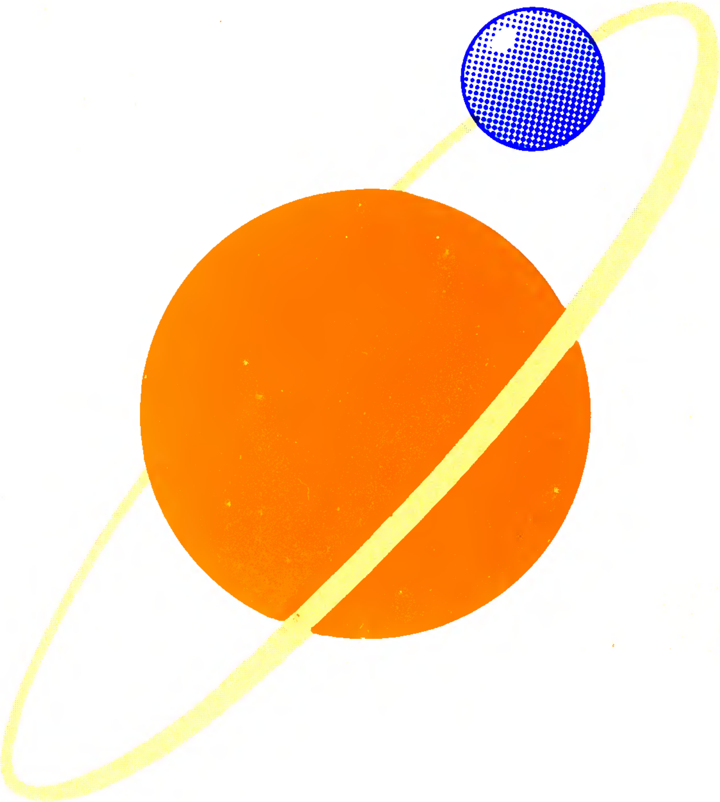
Central Electricity Generating Board



Berkeley Nuclear Laboratories

OPEN DAYS 4-7 JUNE 1986

EMERGENCIES

MEDICAL — Dial 2255 or ask a member of BNL Staff to contact the Medical Department for you.

OTHER PERSONAL — Dial 2218 or ask a member of BNL Staff to contact the Switchboard for you.

FIRE OR SITE EMERGENCY — On hearing an ALARM BELL ringing continuously or a TWO TONE SIREN, please enter the lobby of the nearest building and await further instructions which will be given over the Public Address System.

WELCOME

There can be few who are unaware of the great attention given at home and abroad to the question of the supply of energy for a nation's needs. Our own news media are often dominated by accounts of the cost, availability and effect on the environment of all our principal sources of energy, whether coal, oil or nuclear fission. It is well known that economic supplies of coal and oil are limited, and many consider that there is no alternative to nuclear power for the provision of a secure energy supply in the longer term. Whilst the success of the UK's nuclear power programme in producing electricity safely and at competitive cost has been demonstrated, its future is subject to keen public debate, intensified by recent events in the Ukraine.

In the twenty five years that these Laboratories have existed, the aim has been to provide scientific support in depth in the field of nuclear technology to assist the Central Electricity Generating Board in discharging its role as a purchaser and operator of plant. The purpose of these Open Days is to show something of the scope and quality of the research work we undertake.

It is often said that the nuclear industry has not tried hard enough to create a dialogue with its public. I hope that this occasion will help to dispel some of the mysteries, and that we shall communicate some of the reasons for our confidence in the UK's nuclear systems, their safety and the role they have to play in providing plentiful and economic electricity.

B.C. MASTERS
Laboratory Manager

BERKELEY NUCLEAR LABORATORIES

The Berkeley Nuclear Laboratories were built in 1961 as the specialist research centre for the nuclear power activities of the Central Electricity Generating Board. The Laboratories have nearly 800 staff of whom over 300 are qualified scientists or engineers.

The CEGB is responsible for building and operating power stations and major transmission facilities for the public electricity supply in England and Wales. It does this under the aegis of the Electricity Council which also supervises the 12 Area Boards that distribute and sell the electricity to domestic, commercial and industrial consumers.

Within the Generating Board, the Berkeley Nuclear Laboratories are part of the Technology Planning and Research Division which is also responsible for the Central Electricity Research Laboratories at Leatherhead, Surrey and the Marchwood Engineering Laboratories near Southampton.

A PRE-HISTORY OF ATOMIC ELECTRICITY

Two hundred years ago, in 1786, Galvani attached a copper hook to the carcass of a frog, which he then suspended from an iron railing. The copper and iron acted as electrodes and the body fluids of the frog as electrolyte and the minute electric current thereby generated caused the frog's legs to go into spasm. Galvani had discovered "galvanism"! This stimulated Volta to develop his "voltaic" cell and thus, for the first time, a steady source of electrical power became available for the experimentalist making possible the monumental discoveries in electrical science of the first decades of the nineteenth century. The culmination of these activities was the discovery of electromagnetic induction by Faraday in 1831 leading to the development of the electric motor and dynamo. Thus an accidental observation during an experiment on a humble frog launched the Great Electrical Age - an era through which we are still passing.

A century and a decade after Galvani's experiment, in 1896, Becquerel, by happenstance, developed a photographic plate which had been in contact with some uranium salts. The plate was fogged - Becquerel had discovered radioactivity. A year earlier Roentgen had accidentally discovered X-rays, and a year later Thomson had identified the electron - that fundamental atomic particle which was the carrier of the basic unit of electrical charge. Madame Curie was inspired by all this to begin her lifetime study of radioactivity and during the following year, 1898, isolated polonium and radium, the latter being millions of times more radioactive than uranium. That same year, Rutherford moved from Cambridge to McGill University where, in 1900, he was joined by Soddy. Together they came to the iconoclastic conclusion that atoms are not indestructible.

In those *fin de siecle* years, when radioactivity was hardly even an infant science, electricity had already evolved a technology of some maturity. The main stimulus for this was the development, by Swan and Edison in the early 1880's, of practical carbon-filament electric light bulbs making possible the illumination of domestic properties. In response to the demand for electrical supplies that this created, the first "Electric Utilities" were set up - the forerunners of the CEGB.

In 1886 Ferranti conceived his huge, 90MW, station at Deptford. It was to be capable, in principle, of supplying the needs of the whole of London at the unprecedented pressure of 10,000 volts. Although never a commercial success, it was a brilliant concept - a remarkable forerunner of the modern power station. Its only archaic feature was the use of reciprocating steam engines as prime movers. However, before the end of the century Parsons had developed the steam turbine, and this quickly found wide application.

