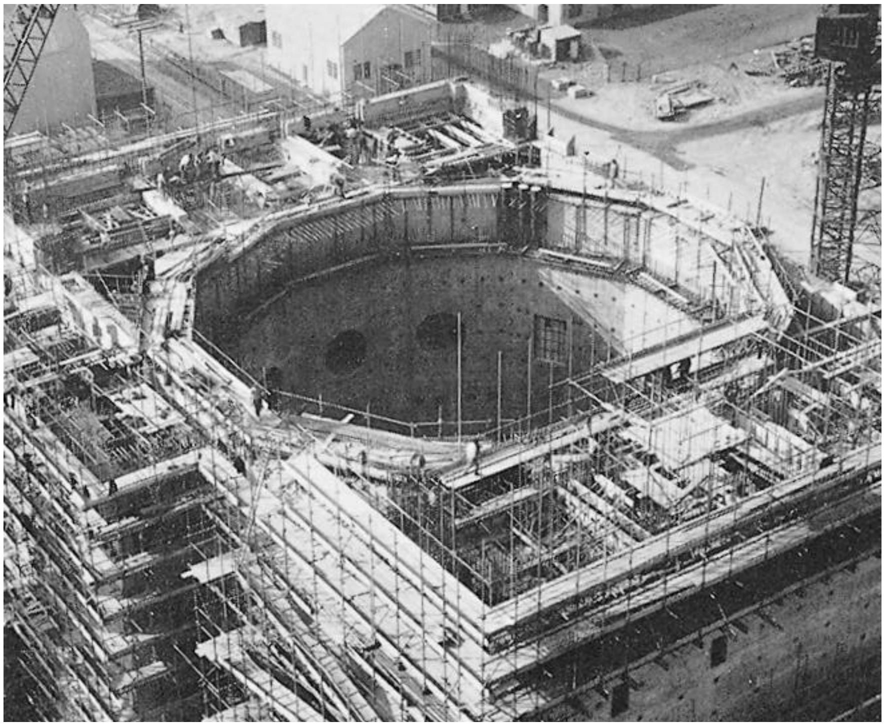
Construction of nuclear power stations

To most of us nuclear physics is a mystery. But the part concrete has played in the development of nuclear power stations is no mystery, nor are the construction techniques beyond the scope of any contractor. Concrete is the only practical material for a large permanent shield against the dangers of radiation. It also offers the advantages of being inexpensive, easy to build with, structurally self-supporting, virtually indestructible, and devoid of maintenance costs.

Authorities in both the United States and Europe are predicting that the economic breakthrough for nuclear power will occur around 1964 and 1965, and that the widespread use of nuclear energy for peaceful purposes will follow rapidly. Nuclear power plants are clean and compact and can be built almost anywhere. Coal and oil can be used more profitably as sources of synthetic raw materials than as sources of heat. It is none too soon to begin thinking about bidding on your first nuclear job.



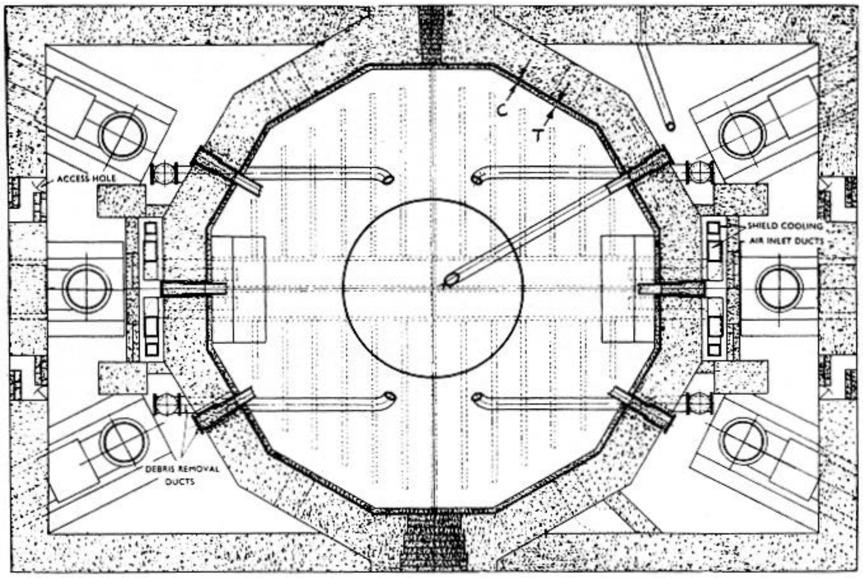
Reactor structure for the British nuclear power station at Hinkley Point on the Bristol Channel just before the roof slab was placed. Note the many openings in the walls for operational and testing purposes.

