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EUROPEAN ATOMIC ENERGY COMMUNITY – EURATOM
CENTRE D'ÉTUDE DE L'ÉNERGIE NUCLÉAIRE – CEN/SCK

THE BR2 TESTING REACTOR AND ITS CONNECTED LABORATORIES

Annual Progress Report 1964

1966

Work performed at the
Centre d'Étude de l'Énergie Nucléaire - CEN/SCK, Mol, Belgium
BR2 Operating Group

Association No. 006-60-5 BRAB

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SUMMARY

The BR2 reactor was operated for 222 days without noteworthy incident at a power of about 34 MW and with a core containing 20 fuel elements. The number of experimental devices used for materials testing rose steadily throughout the year, some 25 to 30 experiments being operated concurrently for most of the time, both for the member states of the European Community and for foreign countries. About 40 % of the irradiation devices loaded into the reactor core were built at Mol, the remainder coming from either nuclear centres or from industry. Improvements were made in the reactor complex to follow more closely the requirements of the experimenters, and in particular the equipment for the medium activity hot laboratories was installed and the construction of the high activity cell was completed.

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The BR2 Testing Reactor and its Connected Laboratories (*)

1. SUMMARY

The BR2 reactor and its connected installations were operated on the basis of the contract of association drawn up between the Euratom Commission and the CEN. Under the terms of this agreement, which was concluded in 1960, the contracting parties use the jointly operated installations for their own requirements and can also make them available to third parties of their choice for the requirements of these latter. Execution of the agreement is in the hands of a management committee which met seven times in 1964 in order to establish programmes and to ensure the technical coordination of the uses to which the various installations are put.

The number of tests carried out in the reactor on nuclear materials by scientists from Community member states and other countries has increased. The main appeal of the BR2 lies in the fact that it provides a high neutron flux of both slow and fast neutrons. As a result of the considerable nuclear heat to which the targets are subjected, high temperatures can also be obtained in small volumes.

Among the main experiments carried out, mention should be made of the irradiations of stainless steel, uranium oxide and graphite up to 1,200 °C for the UKAEA, the irradiation of zirconium and the preparation of graphite and plutonium irradiations for the French CEA, the irradiation of graphite at 900 °C for the OECD Dragon project in a loop constructed at Mol, irradiations of stainless steel for the Karlsruhe centre and the preparation of several large-scale irradiations for German industrial companies, together with numerous irradiations for universities and industries throughout the Community. The production of high-activity cobalt and iridium was mainly undertaken for the CEA-CEN-SORIN association. The production of transplutonium elements was also carried out on behalf of Euratom and the CEN. Physicists from the CEN and Jülich nuclear centre continued their work on neutron beams.

The number of experimental devices loaded in the reactor increased regularly throughout the year, 25-30 channels being occupied almost continuously. About 40 % of the devices irradiated in the reactor core were constructed at Mol. The design and fabrication of these devices constituted a major task which was carried out in collaboration with industrial companies or other nuclear centres. These devices are available to all users. Certain devices are of an exceptional nature, such as the loop used for the cooling by

(*) Manuscript received on November 3, 1965.

sodium of fissile pins producing up to 3000 watts/cm^3 which was constructed for the French CEA.

In order to ensure the safety of this equipment numerous checks were necessary, theoretical verifications being carried out by an experiment examination committee and practical tests by an independent acceptance group responsible for detecting material defects by means of the entire range of non-destructive tests. These checks helped to reduce the number of incidents which occured in 1964.

Operation of the reactor and its connected installations continued regularly, and assumed more and more the character of industrial exploitation. The reactor ran without noteworthy incident for 220 days at the rated power of 33 MW. Several unscheduled shut-downs occurred, however, when the control-rods fell owing to water entering the submerged circuits. The circuits have now been modified and by the end of the year the number of unscheduled stops had decreased.

Several alterations were carried out to the installations in order to improve operating safety and further the requirements of the experimental scientists. In particular, the equipment for the medium-activity hot laboratories was installed and the construction of a high-activity cell finished.

The medium-term estimates concerning the utilization of the reactor showed that the present core would have to be widened in order to hold more experiments. A new configuration will be installed in late 1965, after large-scale preliminary studies have been carried out. The long-term estimates, based on a detailed study of the market, have confirmed the view that the BR2 will play an important part in the implementation of European materials irradiation programmes.

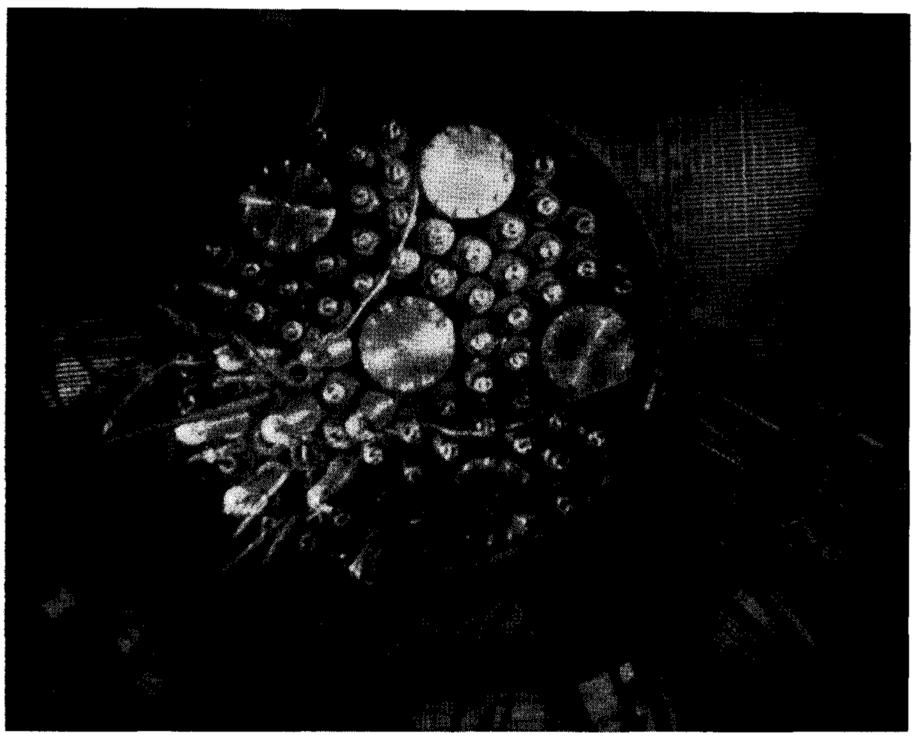


Figure 1
Top of BR2 reactor.

2. FABRICATION AND DEVELOPMENT OF IRRADIATION DEVICES

Of the 52 devices used in the reactor core in 1964, about 20 were constructed under contract by the operating group, the remainder being built by the clients themselves. Fruitful collaboration was set up in this connection with the CEN and several companies in the Community and the United Kingdom. The fabrication of the experimental devices necessitated the development of special techniques with regard to instrumentation and the use of molten metals. The main devices are now briefly examined.

2.1. Loops

The IPCTL loop continued to be used for the Dragon project (OECD). This loop, which was the first to be built at Mol for the BR2, consists of a helium circuit of 10 kg/cm^2 pressure, into which various gaseous impurities can be injected at different concentrations. The loop was intented for studies on the effect of radiation on the physico-chemical equilibrium of graphite in the presence of helium impurities. Preliminary marking of the graphite targets with carbon-14 facilitated the measurements. An out-of-pile section identical to the in-pile part operated in parallel with it, as a result of which a distinction could be made between the thermal and radiolytical effects.

From 1962 to 1964, the out-of-pile loop ran for 9260 hours at a maximum temperature of 950 °C. From January 1963 to July 1964, the in-pile loop ran for 3740 hours without incident at a maximum temperature of 900 °C in a total epithermal flux of 10^{15}n/cm^2/sec.

The different thimbles used could easily be removed and reloaded. After extraction of the irradiated samples in the hot cell, new samples were inserted. Each thimble was then

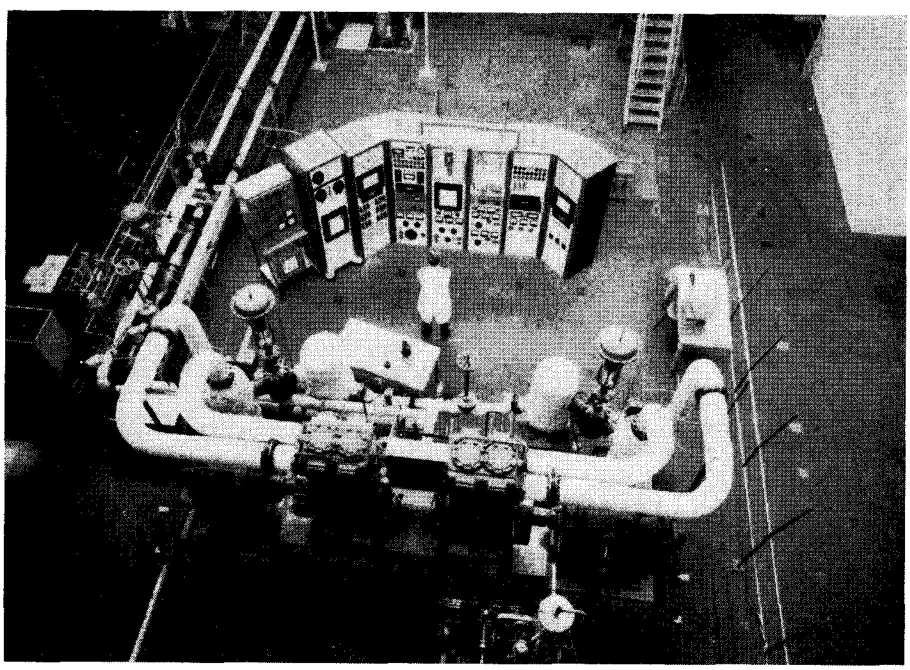


Figure 2
The MFBS sodium loop intended for plutonium irradiation for the CEA.
The picture shows the blower unit and the control panel during the blank tests.

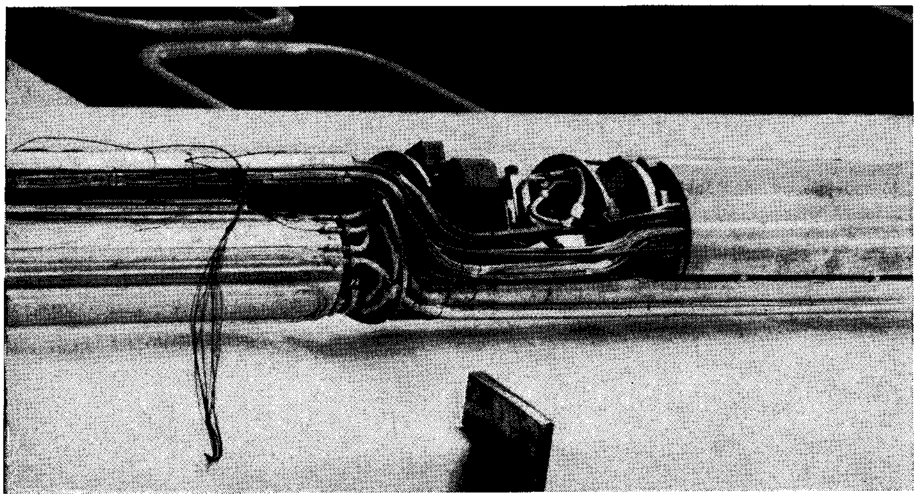


Figure 3
The MFBS sodium loop.
A section of the in-pile part containing the heat exchanger, the flowmeter and the electromagnetic pumps.
The sodium will circulate at a temperature of above 400° C.