Despite having enjoyed the unique benefit of the creativity of Swan, the inventiveness of Parsons and the engineering genius of Ferranti, Britain failed to establish a world lead in electric technology during the opening decades of the twentieth century. In 1914, for example, at the outbreak of World War I, Britain's electrical manufacturing industry was only half the size of Germany's. As late as 1923, the total electrical output of Britain was less than that of Metropolitan New York!

To combat these shortcomings, and following the recommendations of the Weir Committee, the 1926 Electricity (Supply) Act proposed the creation of a national "Grid" of transmission lines. This was completed by 1935. The Weir Committee's other main recommendation, that the number of power stations should be reduced from 438 to 58, was not followed through with any degree of vigour - at the end of the Second World War there were still 560 separate supply undertakings operating about 300 stations, half of which had outputs of less than 10MW.

Returning to nuclear physics; in 1913 Bohr modified Rutherford's model of the atom and later he studied further the implications of quantum theory, and attempted to incorporate wave-particle duality, Schroedinger's wave mechanics and Heisenberg's quantum matrix mechanics in his model. The enormous energy binding together the particles forming a nucleus was identified with the mass lost in the process of atom building, using Einstein's 1905 equation relating mass and energy.

The artificial transmutation of nitrogen in 1917 was Rutherford's crowning achievement. After Gamow had pointed out the possibility of "tunnelling", Cockcroft and Walton were encouraged to build their proton accelerator with which, in 1932, they first "split" an atom by artificial means. In the same year Anderson discovered the positron and Chadwick the neutron.

Fermi realised that the neutron, having no charge, could readily penetrate the potential barrier and be absorbed by the nucleus of an atom. He went on to produce many artificially-induced radioactive elements by neutron irradiation. However, he misinterpreted the results he obtained with uranium, thinking he had produced a transuranic whereas he had in fact witnessed the fission reaction. It was not until 1938 that Hahn and Strassman discovered that the active species in neutron-irradiated uranium was radioactive barium. The only possible explanation was that the neutrons had caused the uranium nucleus to divide, or "fission", forming highly charged elements of lower atomic number (subsequently termed "fission products"). These observations were interpreted by Meitner and Frisch in terms of the Bohr liquid-drop model of the atomic nucleus. The process would be expected to release high amounts of energy, and Frisch showed that this was indeed the case.

Joliot and co-workers demonstrated that more neutrons are produced than are absorbed by the fission process and this pointed to the possibility of a chain reaction. Bohr indicated that fission was much more likely to occur in the lighter isotope of uranium, uranium-235, than in uranium-238 (natural uranium consists of 99.3% U238 and only 0.7% U235). His paper, with Wheeler, was published two days before the outbreak of war. Already Einstein and Szilard had written to President Roosevelt drawing attention to the potential importance of the fission reaction. Early in 1940 Peierls and Frisch calculated that as little as one kilogram of pure U-235 could constitute a "critical mass". In December of the year Seaborg discovered the new element plutonium, an isotope of which, like U-235, is fissile.

During 1941 atomic energy research began in earnest in the USA under the code name "Manhattan Project". On 2nd December 1942 Fermi initiated a controlled chain reaction in the world's first atomic reactor in a squash court at the University of Chicago. World War II ended shortly following the dropping of a U-235 atomic bomb on Hiroshima on 5th August 1945, and a Pu-239 bomb on Nagasaki four days later.

The passing of the McMahon Act in 1946 virtually ended USA/UK collaboration in nuclear research, but already the UK had decided to launch its own nuclear programme; Cockcroft, Penny and Hinton had been appointed and work had began on constructing Harwell. Following the successful commissioning of the experimental graphite piles, GLEEP and BEPO at Harwell, two plutonium-producing piles were constructed at Windscale and both of these were operating by June 1951. During 1957 a serious fire at Windscale led to the closedown of both piles.

In 1956 Calder Hall, the first atomic power station in the world to supply "commercial" quantities of electrical power to a national grid, was commissioned, 1956 was an important year in other ways for the Electric Supply Industry - it saw the publication of the Report of the Herbert Committee, which led to the formation of the Central Electricity Generating Board. Concurrently, the decision was taken (with hardly any reference to the Utility Industry!) that the UK would launch, a Civil Nuclear

Power Programme capable of generating as much nuclear electricity as the combined total of the rest of the non-communist world. The first phase of this was to be the construction of a series of Civil Magnox stations, which would in essence be up-rated versions of the Calder Hall and Chapel Cross designs.

To oversee this massive construction programme, Hinton, "The Father of Calder Hall", was appointed in 1957 to be the first Chairman of the CEGB. Almost as a condition of appointment, Hinton required that the Board should have its own Nuclear Laboratories. In support of this demand he could quote one of the main findings of the Herbert Committee:

> *"Science is not now a thing apart but is intimately associated with all activities and aspects of industry. The Electrical Supply Industry, by its very nature, should be in the forefront of the major industries organising and applying research and development on an extensive scale."*

Recruitment of research staff began the following year and the Berkeley Nuclear Laboratories were officially opened by Lord Fleck in May 1961.

	ELECTRICITY	NUCLEAR ENERGY
1786	Galvani's frog	
1831	Electromagnetic induction	
1882	Holborn Viaduct power station	
1887	Deptford power station	
1896		Bequerel discovers radioactivity
1897		Thomson electron
1898		Curies isolate polonium and radium
1905		Einstein Relativity and equivalence of mass and energy
1906	Tungsten filament lamps	
1911		Rutherford's model of atom
1913	Langmuir gas filled lamps	Bohr refines Rutherford's model
1919	Electricity (Supply) Act	Rutherford artificial nuclear transmutation Aston invents mass spectrograph
1925	Weir Committee	Pauli Exclusion Principle Heisenberg Matrix Mechanics
1926	National Grid proposed	Schroedinger Wave Mechanics
1927		Heisenberg's Uncertainty Principle
1930		Lawrence cyclotron
1932		Cockcroft and Walton split atom Anderson discovers positron Chadwick discovers neutron
1934	Completion of initial 132 kV Grid system	Fermi theory of beta decay Curie and Joliot induce artificial radioactivity
1935	Grid completed	Fermi moderators
1936		Bohr liquid drop model of nucleus
1938		Hahn, Strassmann, Frisch, Meitner - fission
1939		Joliot reports neutron multiplication Einstein's letter to Roosevelt
1940		Peierls and Frisch calculate critical mass
1941		Manhattan Project starts
1941		Maud Report on Uranium
1942	North Scotland Hydro Board proposed	Fermi's Chicago Reactor critical
1943	264 kV Grid system proposed	Quebec Agreement on US/UK collabn. Bohr escapes from Denmark
1945	Fuel and Power Advisory Council appointed	UK decides to have nuclear research and development programme. Hiroshima and Nagasaki atom bombs Decision to establish AERE
1946	Introduction of Electricity Bill for nationalisation of Supply Industry	Construction started at Harwell Atomic Energy Bill Plans for Springfield Plant McMahon Act ends USA/UK collabn.

