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PROGRESS IN GRAPHITE RESEARCH
A Summary of Hanford Laboratories Achievements
in This Program Under General Electric
1956-1964

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INTRODUCTION

The world's first large reactors were constructed at Hanford in the period 1943 to 1944. Three reactors were constructed almost concurrently, B-Reactor being the first to go critical in September, 1944, with D- and F-Reactors following within the next few months. It was clear, even before these reactors were completed, that radiation damage to the graphite moderator might cause serious operational problems and perhaps even render the reactors inoperable.⁽¹⁾ More information on radiation effects in graphite was clearly needed and a research program was established at Hanford. Early research on graphite was also carried on by Argonne National Laboratory and North American Aviation.

Serious problems were subsequently encountered with the graphite, principally from radiation-induced expansion. In fact, when it appeared at one time that the useful life of the reactors might be severely limited, B-Reactor was shut down and held in reserve and DR (D-Replacement) was constructed. However, when more was learned about radiation effects in graphite, means were found to reduce the expansion.

The research performed for these early reactors led to new graphites and to design changes to alleviate the expansion problem in reactors that were subsequently constructed. Eight production reactors have been built. A ninth, N-Reactor, which is now undergoing start-up tests, will produce steam for the generation of approximately 850 MW of electrical power in addition to producing plutonium.

In addition to the graphite expansion a number of other problems arose that required solutions. Some of these were only potential problems, arising from the almost complete lack of knowledge about radiation effects in graphite. Other problems were real. A partial list of these would

include: nuclear purity, strength, quality control, and machining of the bars; radiation effects on mechanical properties and thermal conductivity; the accumulation of stored energy; and the radiolytic and thermal reaction of oxidizing gases with the moderator bars. A good indication of the problems associated with the graphite can be obtained from a listing of the reports on reactor graphite published⁽²⁾ in 1955 and updated⁽³⁾ in 1958.

The changes in level of effort over the years are shown in Figure 1. From 1951 to 1955, work was increased to develop and evaluate graphite for the K-Reactors. In the period 1959 to 1960 a similar development

FIGURE 1

Graphite Research and Development Operating Costs
FY1951-1965

program was established for N-Reactor. Because the latter was the first reactor constructed at Hanford with the prior knowledge that graphite contracts at high temperatures (> 300 C) transverse to the extrusion direction, efforts centered around the development of a graphite in which this effect would be minimized.⁽⁴⁾ Work sponsored by the Division of Production has leveled off in the past few years, the principal research being conducted on the contraction effect and on compatibility of the graphite with zirconium and impurities in the gas atmosphere.

In 1958, when some of the Hanford graphite technology was directly applicable to problems expected in graphite-moderated gas-cooled reactors, a small amount of work was sponsored by the AEC Division of Reactor Development. This has steadily grown to a sizeable effort which, in 1964, accounted for about two-thirds of the Hanford graphite research. The program has now evolved into a more general one whose objective is to anticipate the major problems and develop the understanding and technology required for their solution in all graphite reactors. These include the following types: high-temperature gas-cooled, sodium-cooled, molten-salt, pebble-bed, and nuclear-propulsion reactors. The emphasis in all of these toward higher temperatures and specific powers is reflected in the graphite studies summarized in this report.

It is beyond the scope of the present report to consider the graphite problems and experience with the Hanford production reactors in detail. This could, in itself, be the subject of a very interesting story, but much is still classified. Suffice it to say that this early experience with graphite formed the basis for extension of graphite research at Hanford to gas-cooled and other civilian power reactors.

In this report, the accomplishments of graphite research at Hanford will be summarized with emphasis on the period from 1956, when the Hanford Laboratories was established, to 1965, at which time the operation of the Laboratories will be transferred from the General Electric Company to Battelle Memorial Institute. The work will be divided into three major activities: radiation-damage, neutron dosimetry, and gas-graphite reactions.

Cooperative efforts with several carbon companies in developing better materials will be described, and finally, the technical exchanges with foreign countries will be discussed.

SUMMARY AND CONCLUSIONS

The early pioneering studies of radiation damage and chemical reactions of graphite in support of the Hanford production reactors made it possible to continue the operation of the reactors. These studies also contributed substantially to nuclear graphite technology.