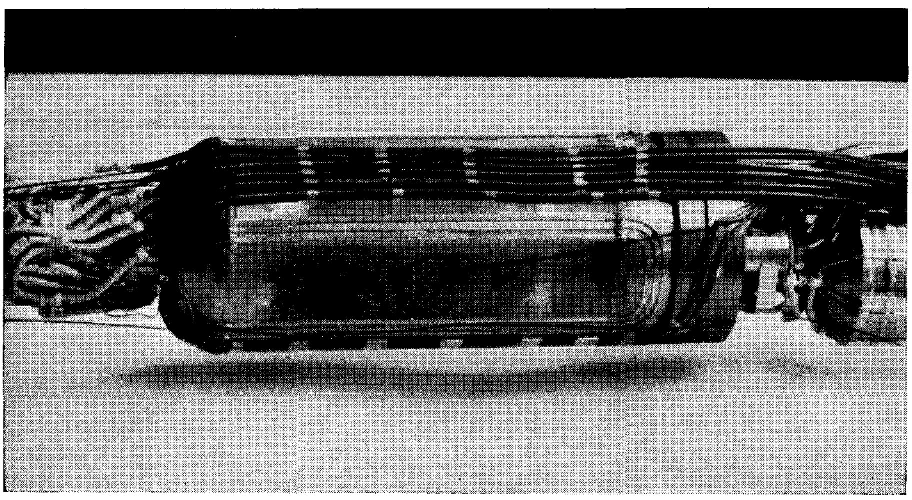


Figure 4
The MFBS sodium loop.
Thermocouples and heating wires attached to the primary circuit reduction flask.

sealed by remote welding and tested, still in the hot cell, for leaktightness and mechanical strength. The thermocouples were also recalibrated.

Construction work on the MFBS loop was continued on behalf of the Rapsodie Project (CEA). This loop consists of a circuit of sodium at a pressure of 6 kg/cm^2 and a temperature of 450 °C. It is intended for studies on the behaviour of Pu-based pins for heat ratings up to 2000-3000 watts/cm^3 under conditions similar to those encountered in fast reactors. The pins are surrounded by a double shield of B_4C-Cd in order to absorb the thermal neutron flux, only allowing the fast flux to pass through.

Construction of the out-of-pile section was completed and work on the in-pile section is almost finished. Numerous technological problems have to be solved, notably those concerning the electromagnetic pumps, the sodium-gas and gas-water exchangers and the cadmium and boron carbide shields. Models of the primary circuit were made for the hydraulic tests, the electromagnetic pump operating tests, the sodium filling and emptying tests and for dosimetric purposes.

The first irradiation programme will be carried out during 1965.

Relations were maintained with the SERAI company, which is constructing a gas loop (CO_2 at 60 kg/cm^2 and 600 °C) for Siemens. This loop is intended for the study of UO_2 fuel elements for use in gas-cooled reactors. Irradiation should begin during 1965 and will last several years.

The draft design work on another gas loop (CO_2 at 60 kg/cm^2 and 400 °C) was continued in close collaboration with the experimenters, namely, the Germany company of Babcock. The purpose of the experiment is to study the behaviour of various types of graphite under irradiation. The information obtained from the IPCTL loop was put to good use in the design of the in-pile section and for the out-of-pile auxiliaires. The construction work is to be carried out by the experimenters. Irradiation should begin in 1966.

2.2. Regulated capsules

Several experimental devices were built in which the temperature of the targets can be regulated.

A boiling water capsule was designed for the CEN-Belgonucléaire plutonium project. With the aid of this device information will be available at any given moment on the temperature of the targets and the power dissipated. The thermal barrier around the target consists of a combination of water under adjustable pressure, NaK and a gas layer.

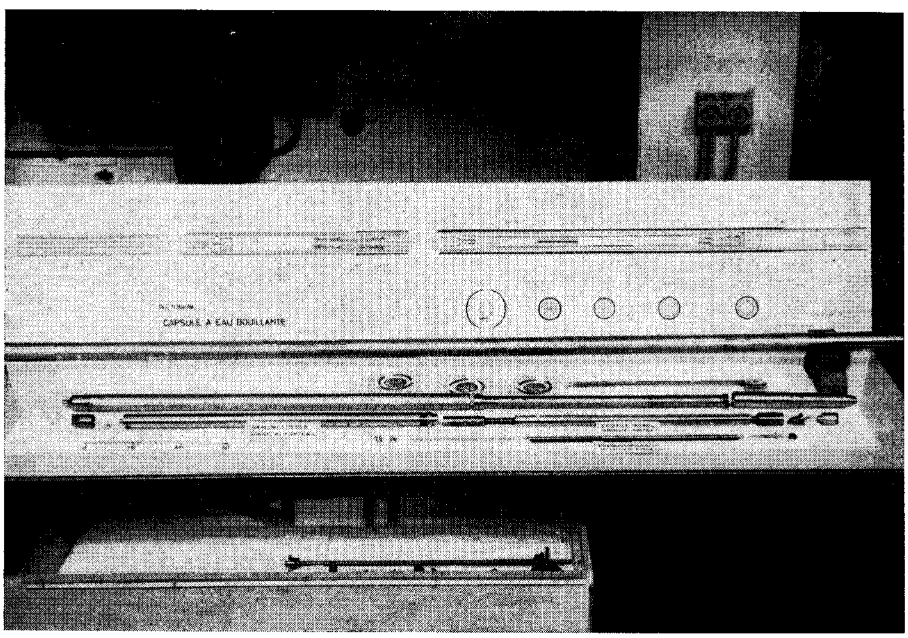


Figure 5
The boiling water capsule designed for plutonium pin irradiation can be used to ascertain the exact irradiation condition (power released by pins and cladding temperature). All components are displayed.

The temperature of the target is due to the pressure applied to the water. Since the pressure can be varied from 1 to 15 kg/cm², there is a corresponding variation of 90 °C in the boiling point of the water, which has a direct effect on the temperature of the target. Boiling only occurs beyond 50 watts/cm. The heat path is measured by thermocouples placed on the arms of a central nickel cross in the middle of which there is a fissile pin. The power dissipated can be fixed by preliminary calibration.

An out-of-pile prototype was first built to permit final thermal calibration and to enable the joints and penetrations to be checked. The first capsule is to be irradiated in 1965 and will contain a plutonium oxide pin dissipating up to 250 watts/cm, the temperature of the cladding being around 400 °C.

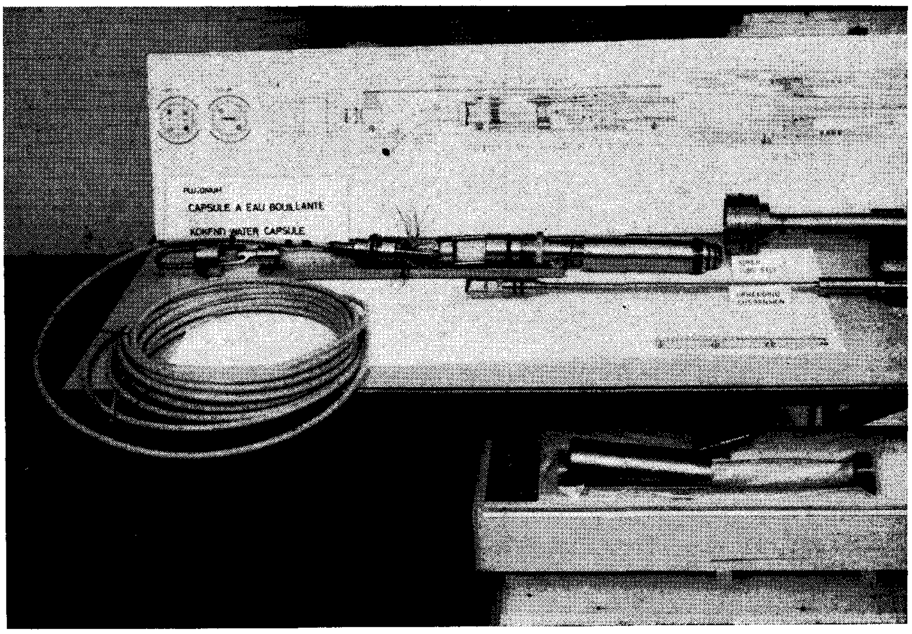


Figure 6
Boiling water capsule - The rig head.

Studies are now under way on a capsule design with which higher powers could be achieved while retaining cladding temperatures at values of around 400 °C.

Two regulated capsules are now in preparation for the irradiation of graphite for the Grenoble Nuclear Centre. The graphite samples are placed in furnaces. They must be kept within narrow temperature limits, in the 150-350 °C range. Since these temperatures are relatively low, the thickness of the gaseous film around the furnaces has had to be reduced as much as possible (0.05-0.06 mm). The coextrusion method for the fabrication of the outside aluminium sheath, with very low tolerances, was developed by the metallurgy department of the CEN. The specifications were drawn up for a standard control bay, with complete remote control of the furnaces and automatic recording of the results. The contract for the work was awarded to outside firms. The irradiations will take place in 1965.

Another type of furnace, called the Chouca, has been developed by the Grenoble nuclear centre for the irradiation of non-fissile materials in the French swimming-pool

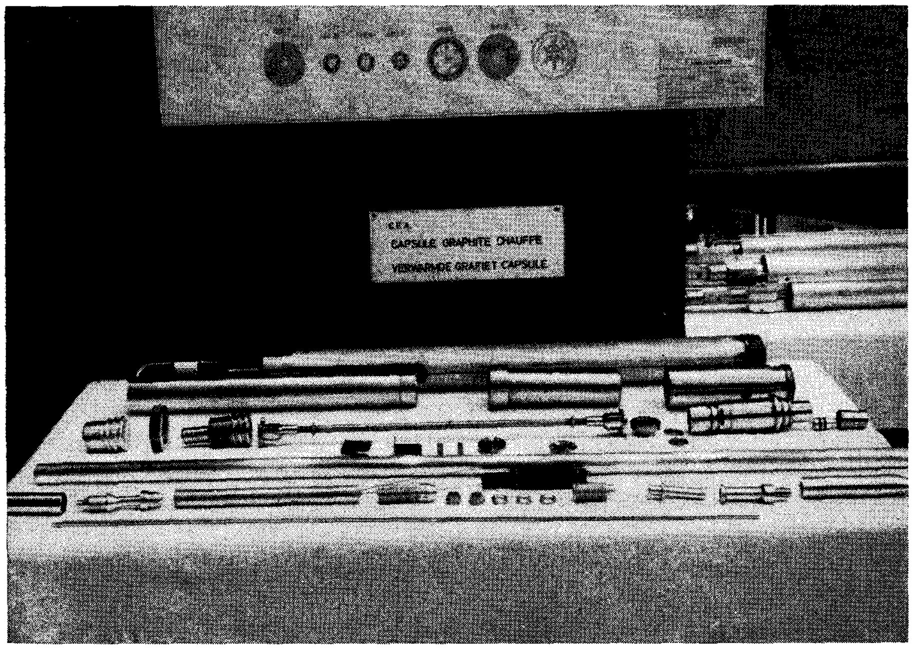


Figure 7
Regulated capsule for graphite irradiation between 150° C and 350° C.
All components are displayed.

reactors. Studies were carried out in conjunction with the CEA, to adapt the device to the geometrical and thermal characteristics of the BR2. Irradiations of the steel contained in a eutetic of molten metals are planned for the end of 1965.

With the aid of one of the devices it was possible to carry out the irradiation of metallic copper for the Max Planck Institute, Stuttgart. The sample was placed in a leaktight containment, filled with an inert gas, the pressure of which could be varied in order to obtain the desired temperature at the sample.

Close collaboration was set up with the experimenters who are constructing their own devices. There was a particularly voluminous exchange of information with the UKAEA and the Karlsruhe research centre (GKK).