1947	Electricity Supply Industry Nationalised Lord Citrine chairman British Electricity Authority (BEA)	Harwell's GLEEP goes critical Plans for Windscale Piles First British radioisotope used in hospitals
1948	14 Area Electricity Boards set up Vesting Day - BEA and Area Boards	Springfields begins production Harwell's BEPO goes critical
1949	Sir Harold Harty first chairman of Electricity Supply Research Council	Enrichment Plant at Capenhurst
1950	First BEA/EDF Cross Channel link British Electricity Laboratories opened (now CERL)	Windscale No.1 Pile fire critical Aldermaston site started
1951		Windscale No.2 Pile goes critical
1953	BEA starts nuclear power branch	Construction Calder Hall starts
1955	*First nuclear power programme announced*	
1956	Publication of Herbert Report	Calder Hall opened by Queen
	Contracts placed for Berkeley and Bradwell Magnox Stations	
1957	The Electricity Act - creation of	Both Piles at Windscale closed after fire in No.1 Pile
	Trebling of Nuclear Power Programme announced (to 5-6GW)	
1959		Chapelcross and DFR start-up
1960	*Nuclear Power Programme slowed down (5GW by 1968)*	
1961	*Berkeley and Bradwell reactors go critical*	
	Berkeley Nuclear Laboratories opened	
1962	Leatherhead Laboratories opened Plans for 400 kV Grid System	Windscale AGR goes critical
1963	*Hinkley Point A and Trawsfynydd go critical*	
	Marchwood Laboratories opened	
		Plan for Winfrith SGHWR
1964	*The Second Nuclear Power Programme (5GW in 1970-75)*	
	AGR chosen for Dungeness B	
		Winfrith HTR (Dragon) start up
1966	First 500 MW set - Ferrybridge	Plan to build PFR
1967	*Start-up at Oldbury - first Magnox station with concrete pv*	
1968	First 2 GW stations	SGHWR full power
1971	*Wylfa start-up; completion of First Nuclear Programme*	
1975	*Proposal to construct SGHWRs at Sizewell and Torness*	
		PFR operational
1976	*First commercial AGRs start-up Hunterston B and Hinkley B*	
	Marshall Report and Flowers Report published	
1977		THORP Inquiry: DFR closes
1978	*Work on commercial SGHWR stopped - 2 more AGRs to be ordered*	
	Qualified approval of UK buying a PWR	
1979	*Accident at Three Mile Island*	
	Nuclear Power Programme - 15 GW over 10 years starting 1982	
1980	*CEGB announced Sizewell to be site for first PWR*	
	Work on AGR sites at Heysham II and Torness starts	
1981		Windscale AGR closes
1982	Lord Marshall chairman CEGB	
1983	*Sizewell B Enquiry opened*	
	Black Enquiry starts	
1984	*Study - no adverse health aspects amongst 11,000 Windscale workers*	
1985	*End of Sizewell B Enquiry*	

GUIDE TO NUCLEAR TERMS

ABSORBER. A substance which absorbs nuclear particles and radiation. Nuclear reactors are commonly controlled by absorber rods of steel incorporating Boron or Cadmium.

ACTINIDES. Heavy elements with Atomic Numbers › 89 and chemically similar to Actinium. They are fission products.

ACTIVATION. The process of inducing radioactivity by irradiation.

ACTIVITY. The number of disintegrations occurring per unit time.

ADVANCED GAS-COOLED REACTOR. The second type of reactor owned by CEGB. It operates at a higher temperature and efficiency than the Magnox type and uses uranium dioxide fuel.

ALPHA PARTICLE. A positively charged particle composed of two protons and two neutrons. Emitted during the decay of some radioactive nuclei, it is identical with the nucleus of a helium atom.

ATOM. A unit of matter comprising a nucleus surrounded by electrons. They are the basic building blocks of all substances and cannot be broken down further by chemical means.

ATOMIC NUMBER. The number of protons in the nucleus of an atom. In a neutral atom, it also equals the number of electrons which in turn decide the chemical properties of the atom.

BACKGROUND RADIATION. The natural ionising radiation due to cosmic rays from space and from the naturally radioactive elements in the ground and the human body.

BETA PARTICLES (or RAYS). Electrons emitted from a radioactive substance during decay.

BIOLOGICAL SHIELD. A wall or mass of concrete or metal which reduces the radiation from a radioactive source to an acceptable level: commonly, the shield placed around a nuclear reactor.

CAPTURE. A nuclear reaction in which a nucleus absorbs an additional neutron or proton.

CARBON. In the form of graphite, carbon is used in Magnox and AGR reactors to slow down fast neutrons so that they are more effective in causing fission.

CARBON-14. A radioactive form of carbon. It forms naturally in the upper atmosphere by the interaction of cosmic neutrons with nitrogen and becomes incorporated in living matter.

CARBON DIOXIDE. A relatively inert gas used as a coolant in Magnox and AGR reactors.

CHAIN REACTION. A self sustaining nuclear reaction. In nuclear fission, a neutron causes a nucleus to fission and releases more neutrons to cause more fissions.

CLADDING. An outer layer applied to provide protection from a chemically reactive environment, or structural support. The term is often used to describe a fuel can.

CONTAINMENT. A gas tight shell around a reactor to prevent leakage of radioactive material escaping to the atmosphere.

CONTROL ROD. A rod, usually of steel incorporating boron or cadmium, used to control the power level of a reactor.

COOLANT. A liquid or gas circulated through the core of a reactor to remove the heat generated by the fission process.

COOLING. A colloquial term used to describe the storage of material to allow the radioactivity to decay. Storage is often under water in special 'cooling ponds'.

CORE. The portion of a nuclear reactor containing the fissile material (fuel).

CRITICAL. The condition of a reactor just capable of sustaining a chain reaction.

CRITICAL MASS. The minimum amount of fissile material needed to sustain a chain reaction.

DECAY. The decrease in activity of a radioactive substance as it transforms spontaneously to another energy state of the same nuclide or into a different nuclide.

DECAY HEAT. Heat from the decay of fission products in the fuel of a reactor after it has been shut down.

DEUTERIUM (D). A stable naturally occurring hydrogen isotope of mass 2. It combines with oxygen to form heavy water.

ELECTRON. An elementary particle carrying a unit negative charge. Their flow through a conductor constitutes an electric current. Electrons determine the chemical nature of a substance.