Since 1958, the special facilities and technical skills developed at Hanford in this early work have been increasingly applied to problems anticipated in graphite-moderated civilian power reactors. The objective of the present program is to develop the understanding and technology required for the use of graphite in all types of reactors. Major areas of study have included: nuclear purity, quality control, and production machining; radiation-induced changes to dimensions, mechanical properties, crystallite parameters, and thermal conductivity; accumulation of stored energy; and radiolytic and thermal oxidation.

The carbon manufacturers have cooperated closely in the development of new graphites since the earliest days of the Hanford project. A great deal of work remains to take full advantage of the wide range of carbon materials that can now be made.

Formal agreements with other nations have been mutually beneficial in providing the mechanism by which information can be rapidly exchanged. Small, informal meetings with United Kingdom scientists have been particularly useful in recent years because of the very extensive graphite research program there.

At present the Hanford graphite studies are concerned with problems associated with the higher fluxes and graphite temperatures of advanced reactors and the increasing demands placed on the strength and creep of graphite. New functions such as low-permeability fuel cans, high-temperature matrix and coatings for fuel particles, and poisoned-graphite

materials for control rods and shields for fast reactors, require the development and testing of materials with special properties. The higher temperatures of modern reactors have also focused attention on the oxidation of graphite by gases and compatibility with other materials.

RADIATION DAMAGE IN GRAPHITE

Dimensional Changes

One of the major accomplishments of the Hanford graphite research has been the work on radiation-induced dimensional changes. When the studies were begun in 1945, almost nothing was known. The initial interest was in effects near room temperature. It was found that graphite bars expanded perpendicular to the extrusion direction and contracted in the parallel direction. Irradiations have been continued over the years to high neutron doses. The results for several graphite grades used in the construction of Hanford reactors are shown in Figure 2.

FIGURE 2

Dimensional Changes of Nuclear Graphites Caused by Irradiation at 30 C

The qualitative effects can be explained on the basis of changes to the crystal structure. Carbon atoms displaced by fast neutrons come to rest between the layer planes. These single displaced atoms are relatively mobile at room temperature and react with other displaced atoms to form clusters whose size depends on the temperature and perfection of the crystal. These clusters force the planes apart, increasing the c spacing. Lattice vacancies are formed concurrently, but apparently do not play an important role in the effects produced at room temperature. The a spacing decreases, probably as a result of buckling of the planes rather than an actual decrease in the carbon-carbon distance.

A fraction of the dimensional changes of the crystallites, which may vary from about 5 to 50% depending on the porosity of the graphite, appears as a bulk dimensional change. As a consequence of the preferred orientation of the particles produced during extrusion, the crystallite changes cause the bulk dimensions to expand transverse to the extrusion direction and contract in the longitudinal direction as shown in Figure 2.

The different growth rates can be attributed to structural differences in the graphite. The KC graphite is a highly graphitic, anisotropic material used in some of the early Hanford reactors. The growth rate is lowest in TSGBF graphite, which is less graphitic and more isotropic.

Irradiation tests conducted in the late 1940's showed that expansion transverse to the extrusion direction and contraction in the longitudinal direction could both be reduced by higher irradiation temperatures, and a few years later it was found that graphite actually was beginning to contract in the transverse direction at temperatures above 300 C. These and other events associated with the dimensional stability of graphite are summarized in Table I.

The distortion caused by contraction of graphite is still a serious problem in graphite-moderated reactors, and is currently receiving more attention at Hanford than any other graphite problem. Many nuclear and experimental graphite grades are continuing to be irradiated in the Hanford reactors and in high-flux test reactors. These tests have pointed to certain

properties of the graphite which affect the contraction behavior. For example, it was found that the transverse contraction rate increases when the graphitization temperature (normally about 2800 C) is reduced⁽⁵⁾ or a nongraphitizing raw material such as carbon black⁽⁶⁾ is used. The effect of graphitization temperature is shown in Figure 3. These and other studies suggest that the graphite should be well crystallized to minimize contraction at high temperatures. In contrast to this, transverse expansion below 300 C is less in materials that are less fully graphitized. Criteria for high-temperature stability have been proposed and some were included in the specifications for the Experimental Gas-Cooled Reactor (EGCR) and N-Reactor moderators.⁽⁷⁾