The UKAEA has launched a vast programme of irradiations in the BR2 covering graphite, steel and beryllium oxide. Very low diameter capsules have been developed. The reactor's nuclear heat is largely used to heat the targets, while the make-up heat is provided by several heating elements, the output of which is only 10-15 % of the total. The main regulation during irradiation is carried out by altering the composition of the gas in the insulating layers. The rated temperatures range from 350 to 1200 °C. Several removable and reloadable devices are planned.

The Karlsruhe centre (GKK) has designed and constructed a device for studying creep in cladding materials. In addition to the samples, the device also contains stress tubes, thermocouples and heating wires. The irradiations will be carried out in 1965 in dual-access channels containing fuel elements.

A project for the irradiation of large graphite pins was coordinated for the SERAI company. Irradiations are to be carried out in 1965 for SIEMENS-PLANIA and the Karlsruhe TECHNISCHE HOCHSCHULE. The devices constructed by an outside firm are regulated by electric heating and by a controlled-mixture gas layer.

2.3. Instrumented capsules

Several irradiation devices, fitted solely with thermocouples, were built for both samples of fissile materials and for construction materials.

Two baskets containing zirconium samples were made and irradiated for the Saclay nuclear centre. The samples, used for tensile and impact strength tests, were cooled directly by the water of the reactor. After recovery in the dismantling cells, the samples will be sent back to the experimenters.

A prototype capsule for the irradiation of steel is now being made for the Centre de Recherches métallurgiques, Liège. The steel is submerged in NaK under a cushion of gas, the temperature of the samples being about 300 °C. The pilot irradiation is to be followed by a series of six to eight others.

A device for the irradiation of niobium was built in order to study the behaviour of a brazed niobium/ceramic joint. Ten joints were inserted in a helium-filled container. The temperature of the samples must be around 230 °C. The device is ready to be loaded at the beginning of 1965.

A capsule for the irradiation of plutonium pins is now being made for the nuclear center at Fontenay-aux-Roses. A pin is placed in sodium, and the high power density causes the core to melt. The device is sheathed in niobium. A complete dosimetry programme has been launched in order to obtain precise data on the fission density. About four or five devices will be irradiated at the end of 1965 for short periods.

Technical links have been set up with various experimenters who are building their own irradiation devices.

The SERAI company, for instance, has designed a device for the irradiation of ordinary steel with well-defined doses for Mitsubishi. Discontinuous vertical and horizontal removal of the samples is possible with the aid of a manual drive mounted at the edge of the reactor pool. In this helium-filled device, the samples, clad in aluminium alloy, are grouped in four lots subjected to temperatures of between 150 and 260 °C. The rated temperatures for each lot are obtained by nuclear heat by surrounding the samples with sleeves of lead and in tin alloy. Two series of irradiations are to be carried out in 1965.

In the same way, links have been established with the Petten nuclear centre (Euratom) which has carried out studies on a device for the irradiation of steel at 500 °C for Interatom. The tensile and impact-strength test samples are immersed in sodium. The correct thermal conditions required are provided by means of a double containment filled with a slowly circulating helium-neon mixture, which also satisfies safety requirements. The irradiation is planned for the end of 1965.

2.4. Non-instrumented capsules

Numerous non-instrumented devices have been designed, built and put into service. With the aid of these devices, leaktight capsules containing various materials, such as fissile pins, stainless steel samples and other cladding materials, can be placed in the reactor.

A capsule was prepared for the irradiation of fuel rods submerged in molten metal. The design of the capsule, which was originally carried out by the client (Mitsubishi), was entirely revised in collaboration with the SERAI company. The original capsule, containing the fissile material, was dismantled and a new capsule constructed in accordance with agreed control procedures and based on experience acquired. In view of the special nature of the device-non-instrumented and containing NaK and low-enriched UO_2 with single containment- a complete pilot programme of assembly, together with intermediate checks, was drawn up. The capsule can be placed in the reactor during 1965.

Design work was carried out on a basket for the irradiation of three fuel rods submerged directly in the water of the reactor primary circuit. The concept of the project, which was originally drawn up by the client (Mitsubishi), was entirely revised. Irradiation will be carried out in 1965 at a specific heat output below 300 watts/cm.

Studies were carried out on the modification of a sheath tube containing samples of cladding materials for irradiation in a high neutron flux. The devices have been assembled on behalf of the Gesellschaft für Kernforschung, Karlsruhe. The experimenters want to irradiate tensile and impact-strength test samples of stainless steel of various compositions, Inconel and vanadium. The samples are cooled directly by the water of the reactor primary circuit and loaded in a six-plate fuel element. At the end of the cycle the radiation doses received can be measured by means of flux detectors. Four devices were assembled and loaded in the reactor in 1964 and it is planned to load a fifth device during the second quarter of 1965.

A device was constructed which can hold a capsule containing zirconium hydride. The purpose of the irradiation, which was carried out for Interatom, Bensberg, is to study the behaviour and irradiation of a moderator material for possible use in power reactors. The samples, immersed in sodium, are housed in an inner stainless steel capsule placed in a leaktight case, also made of stainless steel, which in turn is placed in an aluminum basket. Because of the annulus which is filled with gas, sample temperatures of around 500 °C can be achieved. The device was inserted in the reactor during the second half of 1964. After the irradiation cycle, which is due to end during the first quarter of 1965, the samples will be examined in the medium-activity laboratory.

2.5. Capsules for the production of isotopes

Numerous devices for the production of radioisotopes inside the reactor vessel were designed, constructed and put into service.

A basket containing rods of americium oxide was placed in the reactor during the first quarter of 1964. The device is intended for the production of transuranium elements under a CEN-Euratom contract. It is at present loaded in a standard channel in the reactor. Design work was carried out on a new basket with which it will be possible to place the same targets in six-plate fuel element with a support tube. The basket is to be changed as soon as possible. Devices similar to this are to be used to permit the irradiation of new targets of americium oxide during 1965.

Design work was carried out on a special assembly for the production of transuranium elements from plates containing plutonium. The device, which was developed for the Saclay nuclear centre, is in the form of a fuel element consisting of slightly curved plates of the MTR type. The use of fillers around the box enables it to be inserted in a standard reactor channel. The fuel cartridge is to be built by the experimenters. The device is to be assembled at Mol.

As part of a programme for the production of radioisotopes for different users, numerous devices were designed and a special effort made with regard to the standardization of proven-type devices. The radio-isotopes most in demand are iridium and cobalt, and the main users are the CEN (the radioisotope department acting on behalf of the CEA-CEN-SORIN association), the Iridium Gesellschaft Karlsruhe, Philips-Duphar (Amsterdam) and the UKAEA, Harwell. Problems inherent in the routine production of radioisotopes had to be solved, notably those bearing on the rapid recovery of targets in hot cells and the various formalities relating to transportation.

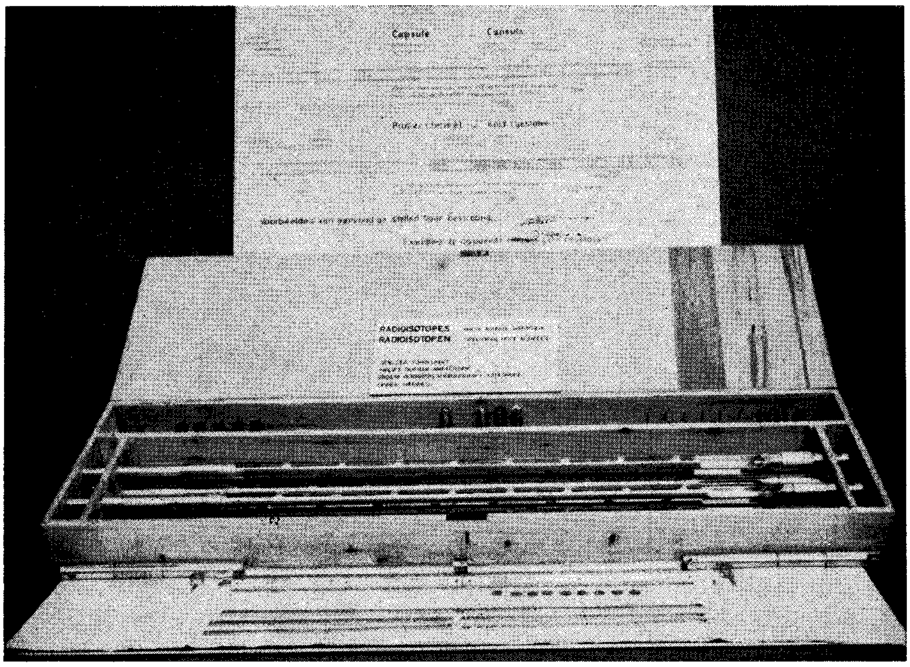


Figure 8
Standard containers for the production of high-specific activity isotopes.

2.6. The irradiation devices in the pool

The experimental space left free around the reactor vessel at the level of the core can be used for the insertion of irradiation devices of various design. Among the experimental possibilities open, mention must be made of the support tubes mounted obliquely in the pool, the lower end of which is situated near the vessel, the upper emerging at the level of the working platform inside the pool. These tubes can house targets for brief periods of irradiation or those requiring neutron fluxes one or two powers of ten lower than those available in the vessel. The main effort was directed at the installation of single tubes which can be used for irradiation independent of the reactor cycle.

A first support tube was used for the rradiation of graphite balls containing a fuel pellet. The irradiations were carried out for he company of SERAI acting on behalf of BBC-Krupp. The purpose of the irradiatioi s was to study the migration of gaseous fission products inside the graphite matrix. The programme can be regarded as completed.

The same support tube is now being used continuously for the production of gold and iodine-131 from tellurium oxide. These irradiations are being carried out for the CEN (Radioisotope Department) in a carousel device inserted in the support tube. This device can hold at the same time five piles of capsules, which can be unloaded by remote control. During the unloading operation—in a lateral pool—the five capsules at the bottom of each of the piles are released from the basket simultaneously and collected in a shielded sample holder.

The same support tube will also be used for the irradiation of a cermet fuel pin. The assembly is being designed and constructed by the metallurgy department of the CEN. During the irradiation the experimenters wish to measure the temperature gradient in the pin core (thermal conductivity to be determined) and in the rather thick cladding (thermal conductivity known).

In order to cope with the growing demand for radioisotopes, in particular iodine, it was decided to have three additional support tubes made. One part of the structure was installed in the pool at the end of 1964 and work is to be completed by the end of February 1965. A tubular basket, in which four piles of capsules can be housed simultaneously, can be placed in each guide tube. At the bottom of each of the four piles there is an ejector, and by angular displacement the bottom capsule can be extracted from the pile. Each basket can be manœuvered in the guide tube with the aid of a hoist operated from the edge of the swimming-pool. The operations of loading and unloading the capsules in the basket are carried out in a lateral pool and are independent of the reactor operating cycle.

Work was commenced for the CEN (Chemistry Department) on the design of a device for the irradiation in the pool of rods of fissile material. The experimenter intends to use these irradiation rods subsequently for the study of reprocessing problems. The device, which is mounted on a pivot and can also describe an axial movement, will be able to hold groups of 20 rods of UO_2. There will be a total of 300 rods to be irradiated. Design work on this device will be continued in 1965.

2.7. Gamma irradiation devices

Devices for irradiation in the gamma facility have been designed, constructed and operated on behalf of different clients.