ELEMENT. All the atoms of a given element have the same Atomic Number. It is thus a simple substance which cannot be further broken down by chemical means. There are 92 natural elements.

ENRICHED FUEL. Nuclear fuel containing more than the natural abundance of fissile atoms.

FAST NEUTRONS. Neutrons from fission that have not been intentionally slowed down by a Moderator.

FAST REACTOR. A reactor in which the fission process is sustained by fast neutrons. In a Fast Breeder Reactor the core is surrounded by a 'blanket' of fertile material which is converted to new fuel.

FERTILE MATERIAL. A material which can be transformed in a reactor into fissile material by neutron capture.

FILM BADGE. A piece of special photo film worn like a badge. After development, examination allows the dose of radiation received by the wearer to be assessed.

FISSILE. Capable of undergoing Fission, usually after absorption of a neutron. The most important fissile materials are Uranium 233, Uranium 235 and Plutonium 239, all able to fuel a chain reaction.

FISSION. The splitting of a (usually heavy) nucleus into two smaller nuclei accompanied by the release of neutrons and energy which appears as heat.

FISSION PRODUCTS. The smaller nuclei produced as a result of Fission. More than 300 FPs have been identified. They represent isotopes of some 35 different elements.

FUEL ASSEMBLY. An assembly of Fuel Elements and supporting components.

FUEL CAN. The container into which fuel rods or pellets are sealed. It is often finned to improve the heat transfer.

FUEL ELEMENT. Fuel and its can.

FUELLING MACHINE. A machine used to load fuel into a reactor or to unload it.

GAMMA RAYS. High energy electromagnetic radiation emitted during radioactive decay. They are highly penetrating but are absorbed by dense matter such as lead.

GAS COOLED REACTOR. A reactor from which the heat is removed by a gas, commonly Carbon Dioxide as in the CEGBs Magnox and AGRs.

GRAY (Gr). The unit of dose of absorbed ionising radiation. See also Sievert.

HALF LIFE. The time taken for half the atoms of a radioactive material to disintegrate and so lose half its radioactive strength. Each radionuclide has a unique half life.

HEAT EXCHANGER. A piece of plant which transfers heat from one flow of gas or fluid to another, for example from hot gas to water.

HEAVY WATER. Water containing a substantial proportion of Deuterium (heavy hydrogen).

ION. An elementary particle, atom or molecule which has lost or gained electrons and therefore has an electrical charge.

IONISATION. The process by which a normally neutral atom gains or loses electrons and becomes an Ion.

IONISING RADIATION. Radiation of sufficient energy to ionise matter through which it passes.

IRRADIATION. The exposure of matter to radiation.

ISOTOPE. Species of an atom having the same number of protons in their nucleus but a differing number of neutrons. Isotopes have similar chemical properties but different nuclear characteristics.

MAGNOX. A magnesium metal alloy used to can uranium fuel. It has given its name to a type of reactor.

MASS NUMBER. The total number of protons and neutrons in the nucleus of an atom. Uranium 235 has 92 protons and 143 neutrons.

MODERATOR. A material such as ordinary or heavy water and graphite used to slow down or 'moderate' neutrons to increase the probability of further fission.

MOLECULE. The smallest piece of a substance that retains the characteristics of that substance. Further subdivision would break it down into its constituent atoms.

NATURAL URANIUM. Uranium as it occurs in nature and thus containing 0.7% of fissile Uranium 235.

NEUTRON. A neutral (ie uncharged) elementary particle of approximately the mass of a proton and associated with it in the nucleus of an atom.

NUCLEUS. The central positively charged portion of an atom. Made up of neutrons and protons, it accounts for most of the mass but only a small fraction of the volume of an atom.

NUCLIDE. Another name for Isotope.

PLUTONIUM. A heavy element of atomic number 92 produced artificially in a nuclear reactor when Uranium 238 absorbs a neutron. Plutonium 239 is an important fissile material.

POTASSIUM-40. A naturally occurring isotope of half life 1,000,000,000 years found in the human body.

PRESSURE VESSEL. The immensely strong steel or concrete vessel immediately surrounding a nuclear reactor to enable it to be cooled by gas or liquid at high pressure.

PRESSURISED WATER REACTOR (PWR). A reactor cooled and moderated by water which is under high pressure to prevent it boiling.

PROTON. An elementary particle with a charge equal but opposite to that of an electron. It has 1847 times greater mass than an electron and is a constituent of all nuclei.

RAD. A unit of dose of absorbed ionising radiation. Now superseded by the Gray.

RADIATION. Energy propagated through matter or space in the form of electromagnetic waves or particles.

RADIOACTIVITY. The property possessed by some atoms to disintegrate spontaneously with the emission of radiation.

RADIOISOTOPE/RADIONUCLIDE. A radioactive isotope of an element.

REM (R). A unit of dose of ionising radiation absorbed by biological matter. Now superseded by the Sievert.

REPROCESSING. The recovery for reuse of fissionable material from spent fuel.

SHIELDING. Material surrounding a reactor or other source of radiation in order to reduce the intensity of the radiation to an acceptable level.

SIEVERT (Sv). The unit of dose of ionising radiation absorbed in biological matter. See also GRAY.

SLOW NEUTRONS. Neutrons which have been slowed down to increase the probability that they will induce fission on collision with a fissile nucleus.

SOMATIC. A term used to describe effects arising from damage to body cells but which, in contrast to genetic effects, are not passed on to offspring.