Radiation

How does a nuclear reactor work to produce electric power? Briefly stated, nuclear fission (the splitting of the atom) takes place at the center of the reactor. The splitting is done by bombarding the fuel (either uranium or plutonium) with neutrons. During the process vast quantities of energy are given off in the form of heat. This heat is absorbed by a primary cooling medium (frequently carbon dioxide gas), which passes to a heat exchanger. In the exchanger water is converted to steam and is used to drive a turbine and thus to generate electricity in the conventional way.

The most important task of concrete in this process is to provide a biological shield—an effective barrier against the lethal radiation. Just how the concrete behaves to absorb this radiation is difficult to explain, but some understanding of the action will make a nuclear concreting job more interesting. Essentially the two most severe forms of radiation emitted as products of nuclear fission are high energy gamma rays and fast neutrons. For practical purposes these two forms of radiation are the ones that the shield must absorb. Attenuation of the gamma rays is comparatively easy and is almost directly proportional to the density of the shield material. As density increases greater protection is therefore provided per unit of thickness.

The neutrons, on the other hand, are slowed down more effectively in an entirely different way—by collision with fighter chemical elements. This simple elastic collision transforms the neutrons into low energy thermal neutrons, which are absorbed in proportion to the capture cross section of the various chemical elements in the concrete. The nuclei of hydrogen atoms are the most effective in slowing down the high energy neutrons and absorbing thermal neutrons, since their mass is almost the same as that of neutrons, and they have a high capture cross section. The hydrogen atoms in the concrete shield are provided by water which combines with the cement during placing.



In this cross-sectional plan drawing of a reactor structure the letter "T" designates the thermal lining and the letter "C" indicates the space for the cooling medium.

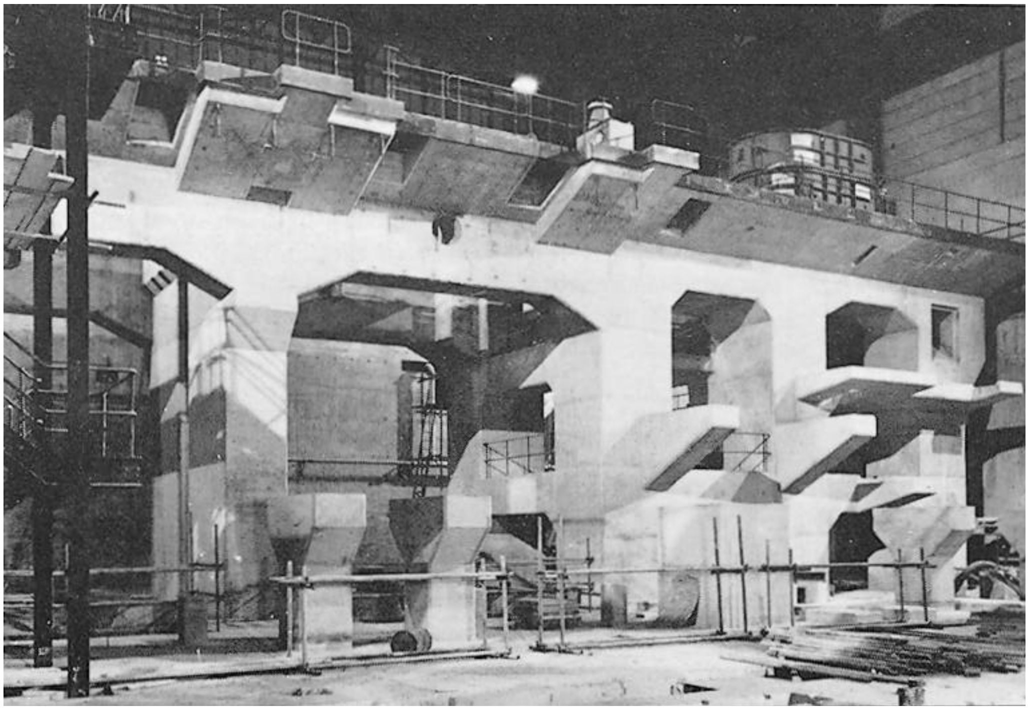
Unfortunately maximum density is not compatible with maximum hydrogen (water) content. A balance must therefore be struck between these two factors if both gamma rays and neutrons are to be absorbed. In the design of the shield the degree of protection desired must also be related to the space available and to overall cost. Ordinary concrete provides the cheapest shield, but the thickness of the walls can be reduced by using special heavy aggregates to produce concrete of a greater density. The best known of these heavy aggregates are barytes, limonite, magnetite and graded steel scrap.

The British program

In British nuclear power stations ordinary reinforced concrete is used almost entirely for shielding purposes. Barytes concrete is used at some points where thin walls are needed for access purposes, but in general it is not popular. The high cost of special aggregates in Britain is probably the main reason for this. Barytes concrete has, however, found wide acceptance for many experimental reactors and in laboratories.