A capsule with a continuous sweep circuit was constructed to round off the tests carried out with the high temperature gas loop for the Dragon project (OECD). With this installation, studies are possible on the influence of gamma radiation on the physico-chemical equilibrium of a mixture of helium and carbon dioxide. The circuit can operate at a pressure of 20 kg/cm^2 and with a flow of 0.1 l/sec. The irradiations were commenced during the last quarter of 1964 and were interrupted at the end of the year, this break being utilized in order to attempt to interpret the results obtained and to determine the remainder of the programme. The capsule was inserted in a freshly burnt six-plate fuel element with a central tube. The gamma flux varies from $4 \cdot 10^7$ to $5 \cdot 10^6$ rad/hour, during one period of irradiation.

A device was designed so that the gamma irradiation of Fingal glass could be carried out for the UKAEA, Harwell. The irradiations, which are conducted at high temperatures, commenced during the second half of 1964 and will last about one year. The device was inserted in the centre of a freshly burnt fuel element placed in the middle of a ring of elements. The gamma flux varies from $5 \cdot 10^7$ to $5 \cdot 10^6$ rad/hour during an irradiation run.

2.8. Instrumentation and special techniques

During 1964, studies were continued on special techniques which find immediate or short-term application in different BR2 irradiation projects. Note should first be made of the research work carried out with regard to the instrumentation of irradiation devices:

— For studies on thermocouples, special furnaces were built as a result of which tests could be made on the determination of response times and measurements of the homogeneity of wires.

— A new method was developed for the a posteriori measurement of the maximum temperatures along a given section of a test piece. This study formed the subject of a patent application.

— Techniques for the measurement of pressures, flow rates, mechanical stresses, vibration amplitudes, etc. by means of strain gauges were developed.

— The facilities for analysing vibration conditions were extended. The main activity concerned the precise determination of resonance frequencies, the analysis of frequency spectra in the low frequency region and the use of very low amplitude signals supplied by different transducers.

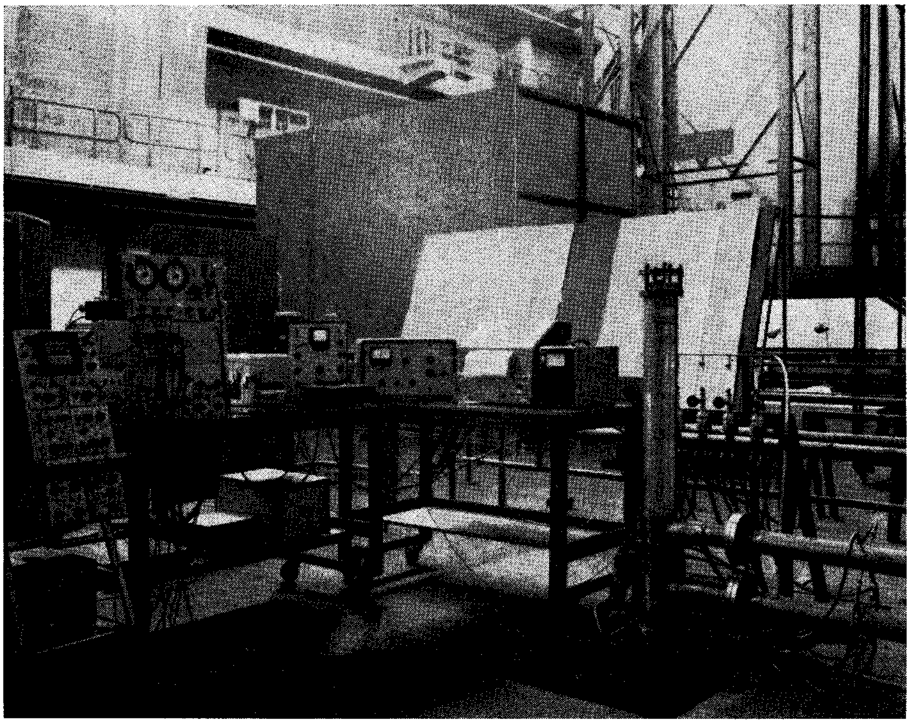


Figure 9
The instrumentation laboratory.
Measurements are being performed on the vibrations to which an ESSOR fuel element is subjected by placing it in a loop simulating actual operating conditions.

— Connections were developed for heating elements together with leaktight penetrations for thermocouples and heating wires.

— The maximum currents permissible in the heating wires were determined.

— Studies were continued on high linear density heating rods for the out-of-pile simulation of the thermal phenomena encountered in targets irradiated in the reactor. The heating rods are mainly used for the "boiling water capsule" and for the capsules filled with molten metals (Na and NaK).

— Work was continued on the design and perfection of furnaces and heating jackets for irradiation capsules.

— Studies on the brazing of high-temperature conducting wires were carried out in collaboration with the Metallurgy Department of the CEN.

— Final tests were conducted in order to carry out the satisfactory brazing of a long nickel cross inside a stainless steel sheath.

The programme of work carried out on molten metals (Na and NaK) was continued, the main attention being paid to the studies or applications requested by reactor experimenters and industry:

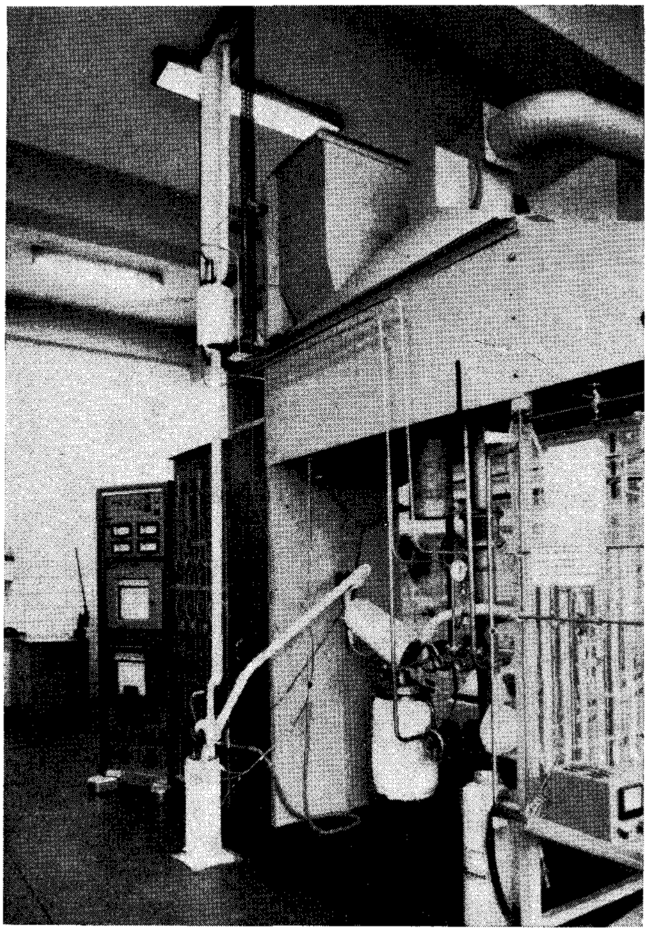


Figure 10
Sodium filling device for irradiation capsules.

— Several devices for handling molten metals were constructed and put into operation. In particular, the NaK decanting installation, made entirely of pyrex glass, for the controlled volumetric filling of capsules with molten metal, was used without incident. Several protype capsules for use in various tests were filled. The installation is satisfactory and will be used regularly during 1965.

— An assembly was designed and constructed with the aid of which it is hoped to obtain more detailed knowledge of the effects of the NaK-H_2O reaction in a sealed containment. The device, which is completely instrumented, permits the controlled feed of water to a tank containing NaK. It is hoped that the temperatures and pressure waves can be measured. In addition, it is hoped that studies can be carried out on problems relating to the cleaning with alcohol of a sealed containment which has contained NaK. The device is ready and tests will commence in 1965.

— Work was continued on the final development of a continuous sodium-level gauge (patent application submitted in 1963) and on the welding of pipes through which molten metals have been passed.

— Tests were also continued on the behaviour of heating wires of the Thermocoax type, both without defects and broken, in the presence of sodium, and on the behaviour of Nicrobraz welds in sodium.

All these projects, which will lead to the complete instrumentation of the capsules and loops in the future, will be continued in 1965 depending on demand.

3. VERIFICATION OF THE IRRADIATION DEVICES

The number of incidents which could be ascribed to technological defects in the experiments was very small in 1964. This was due to the efficient operation of the system used to ensure the smooth running of experiments by systematically checking them at various stages. First of all, each experiment is in the hands of only one person, namely, the project engineer, who is responsible for coordinating the work of a number of specialized departments. Each project is then scrutinized by an "experiment examination committee" consisting of independent members, the majority of whom are not directly connected with the work in hand. This committee studies the various documents and examines the projects not only from the safety angle but also with regard to their smooth operation. The committee's checks are made in three stages:

Stage 1:

Examination of the draft design, with particular attention to the basic principles of the experiment and the method contemplated for solving the safety problems. The clearance given is termed "permission to undertake a detailed project on the basis proposed".

Stage 2:

Examination of the detailed project from all angles. The clearance given is termed "permission to construct".

Stage 3:

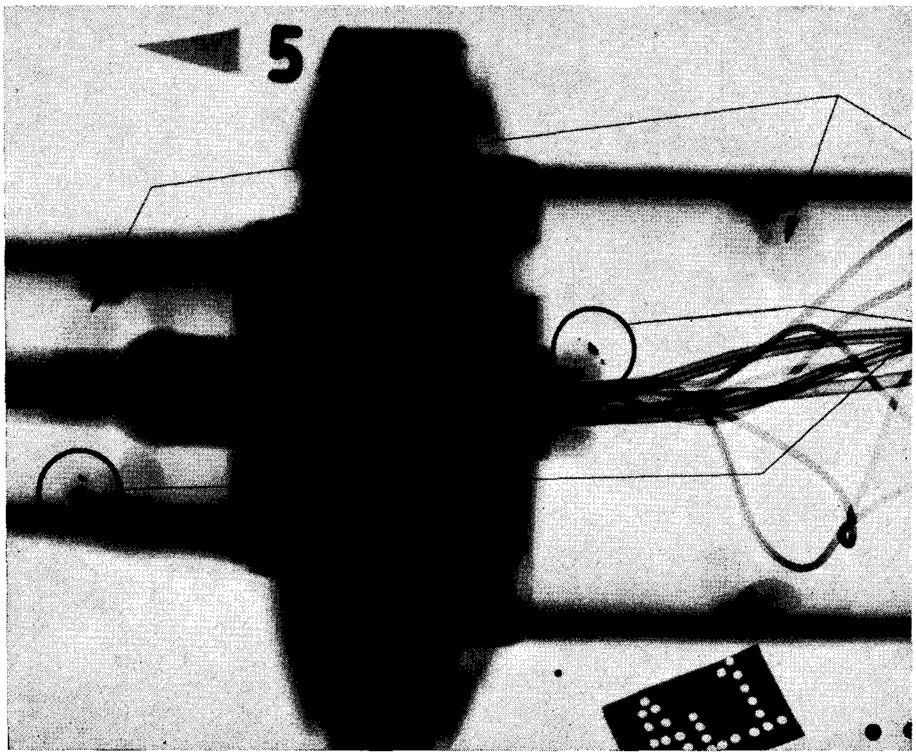
Examination of the final construction, the tests and operating procedures. The clearance given is termed "permission to install in the reactor building".

During 1964, the committee met 36 times and examined 132 experimental stages. It should be pointed out that these were new experiments, since so-called standard experiments or ones which are repeated do not generally require clearance by the committee.

Finally, the checking of all the experimental equipment, the incorrect functioning of which could disturb the operation of the reactor, is in the hands of an independent control group. This team examines the acceptance procedures drawn up by the constructors, collects the acceptance documents supplied by outside control bodies and itself carries out all the safety checks. The specialized personnel and equipment used by this group for the mechanical and electrical tests and for the materials checks can also be placed at the disposal of the experimenters to enable them to carry out certain fabrication checks, which is frequently done. In 1964, the work of this acceptance group was distributed as follows:

RADIOGRAPHIC INSPECTION OF WELDS AND CONNECTIONS FOR DEFECTS.