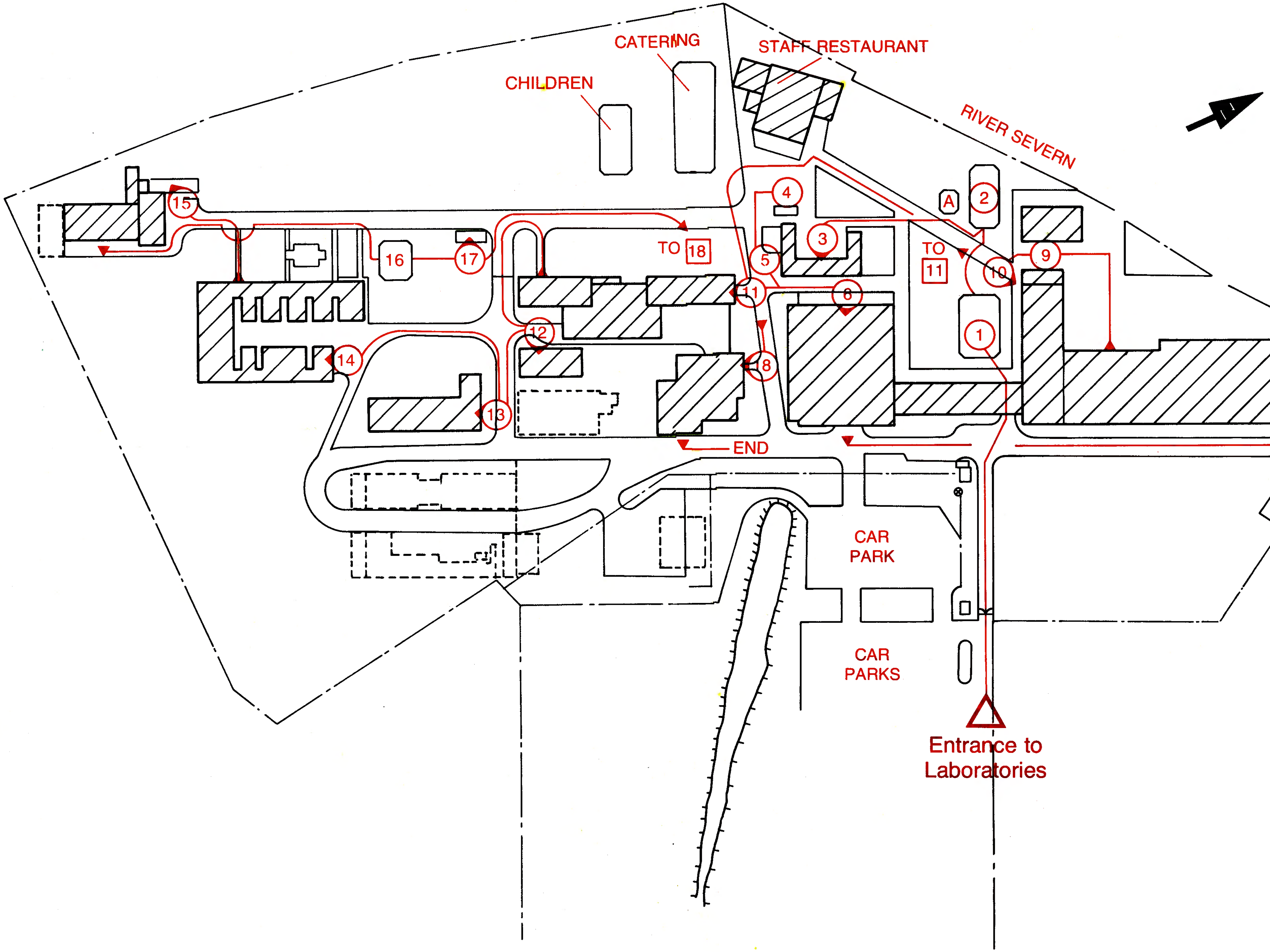
THERMAL NEUTRONS. Slow neutrons.

THERMAL REACTOR. A reactor in which the fission chain reaction is primarily sustained by thermal neutrons produced by using a moderator to slow down the neutrons emitted during fission.

TRITIUM (T). A naturally occurring hydrogen isotope with a mass 3. It is also produced from impurities in the graphite of gas cooled reactors.

URANIUM (U). A heavy slightly radioactive metal with atomic number 98. As found in nature, uranium is mainly a mixture of 99.3% of U-238 and only 0.7% of fissile U-235.

URANIUM DIOXIDE. A compound of Uranium and Oxygen used as fuel in AGRs and PWRs.



CEGB BERKELEY NUCLEAR LABORATORIES PLAN SHOWING LOCATION OF EXHIBITIONS AND DISPLAYS FOR **OPEN DAYS 4 - 7 JUNE 1986**

The Exhibits and a Recommended Tour

Visitors wishing to make a complete tour of the many exhibits are strongly recommended to follow the sequence below, based on two loops which come together near the Catering facilities. The routes are clearly signposted and Visitors are requested to keep to the marked routes.

The routes can, of course, be joined at any point or the displays visited in any order desired.

Reception Marquee

In addition to dispensing initial information about the Open Days, this marquee houses small 1
exhibitions.

One of these describes the role of the Berkeley Nuclear Laboratories within the Technology Planning and Research Division of CEGB and its wider relationship with the Electricity Supply Industry.

A second places nuclear power in the general context of the UK and provides an introduction to the more comprehensive displays in the Exhibition Marquee.

Another exhibition, provided by the South Western Region of CEGB shows some of the features of electricity supply in this Region.

Some of the inventions and other developments originated during CEGB research are suitable for application elsewhere. A further exhibit shows some items already being manufactured by commercial firms under licence from CEGB and other items now available for exploitation.

Nuclear Power Exhibition

This exhibition, kindly loaned by the United Kingdom Atomic Energy Authority, deals with the
how, whys and wherefores of nuclear science and technology. It incorporates some especially 2
interesting models and demonstrations which will help the non-expert more easily to appreciate the
research displays elsewhere on site.

Vibration Control

Excessive vibration of reactor internal components is undesirable; it could lead to unacceptable
wear or to fatigue cracking. This display covers the assessment of component vibration behaviour 3
and the development of techniques for controlling the vibration response of reactor components.

Fuel Component Evaluation

Reactor fuel components must be designed to withstand the loads which act on them during
refuelling and while in the reactor. This display demonstrates how fuel components are evaluated 3
by mechanically simulating these aerodynamic loads and theoretically modelling the components'
dynamic behaviour.

CEGB Mobile Exhibition

A small exhibition showing some facets of the operations of the CEGB. 4

Safety of Pressurised Components

Nuclear reactors contain gas or water and steam at high pressures. Every precaution is taken during
construction and operation to ensure that no defects remain in the welded steel components
forming the pressure vessels. Nevertheless it is prudent to consider the types of defects which may 5
cause failure and the possible consequences. The exhibit shows some of the work on pressurised
components at the BNL remote test site at Breakheart Quarry, Dursley.

Residual Stress Measurement

A knowledge of the residual stresses locked into a component during manufacture is important in
the design of structural components. Two techniques for measuring these stresses have been 5
developed at BNL. The 'Air-abrasive' technique measures stresses at the surface of components and
is now the acknowledged industry standard.

The 'deep hole' technique, which measures residual stress right through the thickness of components, is unique. Although still under development, the method has already been used to provide data for the PWR programme.

Effect of Oxide Growth on Structural Integrity

Growth of oxide on mild and low alloy structural steels in the high temperature CO_2 coolant of
Magnox and AGR reactors can deform components and lead to mechanical damage even when the 6
thickness of the metal consumed is small. Concentrated research effort has led to a detailed
understanding of the phenomenon, enabling potential operating difficulties to be avoided. This is
illustrated for bolted, welded and dowelled joints.