At present there are some twelve major nuclear power stations either in service or at some stage of construction in Britain, each of which contains, or will contain, from 70,000 to 350,000 cubic yards of concrete. The special position of Britain in this field should perhaps be explained. For centuries Britain has relied on coal as her only source of energy. The best quality seams of coal are now played out and the alternative is either imported oil or nuclear power. Strategically, nuclear power is preferable—hence the construction program.

The largest contractor for nuclear power work in Britain is Taylor Woodrow Construction/Ltd., of Southall, Middlesex. This organization has just completed the civil engineering work for the Hinkley Point station on the Bristol Channel and is now breaking ground for another 5-year job at Sizewell in Suffolk.



View of the turbine hall at Hinkley Point showing some of the complex machinery foundation which are typical of such structures.

A study of the Hinkley Point project shows the extent to which concrete is used for a nuclear power station. The work is typical, even though Hinkley Point is the world's largest nuclear station, with an output of 500,000 kilowatts for the two reactors. The total quantity of concrete placed exceeded 300,000 cubic yards.

The reactor structure

A cross-sectional plan of one of the Hinkley Point concrete reactor structures is shown in the accompanying diagram. It comprises primarily a main biological shield 100 feet high, in the form of a 12-sided polygon, with secondary shielding walls surrounding it. The distance across the flats of the polygon is 76 feet and the thickness of the walls 7 feet. The secondary walls enclose an area 100 feet by 140 feet and are 6 feet thick. The whole structure is capped by a slab 11 feet 6 inches thick. The polygonal shape is chosen to minimize shrinkage effects and to give optimum structural benefit.

Each reactor is founded on a concrete raft, 120 feet by 150 feet, and around 11 feet deep, heavily reinforced in both directions. The raft contains some 8,000 cubic yards of concrete and approximately 380 tons of reinforcing steel, mostly of 1 3/8-inch diameter. Construction was in four lifts, with each lift divided into bays, placing proceeding alternately in checkerboard pattern. To allow for shrinkage no concrete was placed against old concrete until three days had elapsed.

The concrete in all the shielding walls and roof slab has an average density, when completely dry, of not less than 140 pounds per cubic foot. Crushing strength is not less than 3,500 psi at 28 days. Placing for the walls proceeded in small lifts again with alternate bay construction and a 3-day delay. This technique does much to reduce both shrinkage and thermal stresses to the minimum. Formwork consisted of 5- by 8½ of 1½-inch board on steel-angle supports. The 11½-foot thick roof slab was placed in 5 lifts, the formwork being suspended from steel girders which spanned between the secondary walls. During placing of all the walls, temporary floors, suspended within the reactor, provided access and working platforms at different levels.

All concrete placing for reactor structures must be subject to rigorous control. Whatever the thickness of the shield or the type of aggregate used, the concrete must be completely homogeneous. The safety provided to the power station staff will be only as good as the weakest section of the concrete. Honeycombing or segregation during placing means that the intensity of the radiation passing through the faulty section will exceed the limit imposed by the design. Obviously shrinkage cracks must also be avoided, and construction joints must be made with care if there is to be a completely homogenous bond between two lifts.

The problem of insuring correct placing and compaction is greatly complicated by the large number of openings needed in the walls for operational and testing purposes. These ducts and instrument channels are of many sizes and shapes and are widely scattered. On small projects an attempt is often made during design to keep all openings within two wall sections only, thus simplifying placing. At large stations this is rarely possible. Hand placing and compaction are standard practice around all openings. Poker vibrators are used at all other points and a wetting agent is usually added to avoid excess water which may cause shrinkage. The introduction of large numbers of delicate thermocouples into the shield presents a further difficulty. These sensitive and easily-damaged instruments must be located accurately and must remain undisturbed during placing if they are to measure accurately the rate of heat rise within the shield as a result of neutron absorption.

Accuracy is a must in nuclear concreting. At the first British station, at Calder Hall, limits of within plus or minus ⅒ of an inch were specified for both vertical and horizontal dimensions. Such a small degree of tolerance had never before been attempted in a reinforced concrete structure. The problem was solved by fabricating a complete steel template gauge. Subsequent experience has shown that such very close limits are not significant, and at Hinkley Point they have been reduced to within plus ¼ inch and minus ⅛ inch for the inner surfaces of the reactor. Thicknesses are simply specified to be not less than the nominal size. Internal accuracy is important because it has a major effect on the efficiency of the reactor operation. For this reason the location of all metal inserts for equipment support must be within ¼ inch.

site casting of components

A reactor. needs a thermal lining, or a surface to take the first shock of the high temperatures generated, and behind which the primary cooling medium can circulate. Solid steel panels, welded together, have proved excessively expensive, so at Hinkley Point this thermal shield is built up of concrete panels precast at the site. Each panel has a rectangular frame of 9-inch steel channel which acted as a permanent form. The 14 casting beds (9 under cover and 5 in the open) were simply a flat steel plate laid over a concrete slab. The plates were oiled and the frame, with a layer of mesh reinforcement welded within it, was laid on the bed and filled with concrete. Finishing was by hand-troweling.