TABLE I
EVENTS ASSOCIATED
WITH THE STUDY OF RADIATION-INDUCED DIMENSIONAL CHANGES
IN GRAPHITE IN THE UNITED STATES

<u>Date</u>	<u>Event</u>
1942-1945	Predictions and first observations of radiation-induced dimensional change
1946-1947	Graphite expansion becomes a problem in reactor operation Contraction in the longitudinal direction first noted
1948-1951	Increases in reactor operating temperature reduce expansion Reactor designs improved to reduce expansion
1952-1956	Special methods of manufacturing graphite developed to reduce expansion First observation of contraction transverse to extrusion direction in irradiations above 300 C
1957-1961	Contraction recognized as a problem in the design and operation of reactors

The mechanism by which contraction occurs can only be stated qualitatively at this time. Contraction is attributed to two separable processes. The first is a vestige of the low-temperature damage; it results in an expansion of the crystallites along the c axis and contraction along the a axis. Because this type of damage is annealable, the amount of crystallite expansion and contraction is a function of the irradiation temperature, and this accounts for the temperature dependence of the stability. The second process is nonannealable and is presumed to result from a further densification of the noncrystalline regions associated with grain boundaries and binder junctions. Extensions of this theory have been

applied to the qualitative interpretation of dimensional changes in raw-coke graphite, pyrolytic graphite,⁽⁸⁾ lampblack-based graphite,⁽⁶⁾ and the effects of sample size⁽⁹⁾ and external stress.⁽¹⁰⁾

FIGURE 3

Dimensional Changes in Molded Texas-Coke Graphites,
Transverse Orientation

[Irradiation temperature = 500 to 600 C;
1 MWd/adjacent ton = 0.95×10^{17} neutrons/cm² ($E > 0.18$ MeV)]

Irradiations in high-flux test reactors have extended the Hanford irradiations to very high doses, comparable in some cases to the lifetime dose in a power reactor.⁽¹¹⁾ The irradiation testing has required the development of special capsules that would function reliably at high temperatures and fluxes for long periods of time.⁽¹²⁾ A particularly successful design that has been utilized for EGCR and N-Reactor graphite testing is shown in Figure 4. Gamma radiation supplies the heat to the sample. With this design, temperatures in the range 375 to 1200 C have been achieved. This capsule has proven to be very reliable. To date, 23 tests of 5 to 6 mo duration have been run in the General Electric Test Reactor (GETR) without failure

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FIGURE 4

High-Temperature Capsule Used in the GETR for Irradiation Tests on Graphite
(The quarter-round graphite sample and capsule parts are shown in front. This assembly slips
inside a 2 in. aluminum tube.)

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The results⁽¹¹⁾ of these long-term tests in the GETR are shown in Figures 5 and 6. It will be noted, first of all, that the longitudinal changes are larger than the transverse changes, and also the longitudinal rate continues to increase, whereas the transverse rate decreases at the higher exposures. A particularly interesting feature of the 800 C transverse sample is the rather rapid expansion at about 6×10^{21} neutrons/cm².

In the temperature range studied (425 to 800 C) the amount of contraction decreases with increasing temperature. There is some evidence from other tests⁽¹³⁾ that the contraction for transverse samples again increases above 800 C.

The practical consequences of these changes are twofold: the dimensional changes themselves must be accommodated in the reactor design to assure that fuel and control-rod channels are not excessively distorted, large gas passages do not form, etc.; and, there is some concern that the flux and temperature gradients through a large graphite bar

FIGURE 5

Contraction of EGCR Graphite (Transverse) as a Function of Exposure

FIGURE 6

Contraction of EGCR Graphite (Parallel) as a Function of Exposure

will produce different amounts of contraction, which may, in turn, create excessive internal stresses. The potential problems have been analyzed for the EGCR.^(14, 15)

Because a graphite moderator is usually subjected to an external stress (whether it be the dead load of the core itself or the constraint of normal dimensional changes), it is necessary to know how a stress may affect dimensional changes during irradiation. Such a study has been in progress at Hanford for several years. It has been found⁽¹⁰⁾ that an external compressive stress accelerates the contraction that a free body would normally experience, and a tensile stress will constrain a part of the contraction.⁽¹⁶⁻¹⁸⁾ It is not yet known whether there is a limit at which graphite fails if the normal contraction is restrained. This problem is presently being investigated.

Other Properties

The radiation effects to several other properties have been investigated, either because they are of technological interest in themselves, or because they may help in understanding other radiation-induced changes. The increase in heat content, usually referred to as "stored energy" has been of concern both at Hanford and elsewhere.⁽¹⁹⁾ The increase in stored energy at several temperatures is shown in Figure 7. It will be noted that relatively large amounts of energy, up to 630 cal/g, accumulate at room temperature. It is interesting that this is several times the interlayer binding energy. This amount of energy is also sufficient to increase the temperature spontaneously from 100 to 1550 C if it is released adiabatically.