High Temperature Design

The testing machines on view in this display are used to extend our understanding of how
materials behave under complex and variable loads at high temperatures. The machines measure 6
the deformation, crack growth and failure characteristics of structural steels. These properties are
then combined with recent advances in structural analysis into new procedures which allow
components to be designed more efficiently.

Heat Transfer & Fluid Mechanics

Almost all electricity is produced by turbogenerators driven by steam raised by the transfer of heat
from fuel to water. The heat transfer process is thus an important topic for research. At BNL, 6
experimental studies are being made into several aspects of heat transfer.

It is possible to model heat transfer using computers and BNL has developed suitable programs such as FEAT. A computer terminal display shows how problems are handled.

Data Acquisition & Pressure Calibration

Computer models need to be checked by experiment which often involve taking many measurements at short time intervals. Some of the techniques and equipment used are displayed. A demonstration illustrates the accuracy achievable when calibrating pressure transducers.

Hot Gas & Steam Release

An example of heat transfer experiments at BNL is the current study of a release of hot gas etc. 6

A release of hot gas or steam, for example from a pipe fracture, could affect nearby cables or control gear. Temperature transients are being investigated and a demonstration shows the flows in the vicinity of a simulated rupture.

Fast Reactor Structural Integrity

Because of its thermal properties, sodium coolant used in Fast Reactors can allow sharp temperature differences to exist over quite small distances. These thermal gradients can give rise 6 to stresses in components. The magnitude and nature of such stresses are being investigated.

The use of water to simulate the sodium coolant of fast reactors is investigated using special laser instruments to measure localised velocities.

Fast Reactor Instrumentation

Blockages in Fast Reactor subassemblies may be identified from the temperature fluctuations 6 resulting from the blockage. A computer code STATEX has been developed to simulate turbulent flows and temperatures and this will be demonstrated using colour graphics.

AGR Optimisation

The power obtainable from a reactor is largely governed by the permissible temperature of the fuel which is influenced by the flow of coolant past the fuel. Fuel temperatures can be reduced by 6 improved heat transfer surfaces but these often offer a higher flow resistance so that more powerful pumps are required. BNL has developed alternative heat transfer surfaces and investigated how the best possible balance can be struck between heat transfer and flow resistance for the AGR. Visitors can operate a computer reactor model to see the effects of their own choice of fuel and operating conditions.

Specially Instrumented Fuel

Actual data from working reactors is obtained by the use of fuel elements fitted with special instrumentation. The displays show the manufacture, installation and benefits arising from the use 6 of such instrumented fuel.

AGR Coolant Optimisation

The coolant gas in an AGR contains corrosion inhibitors whose exact concentrations are economically vital. Too little would allow the graphite to corrode prematurely cutting short the 6 reactor's life - but too much would produce insulating sooty deposits on the fuel cans, requiring a drop in reactor output. Each AGR design will have a different best compromise. The displays show how this optimum has been reached in our AGR station at Hinkley Point.

Electron Microscope Studies of Irradiated Uranium Dioxide Fuel

When the uranium atom undergoes fission it splits into two fragments. About 2%, 4% and 10% of the uranium atoms will have fissioned in the AGR, Water reactor and Fast Reactor respectively by 7 the end of life of the fuel, generating fission products which remain within the fuel.

These can be either solid or gaseous. Solid products remain either as individual atoms in the fuel or as small precipitates: most are intensely radioactive and are a major problem during reprocessing. Gaseous fission products are about 25% of the total, and these will move (diffuse) together at the operating temperatures of the reactor to produce bubbles which will cause swelling of the fuel. The gas will also move to the grain boundaries and from there may be released to the fuel pin interior.

Ideally the gas should be retained within the fuel; but if any is released, it will be retained within the stainless steel cladding of the fuel pin. To ensure safe operation of the fuel during normal and fault operations, it is essential to study the behaviour of the fission products. Because these are so small, they can be observed only with electron microscopes. Although irradiated fuel is intensely radioactive, the specimens used are so small that they can be handled safely. The fission products within the grains are observed using a transmission type electron microscope: a scanning microscope is used to examine bubbles at grain surfaces.

Shielded Area

The Shielded Area is a building specially designed for the examination of fuel rods discharged
from the Board's Magnox and Advanced Gas-cooled Reactors (AGR). As the discharged fuels are 8
radioactive, the examinations are carried out in shielded facilities termed caves or cells which are
built of lead, steel and concrete; the fuel is handled remotely using mechanical hands called
manipulators.

The fuel arrives at BNL by road in heavily shielded transport flasks which are opened under water in the pond. The empty flask is carefully cleaned and returned to the power station.

Fuel Storage and Inspection

Following discharge from the Board's reactors, spent AGR fuel elements are normally stored
under water in cooling ponds. Techniques have also been developed using under water television 8
cameras for inspecting stored fuel and assessing its corrosion behaviour.

It is important to ensure that corrosion is inhibited and electrochemical studies have been made of the localised corrosion of stainless steel clad in pond water.

Magnox fuel elements are lifted into the caves, examined visually to check the external condition and then X-rayed to allow us to measure and check the behaviour of the fuel inside. Some fuel is also cut up and a cross section polished to reveal the microstructure of the uranium fuel or the magnesium cladding.

The external examination of AGR fuel is carried out at Winfrith in Dorset and only small sections come to BNL for examination of their microstructure. Other items from the AGR stringer also come to BNL for examination, notably the tie-bar, a 40ft long metal rod which passes down through the centre of the fuel stringer and supports its weight during loading and discharge. Part of the cave line is equipped for cutting tie-bar samples into short lengths for mechanical properties tests, some sections also being subjected to a surface probe examination of the roughness induced from rubbing against other components. Two cells are fitted with tensile testing machines to carry out the mechanical properties work.

Other cells are used for preparing AGR fuel for microscopic examination. Sections of interest are cut, mounted in plastic and then polished and etched to reveal the microstructure of the fuel and cladding which are viewed through specially shielded optical microscopes with photographic and television facilities.

Magnox Pressure Vessel Embrittlement

The steel pressure vessel of a Magnox reactor surrounds the core and is the primary containment for the coolant gas. It is designed to withstand comfortably the stresses imposed on it under all operating conditions. The fast neutrons emitted by the core during operation, slowly over many years reduce the toughness of the vessel: these changes must be monitored to ensure continued safe operation.

One cell is equipped to carry out fracture resistance tests on irradiated steel samples. This is the only facility in the UK capable of carrying out a complete programme of such tests. A video film shows a test being performed.