DEFECTS OBSERVED

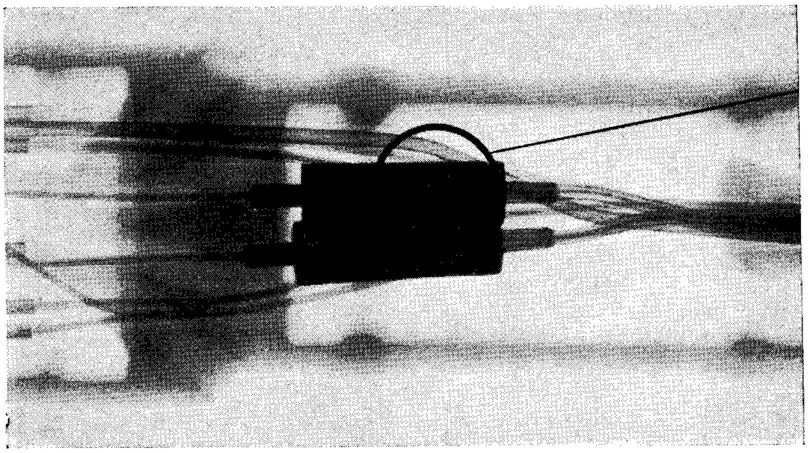


Welding defect
breakdown of weld
with root plan

welding defect
tungsten inclusions;

Figure 11
Instrumented capsule. The upper closure thermocouple passage.

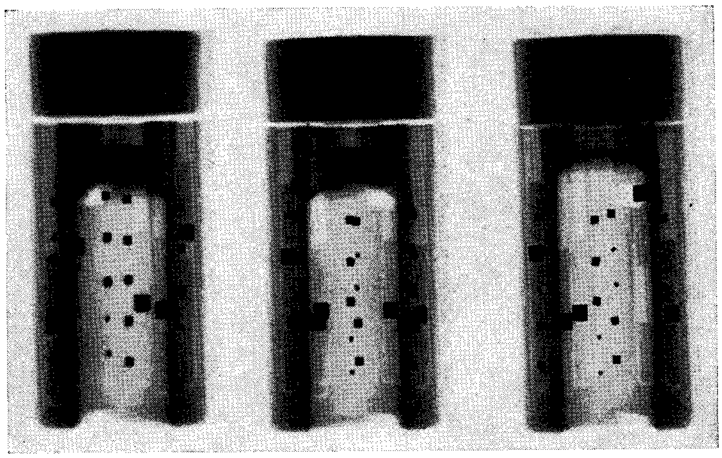
DEFECTS OBSERVED



broken connection.

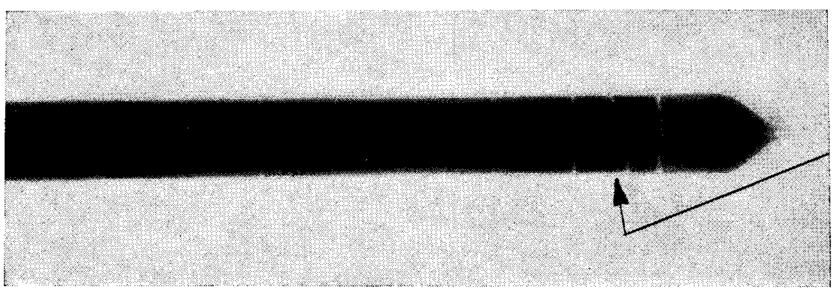
Figure 12
Instrumented capsule. Connection of heater wires in the upper part.

LOADING INSPECTION BY RADIOGRAPHY



none

Figure 13
Production of radioisotopes (unsealed)
3 sample-holders
Check on number and positioning of sources.



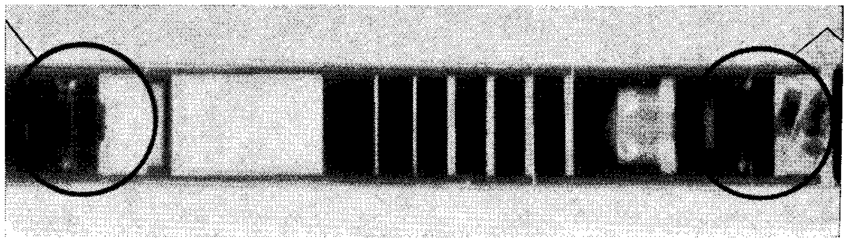
one broken pellet

Figure 14
Experimental fuel needle. Pellets in hermetic cladding.

LOADING INSPECTION BY RADIOGRAPHY

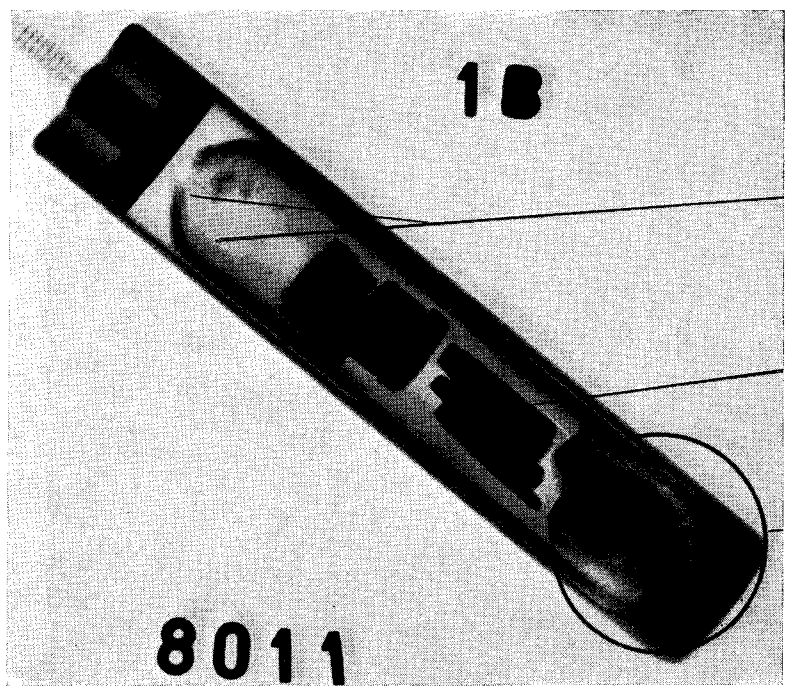
DEFECTS OBSERVED

Detectors in correct position.



detector box
fallen out of position

Figure 15
Experiment fitted with flux detectors.

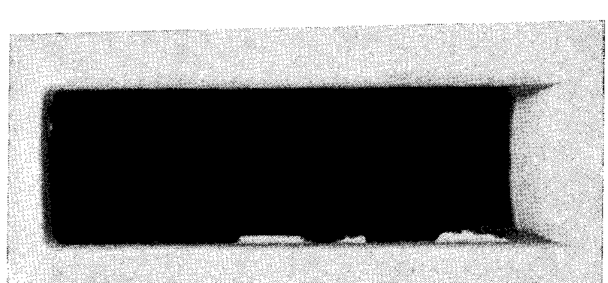


Quartz ampoule cracked

Samples badly arranged

Quartz ampoule broken

Figure 16
Sample-holder with samples sealed in quartz ampoule.



badly filled

Figure 17
Cold-welded sample-holder.

Devices checked	*for GEX*	*for client*
Loops	4	—
Regulated capsules	1	24
Non-instrumented capsules	6	—
Isotope capsules	46	13
Total	57	37

Some of the capsules to be checked contain radioactive materials (radium, irradiated graphite), as a result of which special control techniques had to be developed, in particular with regard to radiography. The means available for carrying out non-destructive tests were extended with the acquisition of a 300 kV X-ray apparatus and vacuum apparatus and autoclaves for the testing of capsules. The scope of the work on "nuclear purity" was widened in response to requests. The chemical cleaning installations were also modified to meet the considerable demand for both the irradiation devices and the internal equipment of the BR2 and of the Venus reactor built by the CEN.

The material checks on experimental equipment made it possible to demonstrate the numerous difficulties encountered in construction and they also provided an indication of the remarkable quality of the work carried out by the constructors or departments accustomed to the high standards of the nuclear sector.

4. THE REACTOR AND ITS USE

In 1964, the reactor operated regularly with a core of 20 fuel elements. The effective operation at the rated power of 33 MW was 222 days. No serious incidents occurred, the experimental load being regularly increased from an average of 15 devices at the beginning of the year to 30 at the end.

4.1. Operation of the reactor

The year was divided into cycles lasting three weeks. Each cycle consisted in theory of a loading period of six days and an operating period of 15 days (360 hours). In practice, owing to unforeseen circumstances, the operating period per cycle did not exceed 302 hours on average. The overall breakdown of the state of the reactor was as follows:

	Time in hours	*Relative time*
Operation	5329	61 %
Scheduled shutdowns	2481	28.3 %
Unscheduled shutdowns	950	10.7 %
Total	8760	100 %

The reactor operating parameters, the core configuration used and its nuclear characteristics are given in the tables overleaf.

AVERAGE NUCLEAR CHARACTERISTICS OF THE 5 A CORE CONFIGURATION

Power = 34 MW Sh = 600 mm (mid-cycle)

Core position	Fuel element			Average thermal flux (1) (2)		Øth max / Øth average	Øth max (3) 10^{14}n/cm^2.s	Ømax > 100 keV (4) 10^{14}n/cm^2.s	H max (5) W/gr Al
	Number of plates	Average burn up at beginning of cycle %	Average burn up at end of cycle %	Ø r BO	10^{14}n/cm^2.s				
DO	5	0	22	1.15	3.30	1.4	4.62	4.76	18.3
BO	5	0	19	1.0	2.88	1.5	4.32	3.46	14.8
C 19	6	0	19	1.0	2.88	1.5	4.32	4.20	16.4
C 341	6	0	19	1.0	2.88	1.5	4.32	4.20	16.7
F 14	6	0	19	1.0	2.88	1.5	4.32	4.20	16.4
F 346	6	0	19	1.0	2.88	1.5	4.32	4.20	16.7
GO	5	0	19	1.0	2.88	1.5	4.32	3.82	15.3
C 41	5	17	29	0.8	2.31	1.65	3.81	2.33	10.7
C 319	5	0	15	0.8	2.31	1.65	3.81	3.19	12.4
H 23	6	13	26	0.8	2.31	1.5	3.47	2.18	10.4
H 337	6	0	15	0.8	2.31	1.5	3.47	2.89	11.8
F 46	6	18	26	0.66	1.90	1.5	2.85	1.69	8.1
F 314	6	18	26	0.66	1.90	1.5	2.85	1.69	8.5
H 37	5	15	24	0.66	1.90	1.45	2.76	1.59	7.6
H 323	5	15	24	0.66	1.90	1.45	2.76	1.59	7.9
LO	6	15	24	0.62	1.79	1.5	2.69	1.43	8.2
B 60	6	20	27	0.55	1.59	1.5	2.39	1.36	6.5
B 300	6	20	27	0.55	1.59	1.5	2.39	1.36	6.8
C 79	6	24	28	0.40	1.15	1.45	1.67	0.70	3.8
C 281	6	24	28	0.40	1.15	1.45	1.67	0.70	3.9

For notes, see following page.

AVERAGE NUCLEAR CHARACTERISTICS OF THE 5 A CORE CONFIGURATION

Power = 34 MW Sh = 600 mm (mid-cycle).