The panels were steam-cured under temporary covers and after 24 hours, when the crushing strength was not less than 2,500 psi, they were removed and placed on edge in the open to mature. The panels are of various sizes and the majority of them weigh about 3 tons each. Handling was by eye-bolts screwed into the frame.

At many stations site cast slabs, usually 4 feet square and 4 inches thick, are also used as permanent formwork for the walls of reactor, turbine, service, and administration buildings. Over 3,000 such slabs were used at the Bradwell Station, Essex. Casting was again on steel plates, laid directly on grade, and separated by timber battens to which the wooden sides of the molds were nailed. Reinforcement was laid in the mold and normal 1:2:4 concrete was placed to within ½ inch of the top. An exposed aggregate topping was then provided by scattering 1½-inch nominal size rounded flint gravel on the surface of the wet concrete. Open spaces were filled by hand-placing of more stones. The whole surface was then firmly tamped and leveled. After the initial set the facing was carefully hosed off with water and brushed with a soft broom to expose the surface of the aggregate cleanly without loosening the bond of the stones. After 48 hours the sides of the mold were removed and the slabs were stacked on end to mature.

Reinforcement for these formwork slabs, which weigh about 800 pounds each, consisted of a single sheet of 6-inch square welded mesh of high tensile wire weighing about 6 pounds per square yard. Joints are formed by an overlapping step, half the thickness of the slab. The reinforcement extends into the step and two mild-steel links were included for lifting and mounting purposes.

The opportunities for using precast components in nuclear concreting are otherwise limited, since the fear of radiation loss rules out structural applications almost completely. Placing the concrete for the roof slab is always a major problem; the weight of a 10- to 12-foot thickness of reinforced concrete and the high degree of accuracy needed involve forms and falsework which must be, to say the least, substantial. The height of the slab from grade (100 to 120 feet) increases the problem. At Hinkley Point the problem was solved, as already mentioned, by suspending the forms from steel girders (actually war-time Bailey bridging). These girders span across the secondary shielding walls. The forms are then stripped and removed through openings within the reactor.

Auxiliary structures

Many subsidiary structures of reinforced concrete are needed at a nuclear power station. The turbine hall, where the electricity is generated, requires a sizable quantity of concrete. At Hinkley Point about 35,000 cubic yards of concrete was placed for the hall and related culvert system. The basement of the hall is around 750 feet long, 130 feet wide, and 30 feet deep. The height of the building is 94 feet. Complex foundations for the machinery introduced many problems in form design.

Water is needed at any power station; for nuclear energy the demand is particularly great -35 million gallons an hour at Hinkley Point. For this reason most British stations are located near the coast where sea water is available. At Hinkley Point the intake comprises a vertical shaft about 2,000 feet offshore, with two 12-foot diameter tunnels to convey the water from the shaft to the pump-house on shore. The outfall was built as two 2,000-foot long rectangular reinforced concrete culverts. At many stations these culverts are constructed using precast pipe as permanent formwork.

The intake shaft at Hinkley Point is an interesting structure. It has the form of a reinforced concrete cylinder 60 feet high and 90 feet in diameter, weighing 3,900 tons. Internal bracing is also of reinforced concrete. The cylinder, with two surrounding rings of sheet-steel piles, was constructed in a dry dock and floated into position. For this purpose a false floor of timber held in place by steel lattice girders was fitted. The operations of floating the cylinder out of the dock, towing, positioning and grounding required particularly deep water and had to be carried out in 4 hours on the day of the year when the highest tide (35 feet—the second highest in the world) was known to occur. Dredging of a channel was necessary near shore and the total distance towed was two-thirds of a mile.

Grounding was accomplished by lowering 8 steel legs down to seabed. When support was established satisfactorily the cylinder was flooded to give it stability at all states of the tide. The next stage was to drive home the sheet piling to form a cofferdam around the cylinder. Inside this cofferdam a shaft was excavated to connect with the intake tunnels being driven from offshore. Concrete for this shaft was conveyed over the water by a ropeway, supported on 4 intermediate towers.

Concrete is destined to play a major role in the construction of the nuclear power stations which are certain to be built in the next few years. Contractors, engineers and architects will all have an important share in these projects. This article has attempted to give some helpful information on construction details. A subsequent article will deal with the properties, value and use of heavy concrete for radiation shielding.

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