Although the embrittlement phenomenon has been recognised for many years, the processes involved have not hitherto been sufficiently understood to allow prediction of future changes. Recent studies at BNL have defined these processes with a model which successfully accounts for all the data accumulated from CEGB Magnox stations. The model has also been successfully adapted to PWR conditions.

Irradiation Effects on Fracture Resistance

The work display in Cell 18 concerns the fracture resistance of pressure vessel steels. The facility
is the only one of its type in the country where a complete programme of sophisticated fracture 8
resistance testing can be carried out in the remote conditions necessary for handling radioactive
materials. In addition to the equipment itself, there will be a video showing a test being done.

High Temperature Testing of AGR Fuel Cladding Tubes

The uranium dioxide fuel pellets used in an Advanced Gas-cooled Reactor are contained in a
stainless steel tube cladding. In the unlikely event of a loss of coolant while the reactor is at full
power, the increased fuel temperature would cause the gas inside the fuel to expand so that some 9
pins might deform and burst. It is important therefore to measure how the stainless steel cladding
would behave at such a high temperature, about 800°.

Specially shaped pieces of fuel cladding are used to investigate the deformation process. Since it is not possible to demonstrate a test on the actual equipment, a simulated test on a specimen of low-melting-point metal is demonstrated. The display includes a summary of how the tests are used to set a safe temperature for reactor operation.

Spectroscopy

Reactions between metals and gas are of great importance in the plant used for electricity generation
which has to withstand high temperatures and corrosive atmospheres. The reactions are often
confined to very thin films on the surface of the metal and a knowledge of their composition and the 9
mechanism of their formation is important when assessing the probable life of components or the
resistance of an alloy to oxidation. Surface analysis can be applied to solving corrosion and cracking
problems in operational plant.

The spectroscopy laboratories are equipped with very modern sophisticated machines for analysing the structure and the chemical composition and state of surface films and the underlying material. They are able to analyse very small volumes, sometimes smaller than a million millionth of a cubic centimetre.

PWR Clad Ballooning

The behaviour of the fuel is important in the unlikely event of the loss of coolant water from the
core of a PWR. It is possible to postulate that under such circumstances the zirconium cladding of 10
the fuel might balloon and thus impede the reintroduction of coolant.

The display show the results of tests conducted to establish the effect of high temperatures and pressures on the ballooning behaviour of cladding tubes and how the research data are used.

The apparatus used for these tests is on show together with the computer-controlled laser gauge used to measure the diameter of the tube continuously during the test.

Graphite Sleeve Integrity

In Advanced Gas-cooled Reactors, the graphite sleeves which direct the carbon dioxide coolant gas
over the fuel must withstand the stresses encountered when loading or unloading fuel. The standard 10
applied is that less than one sleeve in a hundred thousand will crack during these operations.

A test rig has been built to study the mechanisms of cracking graphite. Small samples cut from a sleeve are continually bent between set limits while a microphone listens for the noise emitted during crack growth. Crack growth can also be seen by optical microscopy and a video film shows how cracks start to grow slowly before failure. The knowledge obtained from the rig is used to develop mathematical models of the fracture of graphite.

Reactor Decommissioning

Reactors have only a certain economic lifespan, after which decommissioning of the plant must be
undertaken. BNL has considered how this operation might best be approached and what steps should 11
be taken to minimise problems, for example by proper choice of constructional materials.
Assessments have been made of the total inventory of radioactivity in a reactor to consider the
radiological consequences for decommissioning.

Radiation doses to PWR Operators

The CEGB wishes to introduce PWRs into its system, and intends to ensure that radiation dose
received by operators are the lowest that can be reasonably achieved with this system. Research has 11
therefore been conducted into the causes of radiation to operators from a PWR and how this can be
minimised by choice of materials, coolant chemistry and the removal of radioactive deposits by
decontamination techniques.

Droplet Size in Flashing Water Jets

Superheated contaminated water from a leak in a PWR coolant circuit would produce an aerosol
as the escaping jet flashes to steam. Knowledge of the size distribution of the aerosol is a prerequisite 11
for optimising design measures to limit the spread of contamination. A measurement technique
developed at BNL is demonstrated.

Magnox Fuel Skip Cleaning

To avoid electrolytic corrosion of spent Magnox fuel during pond storage, the steel fuel skips are
coated with special paint. The intense radiation from the fuel and abrasion cause degradation of the 11
paint. Thus a number of skips now have to be refurbished. Several techniques were developed and a
novel wet abrasive method has been chosen for this decontamination.

Magnox Dissolution

Spent fuel from Magnox reactors is prepared for storage or transport by the removal of splitters
and other components which are then stored in the station silo. A process has been developed at BNL 11
in which this mildly active magnesium alloy waste is dissolved in carbonated water. The resulting
solution is filtered and treated by ion exchange methods to allow safe discharge to the sea.

Reactor Decontamination

Doses received during maintenance are the most important in the operation of a PWR. Such doses
can be greatly reduced by decontaminating the system and component before maintenance work 11
commences. Several specialised chemical decontamination techniques have been developed at BNL
and their efficacy proved on water cooled reactors in the UK and abroad.

Radioactivity in Perspective

Radioactivity is not unique to nuclear power, natural radiaactivity permeates the world around us; 11
in rocks, the air, in foodstuffs, even in buildings. Its presence is demonstrated by measurements in
cereals, nuts, sugar, peas, tea and coffee. Garden soil and fertiliser too are radioactive.

Gamma Spectroscopy

It is often necessary to identify the different isotopes and the amount of each involved in nuclear 11
research topics. Recent developments using solid state radiation detectors coupled to mini
computers enable very rapid and accurate determinations to be made.

Iodine and Caesium in Gas cooled reactors

Although the volatile radioactive fission products Iodine and Caesium generated in the fuel are
usually retained within the fuel can, the possibility that some might escape into the reactor must be 11
considered. Studies have therefore been made of the mechanisms of deposition onto reactor surfaces
and the subsequent behaviour of these fission products.

Particle Resuspension

In AGRs small radioactive particles are carried by the flow of carbon dioxide coolant gas around
the coolant circuit and are continually being deposited and resuspended. Since any accumulations 11
of activity may affect the doses received by staff during maintenance, experiments have been
conducted to measure the forces involved in deposition and resuspension in order to be able to
model and predict such behaviour. A demonstration shows the method used.

Computing Hall

Laboratories such as BNL require powerful and comprehensive computing facilities. In addition to many personal and small dedicated computers, BNL has a large number of terminals linked to its own IBM 4341 computer and thence to the CEGB London Computer Centre with its very large machines. BNL are also able to tap into worldwide networks via satellites.

The BNL machines will be in operation and the displays show the extent and scope of the system.

