg; 3 = Gösgen (Däniken, in Solothurn Canton); 4 = Leibstadt. II. Nuclear plants under construction: 1 = Kaiseraugst; 2 = Graben (on the river Aare in Bern Canton). F. = France. L. = Liechtenstein. G. = Geneva.

Employment of large blocks in Switzerland started in 1979. The year also witnessed the installation of the 960 MW pressurized water reactor of the Gösgen Atomic Plant near the small town of Däniken, on the river Aare. Construction of the 955 MW boiling water reactor block of the Leibstadt Atomic Plant has reached an advanced stage. This power station is being built jointly with West German firms, on the Rhine, at the mouth of the river Aare, in northern Switzerland. Following its completion, which is planned for 1981, 20% of the plant's generated electricity will be transmitted to the GFR in return for her share in the investment.

Authorization and construction of other, earlier planned nuclear plants are making very slow progress. Completion of the Kaiseraugst and Graben Atomic Plants is expected for the mid-'80s. Considering the size of the country, the nuclear plant programme to be carried out until 1980 is itself remarkable.

The execution of the important Swiss nuclear plant programme has also been preceded by the setting up of an extensive scientific background. The Swiss federal government has been supporting nuclear research since 1946. The Federal Reactor Research Institute was founded in the settlement of Vürenlingen in 1955. This nuclear reserch institute has become the largest in Switzerland, with several experimental reactors (among them the 30 MW "Dicrit"). Apart from the construction of thermal reactors, research is centred on building fast neutron reactors of different types (liquid sodium and helium cooling systems). The institute also turns out radioactive isotopes, and performs experiments on the production of heating elements, as well as on the reprocessing of spent heating elements. The Swiss Nuclear Research Institute was founded in neighbouring Willingen in 1967, where a large-capacity proton accelerator is working. A number of practical questions are being studied at Swiss universities, too. The universities of Zurich and Neuchatel possess Van de Graaf accelerators, while the University of Bern also has an experimental reactor. The universities of Fribourg and Lausanne also carry on extensive research programmes.

The Federal Atomic Energy Commission was established as a governmental organ in 1958 to supervise the development of nuclear energetics. Swiss production of major nuclear equipment was established in a fairly short time, based mostly on American licences; several types of equipment are even manufactured for the United Kingdom and France. Better-known manufacturing firms include Brown Boveri, Sulzer (in Winterthur), Georg Fischer, Seca (produces robots that load and unload heating elements).

Uranium ore in Switzerland so far was only found in bituminous coals around the village of Blanbach. All uranium and heating elements consumed in Switzerland are purchased from abroad (USA, France), while on the reprocessing of spent heating elements an agreement has been signed with Britain. Establishment of heating element manufacturing facilities in the country is expected for the early '80s.

Among the Benelux countries construction of nuclear plants was started first in *the Netherlands*. In as early as 1969 the Dodewaard Atomic Plant was completed with a boiling water reactor of 55 MW capacity, at the village of the same name, some 15 km west of the town of Nijmegen on the Rhine. Installation of the second nuclear plant has also taken place in Holland. The Borssele Atomic Plant has been built with a 477 MW pressurized water reactor, near the small town of the same names, slightly east of the town of Vlissingen, at the Schelde estuary (on the north bank of the Wester Schelde river branch) (Fig. 3.). But this has marked the beginning of a long break in the Dutch nuclear plant construction programme. The discovered and heavily exploited natural gas deposits have solved the energy problem of this small country in the 1970s. Production of natural gas has now begun to decline and the Netherlands may some day resume generating electricity in new atomic plants.

Belgium has joined the countries operating nuclear plants later. The 920 MW pressurized water reactor of the Tihange Atomic Plant, built in French – Belgian co-operation near the town of Namur, south-west of Liege on the river Maas, has been working at full capacity since 1978. In the same year the first 410 MW reactor block of the same (pressurized water) type was put to use in the Doel Atomic Plant, some 35 km west of Antwerpen on the Gent Canal. The Doel power station has since been expanded by another 410 MW reactor of the same type. In addition, both power plants will be enlarged by one pressurized water reactor block of 900 MW capacity each, now under construction (expected completion date of the two blocks: 1980). This will put Belgium into a position among countries operating large nuclear plants, and a significant share of the generated electricity will be taken over by nuclear plants from once-famous Belgian coal (whose mining involves steadily growing costs). Beyond those listed above an experimental reactor of 11 MW capacity is being operated in the town of Mol, 40 km east of Antwerpen. The Tihange – 3 and Doel – 4 nuclear plants, now under construction, are expected to be completed by 1983 with blocks of 1000 MW capacity each.