The amount of energy releasable at a given temperature, rather than the total stored energy, is actually the quantity of more technological interest. A great deal of effort has been expended to determine stored-energy release spectra for reactor hazards evaluations. Although the stored energy in the Hanford reactors is still determined periodically from corings, it is not considered a serious problem at the present operating temperatures.

The thermal conductivity is another property of technological importance. As with other properties, the changes are greatest at low temperatures. The thermal conductivity is reduced to only 2 to 5% of its original

value by a relatively low exposure (5000 MWd/adjacent ton) at room temperature. For irradiations at 400 to 500 C the room-temperature conductivity is only reduced to about 25% of the original value for a comparable exposure. (20)

FIGURE 7

Accumulation of Total Stored Energy
at Several Irradiation Temperatures
(From Reference 19)

Decreases in thermal conductivity can result in higher temperatures in reactor components. However, if the changes in thermal conductivity can be anticipated, problems can usually be avoided by proper moderator design.

A number of methods of measuring thermal conductivity have been employed at Hanford. Perhaps the one of most interest is the flash method

developed recently.⁽²¹⁾ The equipment used for measurements from liquid-nitrogen temperature (-196°C) to room temperature is shown in Figure 8. By replacement of the liquid-nitrogen cold cell with a furnace,

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FIGURE 8

Equipment for the Measurement of Thermal Conductivity from -196°C to Room Temperature by a Rapid Thermal-Pulse Method (The photograph shows the flash tube for pulsing the sample, the sample cell, a projection bulb for adjusting the ambient temperature of the sample and the power-supply controls. The temperature pulse is monitored on an oscilloscope.)

measurements are made above room temperature. To make the measurement, the front surface of a small sample about the size of a dime is irradiated by a pulse of light from a flash tube or laser. The temperature response on the back surface is measured, and this can be related to the thermal diffusivity (or the thermal conductivity if the heat capacity and density are known). This method is rapid, precise, and adaptable to small samples that are easily irradiated. The method is being rapidly adopted by other laboratories.

A number of other studies should be mentioned. X-ray diffraction has been employed extensively at Hanford as an aid to understanding radiation effects in the crystal. Electrical resistivity, surface area, pore-size distribution, helium density, permeability, strength, modulus, and hardness have been studied to a lesser extent. Optical and electron microscopy have proven to be of particular value in recent years in characterizing different carbon materials and understanding radiation effects.^(22, 23) Replica electron microscopy is currently being applied at Hanford to some of the graphite problems in the nuclear propulsion reactors. At present, any of the above properties can be measured as dictated by the nature of the problem.

NEUTRON DOSIMETRY

Three high-flux test reactors have been used in recent years in the radiation-damage studies. These are the Engineering Test Reactor and Materials Testing Reactor at the National Reactor Testing Station in Idaho and the General Electric Test Reactor at Pleasanton, California. These are water-moderated reactors with different neutron spectra from the graphite reactors. This difference has posed a problem in correlating data and expressing neutron exposures such that data can be generally applied. The method that has finally evolved is to include fast-neutron threshold detectors such as iron or nickel with each test. From the activation of these detectors, a knowledge of their activation cross sections, and the shape of the neutron spectrum, the number of neutrons above 0.18 MeV is obtained.⁽²⁴⁾ Almost all of the radiation effects will be caused by neutrons above this energy. The shape of the spectrum is obtained from

transport-theory calculations. This method is the best currently available, but improvements can be expected as more data are obtained. It provides satisfactory correlation of irradiation data and is certainly an improvement over the earlier exposure unit of megawatt days per adjacent ton.

The dosimetry work undertaken initially for graphite has evolved into a more general program in support of radiation damage studies on structural metals. Through the exchange of radioactive dosimeters the counting methods of the major AEC laboratories have been compared and in some cases modified so that good agreement can now be expected.⁽²⁵⁾

GAS-GRAPHITE REACTIONS

The gas atmosphere surrounding the graphite moderator in the Hanford Reactor serves several purposes. The thermal conductivity of the gas affects the heat-transfer characteristics, and therefore the temperature, of the graphite and the shielding. The gas atmosphere also controls the oxidation of the graphite and provides a means of drying the reactor if water should leak into the stack. Each of these functions has been important at one time or another. Changes in the gas composition (helium, nitrogen, and/or carbon dioxide) have been made to adjust the graphite temperatures, and oxidation of the graphites has been of concern, primarily because of reduction in strength.