Reflector position	Average thermal flux (1) (2)	
	Ø r BO	10^{14} n/cm².s
H 1 (0)		3.89
H 1 (60)-H 1 (300)		3.46
H 1 (120)-H 1 (240)		2.65
H 1 (180)		2.22
B 120-B 240	0.43	1.24
A 150-A 210	0.38	1.10
C 101-C 259	0.46	1.38
K 49-K 311	0.86	2.48
G 60-G 300	0.71	2.05
L 60-L 300	0.25	0.72
B 180	0.26	0.75
D 160	0.09	0.26

Remarks

(1) Unperturbed thermal neutron flux on the fuel element axis: $\left[n \right]_{0}^{0,5} \cdot v_0$ at 2.200 m/s

(2) Average thermal neutron flux on the fuel element length (762 mm).

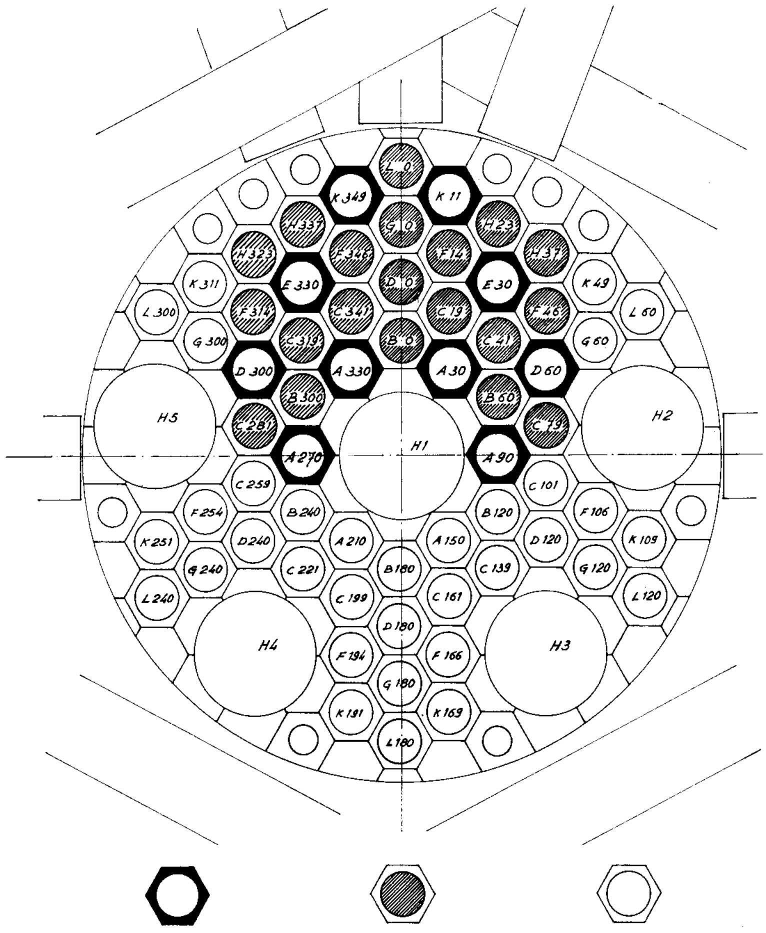
(3) Maximum thermal neutron flux about 100 mm below the reactor mid-plane.

(4) Maximum fast neutron flux: $\int_{100\ \mathrm{keV}}^{\infty} \Phi(E)\,dE$

(5) Nuclear heating of an aluminum sample located on the fuel element axis in the maximum thermal neutron flux plane.

During the year, the integrated power was around 1600 MWd, which corresponds to a consumption of around 9.4 kg of U-235. The number of fuel cartridges used was 163, the average depletion rate being 25 %.

BR 2-CORE CONFIGURATION 5 A (20 FUEL ELEMENTS)



control rod fuel element beryllium plug or experiment

OPERATING CHARACTERISTICS OF REACTOR IN 1964

Nominal power	33 MW
Operating time	222 days
Operating time per cycle	302 hours
Energy dissipated	422 MWd/cycle on average
Weight of U-235 in 20- element core	4150 to 4200 at start of cycle

Primary circuit

Total flow-rate	5600 m^3/h
Inlet temperature	36 °C
Outlet temperature	41 °C
Pump outlet pressure	14.9 kg/cm^2

Reactor inlet pressure	12.4 kg/cm^2
Δp core	3.5 kg/cm^2
pH	6.1
Resistivity	$3.10^6 \Omega/cm$
Purification rate	20 m^2/h
Radioactivity	$10^{-1} \mu C/cc$

Secondary circuit

Total flow-rate	4300 m^3/h
Tower inlet temperature	35 °C
Pool outlet temperature	27.5 °C
pH	5.5-6
Resistivity	100,000 Ω/cm
Purification flow-rate	100 m^3/h
Radioactivity	0

Reactor pool circuit

Flow-rate	800 m^3/h
Inlet temperature	31.6 °C
Outlet temperature	33.4 °C
pH	6
Resistivity	$> 10^6 \Omega/cm$
Purification flow-rate	20 m^3/h
Radioactivity	$10^{-4} \mu C/cc$

Uranium fuel plates

Maximum temperature at hot spot	125 °C
Heat flux maximum	360 ± 40 $watts/cm^2$
Water velocity between plates	11 m/sec

Liquid effluents per average cycle

Cold $< 10^{-5} \mu C/cc$	183 m^3
Warm 10^{-5} to 10^{-2} $\mu C/cc$	380 m^3
Hot 10^{-2} to 1 $\mu C/cc$	65 m^3
Chemical 10^{-2} to 1 $\mu C/cc$	82 m^3

Gaseous effluents

Containment building ventilation	38,000 m^3/h
Machine hall ventilation	150,000 m^3/h
Radioactivity	$< 10^{-10} \mu C/cc$

Annual consumption

Electricity	18,000,000 kWh
Demineralized water	161,000 m^3
U-235	9417 g

Consumption per average cycle

Electricity	1,050,000 kWh
Demineralized water	9000 m^3
U-235	523 g

A report was submitted to the Third United Nations Geneva Conference on the safety tests carried out on the reactor in 1963.

4.2. Incidents encountered in operation

The reactor had to be shut down for 10.7 % of the time owing to incidents occurring during operation. The causes of these unscheduled shutdowns break down as follows:

Incident	*Duration of shutdown hours*	*Relative duration %*
Fall of control rods	625	65.8
Other failures of reactor installations	217	22.9
Insufficient reactivity	63	6.6
Piloting error	23	2.4
Failure of irradiation devices	22	2.3
Total	950	100

By far the most frequent cause of trouble was the unscheduled release of control rods. All the incidents involving control rods took the form of an unscheduled drop of the movable neutron-absorbent part. These incidents were due to leaks in the control rod electrical system—electromagnetic arrester and magnetic positioning contacts—which is located in the primary circuit demineralized water and is subject to stresses due to the operation pressure (12 kg/cm^2) and the numerous mechanical stresses set up by the successive pressurization and decompression necessary during reactor operation. Several modifications were carried out in order to make the system leaktight and at the end of the year the number of failures had dropped considerably. Alongside this, the rod manufacturers have just worked out a solution to the problem in which all the electrical parts are sealed in a single metal helix, which is likely to be a more satisfactory method.

The other faults in the reactor installation were mainly of a mechanical nature. Leaks occurred in the primary circuit: two tubes in the heat exchangers developed leaks and had be to plugged; the joints in the main pumps had to be replaced several times, and the pressuriser-degasser also caused some trouble with regard to leaktightness. Some defects also occurred in the electronic control circuits and the normal electric supply broke down on several occasions.

An unscheduled reactor shutdown, with reversal of the primary water flow, happened in June under somewhat peculiar conditions. While the reactor was in operation, the automatic valve which controls the secondary water flow rate, and hence the cooling of the reactor, jammed in the closed position thus causing a rapid rise in the temperature and primary pressure. For some unknown reason, this valve then opened suddenly, the primary water was abruptly cooled and the reactor was tripped automatically as a result of the low pressure signal. Following the established sequence of actions, this signal caused the shut-off valves to close, cutting off the primary flow, and also opened the reactor by pass valve, thus opening the way to natural circulation. No faults were observed in the fuel after this flow reversal, which was in fact merely an unscheduled repetition of the tests carried out in September 1963.

Two incidents involving the expulsion of parts from the reactor occurred when the reactor was put under pressure and the pool was not full of water. Despite the checks carried out, the locks on the sealing plugs of the top plate were not complete. In the first case, which took place in January, a fuel element, non-irradiated, was partially expelled and fell back in place in the core. In the second instance, which happened half-way through March, a cobalt capsule—already irradiated—was completely ejected from the reactor, the suspension tube and the capsule remaining on the pool walk-way. The capsule was covered after the level of the pool water had been raised to assure protection. Fortunately, the incidents caused no harm to the personnel present. In order to avoid further trouble, safety collars, which were already used on each control rod for safety purposes, were fitted to each fuel element. Furthermore, a steel rope was passed through the eyelets on top of the experimental devices in order to hold them together and to prevent their moving by more than a few centimeters in event of an accident. Finally, the locking of the reactor top plate plugs is now checked at zero pressure instead of full pressure as previously. In addition, in future the reactor can only be pressurized if the pool is filled with water, as a result of which the personnel are automatically deprived of access to the top plate before start-up.

Failure of the irradiation devices was not very frequent. There were a few cases where capsules developed leaks with the attendant risk of contamination. In addition, during March, the thimble in the Dragon loop (OECD) jammed in the reactor channel when it was being replaced. A hydraulic jack had to be used in order to shift it, a thrust of 1,260 kg, checked by a dynamometer, being required. The cause of the jamming is attributed to the fact that a small screw at the head of the thimble became loose. Finally, a capsule containing several small targets broke in the middle during removal from the reactor. Six targets fell to the bottom of the reactor pressure vessel without any other damage being caused, while the sheathing semi-tube caught on an internal safety tube and had to be recovered with the aid of the normal tools.

4.3. Reactor equipment

Several major jobs carried out intended to facilite the use of the installation by the experimenters or to improve operational safety or the data available for the reactor:

— A hydraulic conveyor was installed in the reactor and is to be used permanently for the production of isotopes.

— A basin for gamma irradiations was fitted with the necessary equipment.

— The general electrical supply system is now being extended so as to feed the Siemens and Rapsodie loops as well. The network must be capable of supplying experimenters with 1000 kVA by the normal circuit and 400 kVA by the stand-by circuit.

— The measuring probe facilities were strengthened by the addition of output probes for measuring the power in a reactor channel, calorimetric probes for measuring the nuclear heat in the reactor and cobalt integrators to permit integration of the thermal neutron fluxes at each cycle. A television camera (internal diameter 78 mm) was also installed for inspecting the reactor channels and can be used up to depth of 20 meters below the surface of the water.

— A special heavy-duty remote-handler was ordered from an outside firm for recovering pieces which fall down to the bottom of the vessel. The general remote-handling equipment was also added to.

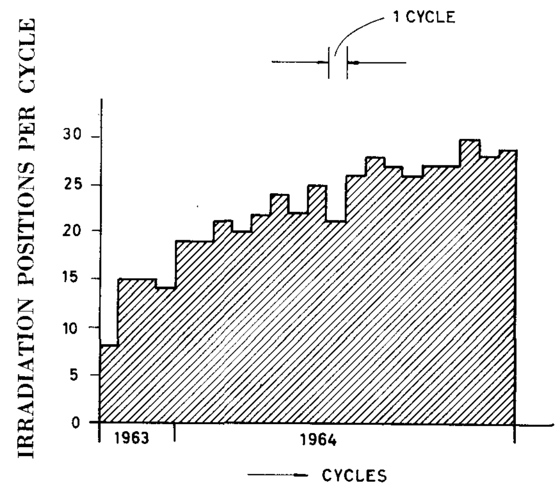
— A safety valve was installed between the primary circuit and the reactor pool in order to ensure that the core remains under water at all times.