The largest nuclear plant of the Benelux states is planned to be built in the south-eastern part of the smallest country: *Luxembourg.* The Remerschen nuclear plant, with its 1300 MW pressurized water reactor, is envisaged for completion by the mid-1980s on the Luxembourgian – West German border, near the river Mosel (Fig. 2.).

It should be noted, that construction of nuclear plants of such immense unit capacity in these small countries (Switzerland, Belgium, and especially Luxembourg) is only feasible because the joint operation of the western European high-tension grid system offers the possibility of building international reserves, besides mutual assistance.

Capacity of the 1300 MW reactor block of Remerschen nuclear plant exceeds that of Luxembourg's entire capacity needs. During its operation a significant share of the generated electricity will have to be supplied to the neighbouring countries. On the other hand, should the power plant be forced to stop running either intentionally, or due to some defect, the small country will then have to satisfy its demand by electric energy supplies from neighbouring countries. Joint operation of the high-tension grid system thus has a decisive influence on the economy of nuclear plants.

Finland has special position among countries constructing and operating nuclear plants. So far two atomic plants have been equipped by reactor blocks. The point of interest lies in the fact that one of them (Loviisa) has been built with two (440 MW cap. each) pressurized water reactors of the Novovoronezh type, while the other (Olkiluoto Atomic Plant) will run by two Swedish-made boiling water reactors of 660 MW capacity each, built on American design. The Loviisa Atomic Plant was constructed near the town of Loviisa, some 50 km from Helsinki on the shore of the Gulf of Finland, while the Olkiluoto Atomic Plant is located on a small island of the same name, somewhat to the north of the town of Rauma, close to the shore of the Gulf of Bothnia, in south-western Finland. (Fig. 6.) The blocks of the Loviisa Atomic Plant, supplied by the Soviet Union, were put to service earlier (in 1976 and 1978 respectively), while those of the Olkiluoto nuclear plant were planned for completion in 1978 – 1980. Future plans include the installation of a 1000 MW nuclear plant near Helsinki (by 1985).

Norway has built two small experimental reactors in Oslo and Halden (Fig. 6.). The latter is of the heavy water type.

In *Austria* the Tullnerfeld Atomic Plant was built near the village of Zwentendorf on the Tullner Feld, west of Vienna on the bank of the Danube. This nuclear plant was equipped with a boiling water reactor of 692 MW capacity. Construction and installation of the plant was hotly debated in public in Austria. The socialist government held a referendum on November 5, 1978 on the installation of the then almost complete nuclear facility. The referendum was won by oppenents of the plant by a slight margin. The outcome of the referendum was undoubtedly influenced by political considerations that went beyond questions of generating electricity by nuclear plants and their judgements of safety. Austria's economic interests are totally incompatible with the result of the referendum, and a number of signs suggest that demand will force the country to complete the nuclear plant and put it to work.

РЕЗЮМЕ

АТОМНАЯ ЭНЕРГЕТИКА ЕВРОПЕЙСКИХ КАПИТАЛИСТИГЕСКИХ СТРАН

В статье кратко рассматривается развитие атомной энергетики европейских капиталистических стран, а также применение атомной энергии. Особенно выделяется роль Великобритании, Франции, ФРГ и Швеции. В этих странах была создана мощная научно-исследовательская база по развитию атомной энергетики, находящаяся в руках государства и частных предприятий. С одной стороны – это сделало возможным разработку собственных типов реакторов, с другой – способствовало быстрому вводу в строй экономично функционирующих атомных электростанций, разработанных в других зарубежных странах. В перечисленных выше странах развитая промышленность, а также недостаток первичных энергоносителей благоприятствовали распространению атомной энергетики. В целом ряде западно-европейских стран атомных электростанций уже и ныне приходится 15 – 28% общего производства электроэнергии.