It has been the practice for many years to monitor the oxidation by the insertion of small graphite samples in channels containing no process tubes. The monitoring data have been very helpful in gaining a better understanding of the gas species responsible for oxidation at various locations in the reactor, the mechanism by which the oxidation occurs (e. g. thermal versus radiation-induced reaction), and the effects of changing the gas atmosphere, flow rates, pressure or other process conditions.⁽²⁶⁾ Through a continued effort in reducing the process-tube water leaks, replacing faulty gas seals, and purging the reactors to remove air, it has been possible to maintain the oxidation at an acceptable level.

As part of the graphite chemistry program, a number of laboratory and in-reactor gas-graphite studies have been undertaken. From early

in-reactor measurements rates of reaction of graphite with the gases commonly present in the reactor atmosphere were measured.⁽²⁷⁾ These studies were often carried out in uncooled process tubes.

To separate the effects of radiation and temperature on the reactions, capsule irradiations were initiated in which the samples were exposed in a water-cooled facility.⁽²⁸⁾ The results of these irradiations led to further investigations in which use was made of gamma radiation as a source of activation⁽²⁹⁾ and finally to higher temperature, in-reactor capsule irradiations.^(30, 31) A particularly useful Co^{60} irradiation facility was constructed and has been in use for several years. The facility and associated equipment are shown in Figure 9. At present, the source contains 90,000 Ci of Co^{60} giving a dose rate within a 2 in. diameter by 10 in. long test space of about 8×10^6 R/hr. Additional cobalt is now being irradiated to increase the source to about 200,000 Ci.

Laboratory investigations have been confined to the study of the thermal reactions of graphite with oxygen, water vapor, and carbon dioxide and the many parameters affecting these reactions. Similar studies are still continuing today on the reactions of new graphites with oxidizing gases under a variety of experimental conditions.

In conjunction with the studies of the chemical reactions of graphite, physical properties either affecting or affected by these reactions have been investigated. The graphite surface area is a prime example and many studies of this property and the pore-size distribution have been performed both with respect to changes from thermal^(32, 33) and from radiolytic⁽³⁴⁾ reactions. Figure 10 shows equipment for measuring the BET surface area, pore-size distribution, and density by helium displacement.

The change in pore-size distribution of CSF graphite caused by oxidation is illustrated in Figure 11. The increase in pores of all sizes is believed to result from the removal of easily oxidizable material which previously blocked access to these pores.

The strength of the graphite is another property profoundly altered by oxidation. The strength has been investigated⁽³⁵⁾ as a function of the

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FIGURE 9

Co^{60} Irradiation Facility

(The cobalt source is located at the bottom of the tank under 13 ft of water. Recording semimicrobalances are used to measure oxidation rates of samples in the radiation field.)

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FIGURE 10

Equipment for Measuring the Surface Area,
Pore-Size Distribution and Helium Density of Graphite

FIGURE 11

Changes in Pore-Size Distribution with Oxidation
in CSF Graphite

[Samples were outgassed at 350 C before measurement of the
pore-size distribution. From Reference (32)]

fractional weight lost by the graphite as a consequence of oxidation. It was found that a uniform oxidation of 10% reduced the compressive strength by 50%.

With the advent of the Gas-Cooled Reactor Program in the United States in 1958, other gas-graphite studies were undertaken. A high-temperature carbon dioxide gas loop was constructed in the Plutonium Recycle Test Reactor.⁽³⁶⁾ However, it has not been used because emphasis shifted to helium-cooled reactors before the loop was completed.

A number of studies were completed on the self-sustained combustion of graphite in air.⁽³⁷⁾ This is a potential hazard that could arise if

the primary coolant system of a gas-cooled, graphite-moderated reactor should accidentally rupture. Because the oxidation of graphite in air is exothermic, it is possible that more heat could be generated than is removed. In such a case, combustion would be self-sustaining.

Figure 12 illustrates a possible heat-transfer condition in a simulated EGCR fuel channel.⁽³⁸⁾ It is seen that if the temperature is sufficiently high, increasing the flow rate produces more heat by reaction than can be removed. The results depend on specific geometries, flow, temperatures, and pressures, and the conditions must be analyzed for each specific reactor design. Several halogen-containing gases inhibit the oxidation of graphite and are currently being considered as safeguards⁽³⁹⁾ to be added to the reactor in the event of an accident.