Design of Nuclear Plant to withstand Earthquakes

Minor earthquakes do occasionally happen in Britain, and those recorded over the past several hundred years have been evaluated to see how they might affect a nuclear power station. The display 13
shows research into the resistance of pipework to damage from earthquakes much more serious than could ever be expected in the UK.

BERSAFE structural analysis computer program

To ensure safety and efficiency, the CEGB makes extensive use of computer programs to provide a clear picture of the stresses and strains in complex engineering structures. BERSAFE is one such programm written at BNL and now used widely throughout the industry. The display shows various applications of BERSAFE and visitors will be able to try our graphics programs.

Fretting Wear

Fretting is wear due to the very small vibrational movements which can occur in power station boilers and similar places. A wear rig is shown in operation. Visitors will be able to observe the small movements of the surfaces and the ejection of small particles through a microscope using stroboscopic lighting.

Computerised Profilometry

The depth and profile of wear damage on reactor components is measured using a stylus profilometer, a device which in some ways is rather like a record player pickup. BNL has modified commercial systems to provide computerised mapping and other facilities and to present the data in highly visual form. The current and the 1960 vintage machines are on show.

Mechanisms Analysis with AMP

The AMP cmputer program provides a 'Meccano kit' for building computer models of mechanical systems. Using AMP is just like constructing and testing a real prototype but is both quicker and 13
cheaper.

AMP was used to model the crash of a train into a fuel transport flask prior to the actual public demonstration in 1984. A similar analysis of a crash of a flask on its rail wagon into a bridge abutment showed this to be much less severe than the standard 9m drop test. A demonstration would have cost more than £1,000,000.

Sodium Fires

Fast reactors use molten sodium as coolant protected with inert argon cover gas during normal operation. However sodium can burn in air to form corrosive fumes and also react with water 14
producing inflammable hydrogen gas. Special techniques have therefore been developed to study sodium fires and methods for their extinction.

Magnox Fires

The magnesium alloy used for canning the uranium fuel of Magnox reactors may ignite if strongly 14
heated in air. Studies have been made of the burning process and methods developed for extinguishing such fires.

Loss-of Coolant-Accident (LOCA) Studies

Studies of the course of a hypothetical loss-of-coolant accident in a PWR show that the condensation of steam affects the reintroduction of coolant into the core of the reactor. A computer colour display illustrates what happens in a LOCA and a demonstration rig shows how condensation can introduce oscillations into the cooling system. 14

Droplet Size Measurement

If a leak occurs from a pipe in the coolant system of a water reactor, the jet of water will break up into droplets. As the size of these will affect the spread of radioactive contamination, experimental studies have been made into the formation and size range of these droplets. Demonstrations show the breaking up of a sheet of liquid and the measurement of droplet size by a laser diffraction method. 14

Sodium Loops

Visitors will be able to see the BNL No 4 sodium loop, which is used to simulate the cooling circuit of a Fast Reactor. The loop is also used for experiments, in particular for experiments concerned with maintaining the purity of sodium coolant. 14

Dosimetry Services Building

Each year, most of the 4000 or so radiation measuring instruments used in the CEGB power stations and other establishments come to BNL to be recalibrated. The BNL facilities are equipped with extensive and varied facilities to deal with the many types of instruments used to measure many sorts and levels of radiation. Much of the equipment is automated to deal with the large numbers of instruments. 15

Some instruments, designed to monitor large areas, have to be checked against large area sources of known strength. As these are not commercially available, BNL has developed a method of making such sources of the required strength and uniformity. This technique is explained and typical sources are on display.

BNL also operates a Personal Dosimetry Service, available throughout the CEGB and to outside industry. Visitors will be shown the film badges and thermoluminescent dosimeters worn by power station staff and others, and will also see one of the assessment laboratories and the computers used to keep individual records for each person.

Health Physics Research

In the operation of nuclear plant, constant attention to radiological protection is necessary to safeguard both the public at large and staff operating the plant. BNL conducts research into a number of important areas as shown by the displays. 16

BNL work on the sensitivity to radiation of the eyes, skin and gonads and on techniques for assessing the dose received by these organs, is now incorporated in the recommendations on safe exposure levels of both UK and international organisations. 16

An unusual technique developed at BNL for the measurement of relatively large doses of radiation in the absence of a formal dosemeter is based on the thinning of hairs. 16

The measurement of doses from the uncharged elementary particles known as neutrons is of particular interest to the CEGB, since they are the initiators of the fission process which is the basis of nuclear power. A demonstration shows how neutron doses are routinely assessed from their effect on small pieces of plastic sheet, each impinging neutron being revealed as a small pit. 16

Such plastic sheet dosemeters require careful calibration and a special neutron source has been developed for this purpose. The special characteristics of the source also make it especially suitable for use in the treatment of brain tumours. 16

The small discharges from power stations must be carefully controlled whilst any leakage of radioactive material may be a potential hazard. Accordingly, we have developed computer models able to predict the composition of the wide range of radioactive substances formed in the fuel of a reactor, how these would become dispersed in the environment and the consequential uptake by plants and animals. These models assist in planning for emergencies and in the specification of emergency monitoring systems at the Board's power stations. 16

Leakages may include material in particulate form and techniques have been developed for the isolation and analysis of such small specks of radioactivity. 16

Flask Impact Research

The impact of a train travelling at 100 mph into an irradiated-fuel transport flask, staged by the CEGB in 1984, was a spectacular demonstration of flask safety. It was the culmination of a more general programme of flask impact research carried out by CEGB. The exhibit features a video of the rail crash, descriptions of the background work and a demonstration of impact testing techniques and instrumentation. 16

NIREX Mobile Exhibition

This illustrates the proposals being put forward by the UK Nuclear Industry Radioactive Waste Executive for the safe storage and disposal of nuclear wastes of all types. 17

Introduction to reactors

The principles of reactors and their design are set out: visitors will be able to participate in a demonstration of how reactors are controlled. 18

The BNL reactor

BNL has a shielded facility in which small reactors are built and operated as an experimental facility to test computer models. Visitors can tour the Control Room and go inside the Shield to see the reactor. 18

Reactor Physics

Safe efficient design and operation of a nuclear reactor is dependant on an accurate knowledge of how it will behave under normal and fault conditions. Such behaviour is best investigated by the use of computer models. A display describes how such models operate and why they are the 'basic tool' of the reactor physicist who uses them to predict radiation distributions within and around reactors. Some details of the models need to be tested against experiment and the use of the BNL reactor and the experimental techniques employed for these tests are explained. There will be a demonstration of the gamma scanning of AGR fuel. This technique allows the irradiation history of the fuel to be determined from the distribution of fission products and gives information on axial and cross channel flux distributions. 18