Великобритания и Франция в пятидесятых и в шестидесятых годах использовались реакторы собственной разработки, в которых замедлителем был графит, а теплоносителем углекислый газ. Вследствие этого обе страны стали независимы от мощностей по обогащению урана в США, так как реакторы с применением углекислого газа в качестве теплоносителя могут использовать и природный (необогащённый) уран. В то же время реакторы с газовым теплоносителем по экономичности уступали разработанным в США водо-водяным реакторам (так называемого кипящего типа, а также с водой под давлением). Франция уже раньше сделала для себя соответствующие выводы и в начале семидесятых годов перешла на использование разработанных американцами реакторов с водой под давлением и кипящих. Великобритания и в семидесятых годах продолжала усилия по повышению конкурентоспособности реакторов с газовым теплоносителем, но по всей вероятности в ближайшем будущем также перейдёт на использование типов реакторов зарубежной разработки.

Остальные европейские капиталистические страны за исключением Швеции строили атомные электростанции, закупленные за рубежом, или же начали производство оборудования для атомных электростанций по иностранным лицензиям. Швеция проявила большую самостоятельность в разработке реакторов кипящего типа, а реакторы с водой под давлением также покупала за рубежом. К середине семидесятых годов ФРГ удалось наверстать отставание в области развития атомной энергетики ввиду более позднего старта. Ныне западно-германская промышленность способна выпускать комплектное оборудование для атомных электростанций с реакторами кипящего типа, а также с водой подавлением.

Великобритания до 1970 года по установленной мощности атомных электростанций занимала ведущее место в мировом масштабе, но уже в последующем году её опередили США, а затем и ФРГ, Франция и СССР. В 1980 году планируемая установленная мощность атомных электростанций должна составить (в млн. квт.) в Великобритании – 11,8, во Франции – 14,5, в ФРГ – 12,0., в Испании – 6,5, в Швеции- 5,0. Как видим и в Испании, и в Швеции также была осуществлена значительная программа строительства атомных электростанций.

Наряду с термическими реакторами в Великобритании, Франции, ФРГ и Швеции большое внимание уделяется разработке реакторов на быстрых нейтронах. В Великобритании и Франции действует по одному реактору на быстрых нейтронах мощностью по 250 тысяч квт. каждый. В ФРГ строится подобный реактор мощностью 300 тысяч квт. Ещё больший реактор на быстрых нейтронах мощностью 1,2 млн. квт. находится в стадии проектирования совместными усилиями Франции, ФРГ и Италии. Этот реактор будет установлен на атомной электростанции «Супер Феникс» в Крейс Малвилле во Франции, которая по планам должна быть пущена в первой половине восьмидесятых годов. В интересах более рационального использования запасов урана начиная со второй половины восьмидесятых годов ожидается распространение атомных электростанций с реакторами на быстрых нейтронах и в других странах Западной Европы.

Всё больший по масштабам, но правда более медленный по темпам чем это планировалось раньше, размах осуществления программ строительства атомных электростанций в Западной Европе выдвинул на первый план решение проблемы обогащения урана, а также извлечения всё ещё значительного количества урана из выгоревших тепловыделяющих элементов (твэлов). Последняя операция осуществляется на специальных заводах по переработке облученного топлива. До сих пор предприятия по обогащению урана были построены в Великобритании, Франции и Голландии (опытная установка действует и в ФРГ). Во Франции в процессе строительства находится новое мощное предприятие по обогащению урана «Евродиф» при финансовой поддержке Италии, Испании, ФРГ и Бельгии. Заводы по переработке твэлов были построены в Великобритании, Франции, и Бельгии. Подобный, но ещё больший по мощности завод строится в ФРГ.

В машиностроении западно-европейских стран сложилось значительное сотрудничество и разделение труда в отношении производства оборудования для атомных электростанций, а также вспомогательных устройств.

Из западно-европейских стран только Франция располагает значительными и экономично разрабатываемыми запасами урановых руд. В Швеции известны большие запасы урановых руд, но содержание урана в руде весьма низкое. Поэтому Швеция свои потребности в уране пока что удовлетворяет за счёт импорта. Вследствие нехватки урана значителен его импорт, а также большую роль играет финансовое и научно-техническое участие европейских капиталистических стран в разработке зарубежных месторождений урана.

В ряде плотнонаселённых западноевропейских стран немалую проблему означает выбор подходящих площадок для строительства атомных электростанций, хотя последние загрязняют окружающую среду только за счёт сброса тёплой воды температурой около 30°C. На атомных электростанциях в качестве охлаждающей воды можно использовать и солёную морскую воду, что благоприятно для их размещения в странах и в отдельных районах стран с засушливым климатом. Дело в том, что важнейшим фактором размещения атомных электростанций является наличие охлаждающей воды.