FIGURE 12

An Example of Self-Sustained Burning
of Speer Nuclear-2 Graphite in Air
[Inlet temperature was 150 C. From Reference (32)]

COOPERATIVE GRAPHITE DEVELOPMENT STUDIES
WITH CARBON COMPANIES

The manufacture and testing of the 3600 tons of moderator and 1800 tons of reflector graphite for B-, D-, and F-Reactors was, of course, on a scale never before known. The development and testing of this and subsequent graphite has required very close cooperation with the carbon manufacturers from the earliest days of the Hanford project.

Because enriched uranium was not available, the initial concern was to get the purest graphite possible. This was accomplished by careful testing and selection of raw materials and through special procedures set up to eliminate contamination during processing, machining, and shipping. The Hanford 305 Reactor, now the world's oldest operating reactor, was built to test the purity of the graphite and other materials. The machining was done at Hanford.⁽⁴⁰⁾

Later, the so-called "F Process" was developed by the graphite manufacturers for the chemical purification of graphite.⁽⁴¹⁾ Special purification furnaces were built in which the graphite bars could be exposed to a halogen-containing gas, usually Freon-12 or chlorine, at 2000 C or higher. The ash content was reduced from about 500 ppm to approximately 5 ppm by this process; and boron, which contributes substantially to the absorption cross section of graphite, was effectively removed.

When the problems with graphite expansion were discovered, a cooperative effort was established to develop a graphite resistant to radiation-induced expansion. The GBF grades resulted from this work. These materials were graphitized only to about 2450 C, and the halogen treatment was carried out during graphitization, thereby eliminating a second heat treatment.

In recent years, the cooperative programs with the carbon companies have been concerned with the development of graphites with good dimensional stability as well as with other desirable properties. Many different materials have been produced from new raw materials or by special process to alter the structure and properties. Some of these

studies are intended simply to increase the understanding of radiation effects in graphite; others are long-term tests of improved materials. Much of this work is still in progress.⁽⁴²⁾

TECHNICAL EXCHANGES WITH OTHER NATIONS

Hanford has participated in a number of technical exchanges on graphite with other nations. The first meeting with scientists from the United Kingdom on a range of graphite topics was held in Washington, D.C. in May, 1953.⁽⁴³⁾ This was followed by a second meeting in Washington, D.C. in the Spring of 1956.⁽⁴⁴⁾ The information from these meetings formed the basis for some of the operating practices in the United Kingdom for a number of years. Following the Windscale accident in October, 1957, a third general meeting was held, this time in the United Kingdom, to discuss stored energy, dimensional stability, and oxidation.^(45, 46)

The Libby-Cockcroft Exchange Agreement, established in 1958, provides a formal mechanism for periodic meetings and document exchange on graphite. Several mutually beneficial meetings in England and the United States have been held.⁽⁴⁷⁻⁴⁹⁾ The exchange continues to be an active and productive one today.

With the establishment of the Advanced Gas-Cooled Reactor Program in England and the Experimental Gas-Cooled Reactor Program in the United States a special exchange agreement was established in 1959. Under this agreement, AGR graphite technology not otherwise available is exchanged for information on EGCR graphite technology. This exchange is also active at present.

A third exchange agreement was set up in 1960, based on technology of the Dragon Reactor in England and the High-Temperature Gas-Cooled Reactor in the United States. Data on low-permeability graphites and graphite-matrix fuels are exchanged under this agreement. As with the other exchange agreements, Hanford has been one of the principal participants in graphite technology.

A United States-Canadian meeting was held in June, 1955, to discuss stored energy and graphite expansion.⁽⁵⁰⁾ The Canadian interests were primarily in the radiation effects to the reflector of the NRX Reactor.

A special meeting on graphite reactors was held at the Brookhaven National Laboratory, November, 1957, with French scientists, at which time a number of papers were presented on radiation effects and oxidation of graphite.⁽⁵¹⁾

The first significant public release of graphite data from Hanford was given at the 1955 Geneva Conference.⁽⁵²⁾ A great deal of information was declassified for this meeting, and reference is frequently made to this paper even today. Hanford was also invited to present graphite papers at the 1958 and 1964 Geneva Conferences.^(20, 53)

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