— Numerous electrical circuits were modified in order to render them insensitive to parasites.

4.4. Use of the reactor

The number of experimental devices loaded in the reactor increased steadily throughout the year, 25-30 channels being occupied almost permanently at the end of the year.

REACTOR LOADING IN IRRADIATION POSITIONS, PER CYCLE
(core, reflector, horizontal channels)



Irradiations in the fuel elements were most frequent, an average of 65 % of the core being occupied. The distribution of samples was as follows, in capsules x cycles:

graphite	119
zirconium	33
Stainless steel	22
beryllium oxide	19
miscellaneous	51
Total	244

Among the main experiments carried out mention should be made of the irradiations of graphite, stainless steel, beryllium oxide and iridium for the UKAEA; the irradiation of zirconium, lithium, bismuth and cobalt for the French CEA; the irradiation of graphite for the Dragon project; the irradiations of graphite loaded with fissile materials, zirconium hydride, radium and iridium for industrial firms; the irradiations of stainless steel, copper, thulium and rare earths for other nuclear research establishments or universities; and the irradiations of americium, cobalt, iridium, gold, iodine, iron, calcium and samarium for the CEN. The neutron beams were also used continuously by the CEN in conjunction with physicists from the Jülich Centre.

Several irradiations were carried out for periods of more than one year. In numerous cases, the period for which the samples are irradiated is longer than the capsule irradiation time. After an initial irradiation, these samples are examined and then replaced in other capsules so that irradiation can continue, the total dose required amounting to an average integral thermal flux of 10^{22} nvt in some cases.

5. PHYSICS STUDIES

The BR02 reactor, which is a zero energy model of the BR2, together with a well-equipped dosimetric laboratory, are available for use by physicists. The studies carried out in 1964 paved the way for the modifications to the reactor core which were necessary in order to place more facilities at the disposal of clients. The safety studies were continued, together with routine dosimetry of irradiations carried out by clients. A report on the reactor physics data acquired was presented at the Third Geneva Conference.

5.1. The BR02 reactor

The reactor was used mainly for preparing the new configuration of the BR2 core. This new configuration is necessary owing to the extension of the irradiation programmes. The experimental study of about twenty configurations was preceded by a systematic examination of the specifications demanded by the clients, mainly the users of the loops. Data were drawn up for each configuration concerning the reactivity balance, the general neutron flux pattern and the radiation field inside certain experimental devices simulated by means of a model. The future configuration will be placed in the middle of the reactor vessel, around the main central beryllium channel, whereas the present configuration is off-set. The fuel load will vary from 26 to 31 elements, and its operating output will be between 55 and 60 MW, the thermal flux at the axis of the central channel being in excess of 10^{15} n/cm^2/sec. By irradiating the MFBS sodium loop (Rapsodie) in the central channel, which is fitted with an adequate absorbent shield, fissile pins can be raised to very high specific powers (2000-3000 watts/cm^3) under the action of the fast neutrons alone.

In addition to the configuration studies, the BRO2 reactor was used for the final development of dosimetric techniques to be employed by clients for the design of experiments for use in the BR2. It was also used for predetermining the irradiation conditions.

The measurement of high antireactivities was carried out, in particular, with the aid of a pulsed and modulated fast neutron source mounted in one of the reactor channels.

A report on the general results obtained in 1962 and 1963 with regard to reactor physics was presented to the Third Geneva Conference and permitted the determination of a number of values which are essential to the operation and use of the reactor. In addition, on the basis of the tests carried out, it enabled an idea to be gained of the usefulness of the BR02 reactor and of the accuracy of the estimates made.

5.2. The dosimetry laboratory

Routine work was continued on installing and analysing all the irradiated detectors in order to serve both clients and the operator of the reactor (flux measurements, integrated flux measurements and calorimetric measurements). A lead cell was also fitted to enable the high-activity detectors to be recovered quickly and transferred to the counting installations.

Work of a more general nature in the field of dosimetry was continued so that the special demands of certain experimenters could be met. The method for measuring integrated fast neutron fluxes by means of iron and titanium was developed for general application, while close attention was given to the use of other integrators (copper, niobium, manganese). With regard to the spectrometry of fast neutrons, the average effective cross-sections in a fission spectrum were measured for numerous threshold detectors. The approximation of the fission spectrum which is possible with the aid of uranium converters was studied experimentally with a view to defining a standard spectrum. Finally, techniques for measuring the fission density in different spectra were studied and applied, being used in particular for determining the specific power dissipated by fuels irradiated in a capsule.

5.3. Theoretical studies

In parallel with the tests, numerous theoretical determinations were carried out. For example, the operating parameters of numerous experimental devices were analysed; in particular the different variants of the MFBS loop (Rapsodie) required numerous calculations for different arrangements in the reactor core.

The studies of some fundamental problems were also continued, notably the theoretical studies of the void coefficient, the studies on the influence of the fuel enrichment on reactor performance and various safety studies.

6. POST-IRRADIATION WORK

In 1964 greater use was made of the shielded dismantling cells adjoining the reactor. Construction and fitting out of the medium-activity laboratory were continued throughout the year. The purpose of this laboratory, the scope of which is limited, is to meet the requirements of the experimenters, who constitute the users of the reactor, as rapidly as possible.

6.1. Very-high-activity cells

The dismantling cells attached to the reactor are only gamma-tight (60,000 curies—3 MeV). In total, 76 experimental devices removed from the reactor were handled in them.

The total occupation time in the cells was 685 hours. The work carried out included the sectioning of irradiated devices and recovery of the targets, the reassembly of irradiated devices with the insertion of "cold" or "hot" samples and the loading of non-irradiated devices with "hot" targets.

No materials incident occurred and the doses received by the operators remained within the limits laid down.

Alongside operation of the cells, the studies on the equipment of the cells were continued to speed up the work, or to increase the safety, or to permit the handling of more complicated jobs than previously, such as the dismantling of a sodium-filled loop. New remote-control machine tools were put in service, as well as a transfer hood permitting easy extraction of the targets. A device was installed for measuring activities in the cells up to 10^6R/h, as well as CO_2 fire-fighting equipment.

Plans were laid for the modification of a working post to enable fissile materials to be sectioned. A start was made on design of an alpha-tight box and its equipment.

Studies were carried out in collaboration with the Petten Joint Research Centre on the radiography of very-high-activity fuel elements. A submersible prototype is being developed at Petten and the results are very encouraging.

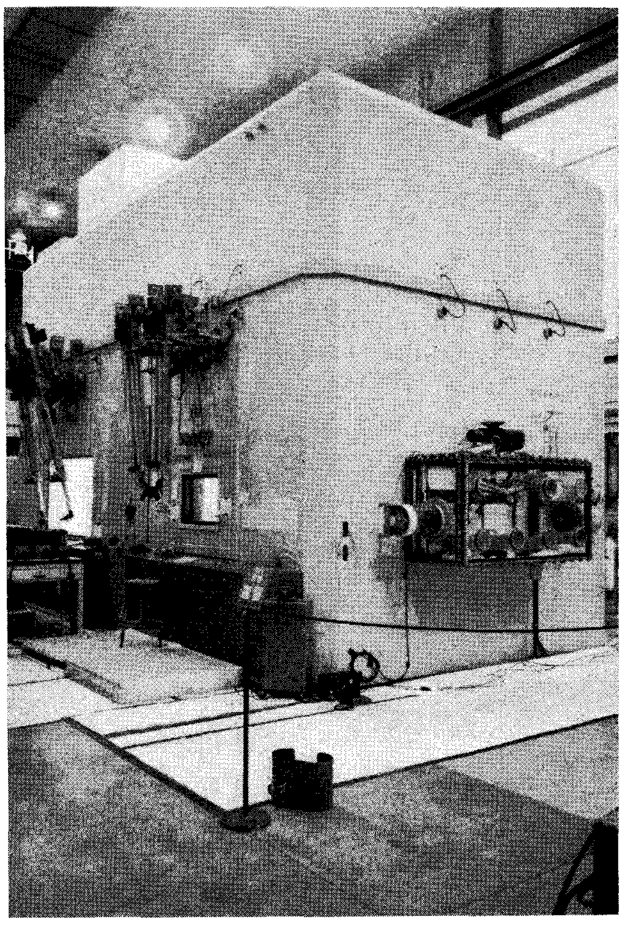


Figure 18
The alpha-tight 1000 curie cell being prepared for curium separation.

A device permitting the complete non-destructive examination of the BR2 type fuel elements was developed in the pool adjoining the hot cells. This device will be used in particular for the examination of an ESSOR element irradiated in the BR2.

6.2. The medium-activity laboratory

The laboratory consists of a concrete cell, lead cells and analytical laboratories. The year's main activities consisted of construction work and the final development of scientific equipment.

6.2.1. *The concrete cell-1000 curies*

The cell was originally designed for handling a 1000 curies (1 MeV) source of trans-plutonium elements emitting $2.8 \cdot 10^9$ neutron/sec. It is alpha-tight.

Construction and the finishing work on the cell were completed during the year. The first active operation was prepared by the CEN transplutonium elements group for the extraction of curium from a target irradiated in the United States. The extraction work proper will commence in the beginning of 1965, when the cell will be converted into a polyvalent cell in which all the tests on irradiated fuels can be carried out, in particular the puncture of capsules to sample fission gases, and the measurement of the gamma-activity distribution.

6.2.2. *The lead cells (180 curies)*

In the lead cells, which are 15 cm thick and alpha-tight, physical and metallurgical tests can be carried out on irradiated samples. During the first half of the year, the cell utilization programme was adapted more closely to the requirements of the first experimenters which allowed the design of certain units to be simplified. Construction work on the cells commenced during the second half of the year. The tests on the scientific equipment adapted for remote-control work resulted in satisfactory solutions, so that all the cells can be made active during 1965.

The "workshop" cell is used for preparing samples for further analysis. Handling is facilitated by the means of tongs, a GM. M150 handler and two small inside gantry cranes. The tools include a lathe, a drill and a saw. The Vickers and Rockwell hardness measurements are conducted in the "hardness and heat treatment" cells. The treatments and thermal cycling can be carried out in two furnaces up to a temperature of 1100 °C, under a vacuum or inert atmosphere.

The "physics measurements" cells contain various devices for measuring the dimensions of samples up to 200 mm long with an accuracy of ± 0.005 mm over the length of ± 0.01 mm over the diameter. Density and electrical resistivity measurements will also be possible.

The "metallography" cells consist of five sample preparation cells (coating with cold polymerizable resins, mechanical and electrolytical polishing, cathodic and electrolytical attacks) and a microphotography cell. This latter is fitted with a Reichart Telaton remote-control metallographic microscope. Photographic techniques were developed for both black and white and colour (in line with the Scientia-Color Gevaert) method. There is provision for the subsequent installation of a system for filling the cells with inert gas. The "mechanical test" cells were designed for the impact-strength and tensile tests. The impact-strength test cell enables transition curves to be determined for Charpy samples

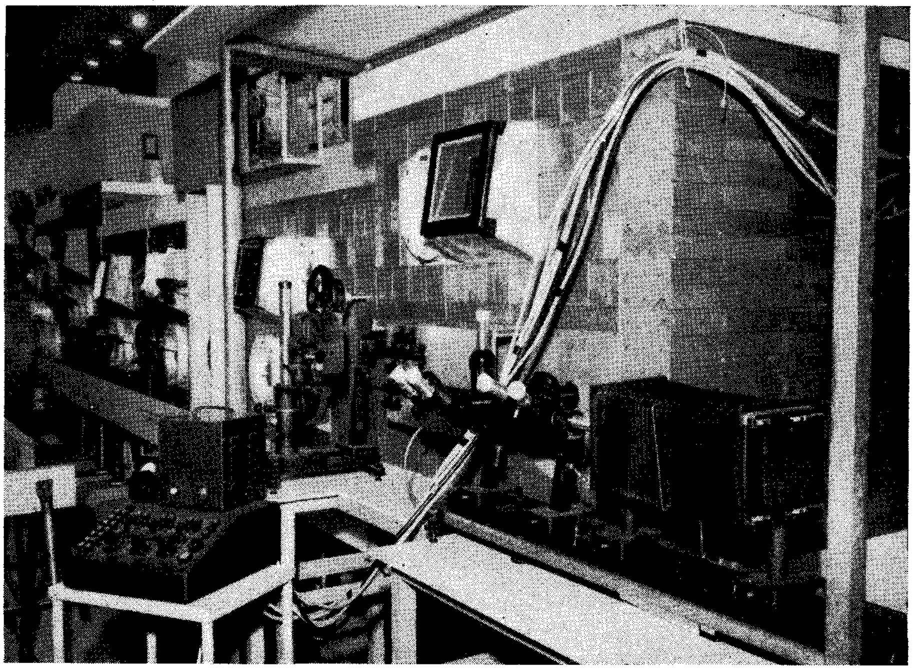


Figure 19
Working face of metallography cell. Microscope in the foreground.

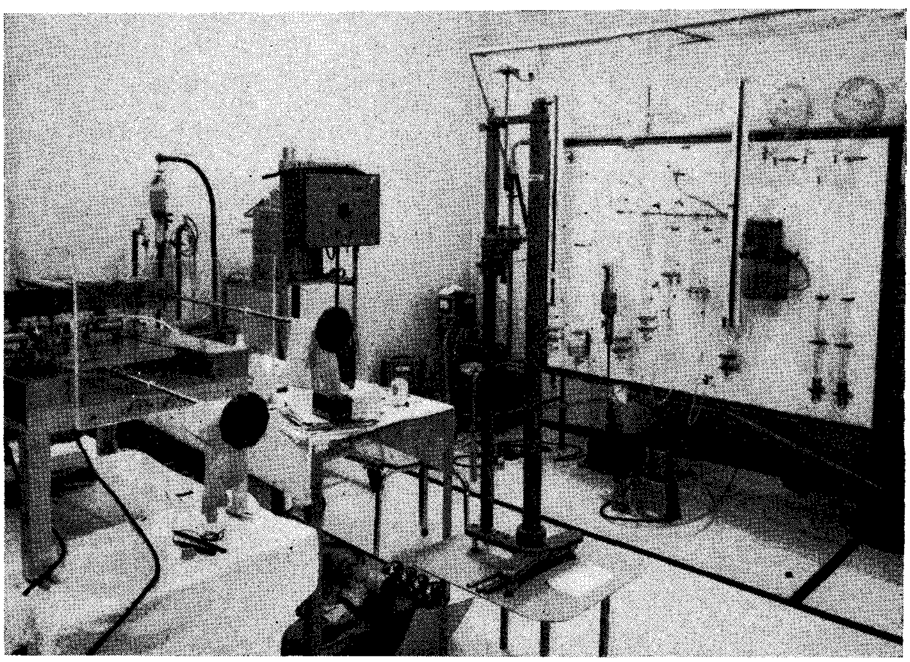


Figure 20
Graphite physical chemistry laboratory.
The metal surface measurement device is on the right (BET).

10 ×10 mm and 5 × 10 mm in cross-section at temperatures ranging from —40 to +250 °C with the aid of a remote-control Tinius Olsen pendulum hammer. The tensile test will be carried out on an Instron machine at temperatures which can be adjusted between ambient and 900 °C under an inert atmosphere. The machine is adapted for twin-step samples with a head diameter of 8 mm (DIN 5212 5 C). The tensile-testing machine is operated by a pair of M7 remote handlers. The micrographs of the rupture surfaces can be made by television.

6.2.3. *The analytical laboratories*

For the examination of samples for the Dragon project (OECD) considerable use was made of the laboratory for the physico-chemical analysis of irradiated graphite. The range of tests carried out has been extended and now covers measurements of weight, porosity, permeability, total surface, electrical resistivity and dilatometry up to 850 °C. Studies have begun of a device for measuring the coefficient of heat conductivity and of devices for the mechanical microtests.

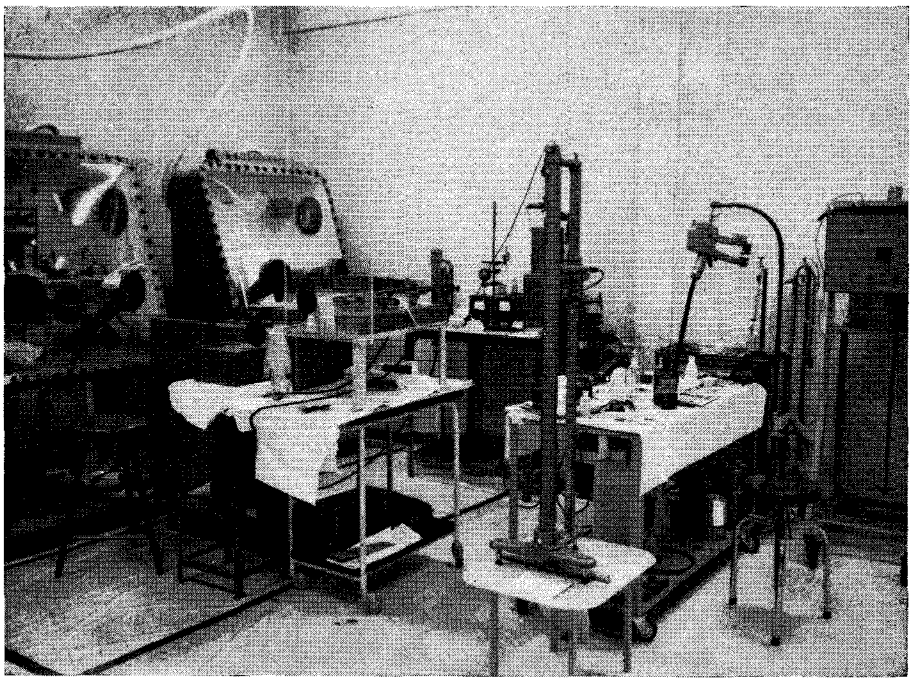


Figure 21
The graphite physical chemistry laboratory used for analysis of the graphite irradiated in the reactor by the dragon project.

The first work on the equipment of a chemical laboratory was commenced. This laboratory will place at the disposal of the experimenters the means for dissolving the fuel elements, separating fission products and determining the burn-up. Work has also been started on autoradiography techniques. The quantitative analysis of the fission products will be carried out in collaboration with the CEN and Eurochemic.

7. PERSONNEL AND FINANCIAL SITUATION

7.1. Personnel

The operating staff consists of both CEN and Euratom employees. The personnel situation at various times breaks down as follows:

Year	*CEN employees*	*Euratom employees*	*TOTAL*
on 31.12.1961	133	33	166
on 31.12.1962	156	36	192
on 31.12.1963	191	40	231
on 31.12.1964	214	41	255

The number of university graduates employed by the CEN and Euratom varied between 14 and 16 and 13 and 16 respectively.

7.2. Financial situation

The table overleaf gives a breakdown of the financial commitments and expenditure. It should be noted that commitments and expenditure tend towards a steady value, while revenue increases steeply as a result of the speed-up in the loading of experiments in the reactor.

EVOLUTION OF BR2 ASSOCIATION REVENUE
(invoiced sums)

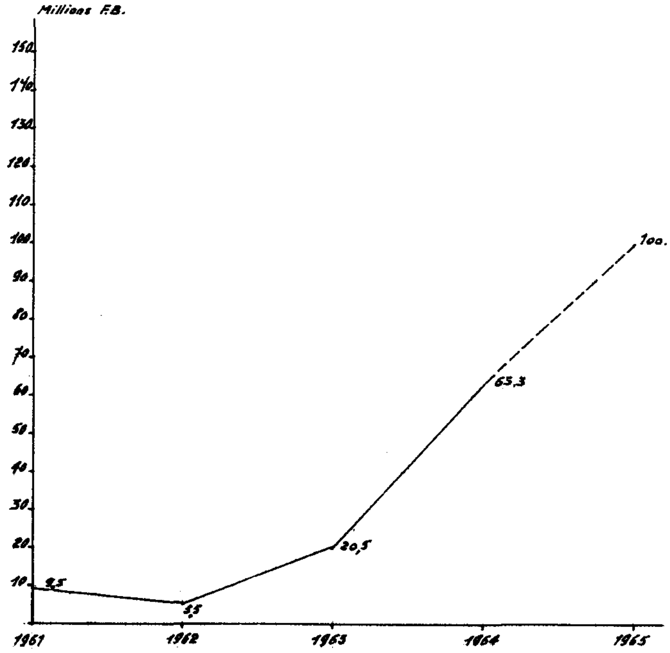
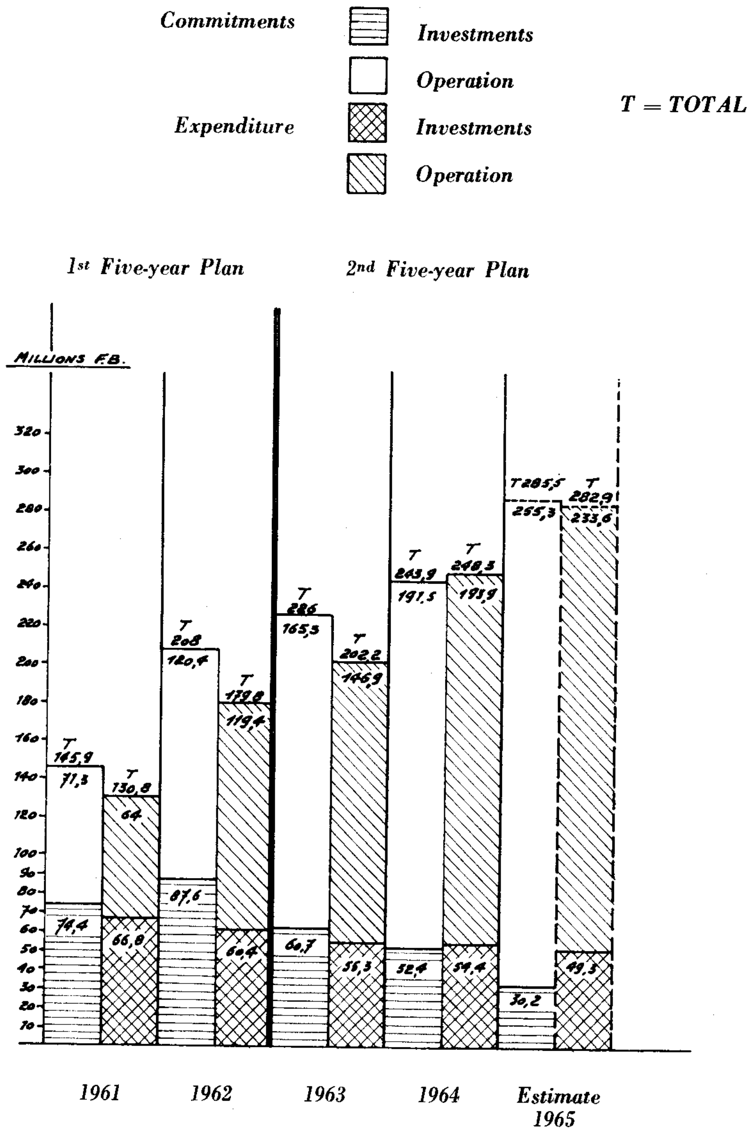


TABLE OF COMMITMENTS AND EXPENDITURE



To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.

Alfred Nobel

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