POWER REACTORS OF THE WORLD

The following table shows the power reactors throughout the world - in operation, under construction and planned – in April 1965.

POWER REACTORS IN OPERATION

Name	*Location*	*Type*	*Net Output (MWe)*	*Criticality Date*
(1) *Belgium*				
BR-3	Mol	Press. H_2O, 3.7+4.4% U	10.5	Aug 1962
(2) *Canada*				
NPD	Des Joachims	Press. D_2O, nat. U	19.3	Apr 1962
(3) *France*				
G-1	Marcoule	Nat. U, graphite air	1.7	Jan 1956
G-2 (G-3)	Marcoule	Nat. U, graphite, CO_2	2 × 28	Jul 58/ June 59
EDF-1	Chinon	Nat. U, graphite, CO_2	68	Sep 1962
EDF-2	Chinon	Nat. U, graphite, CO_2	198.5	Aug 1964
(4) *Germany, Federal Republic of*				
KAHL	Kahl/Main	Boiling H_2O, 2.6% U	15	Nov 1960
(5) *Italy*				
LATINA	Latina	Nat. U, graphite, CO_2	200	Dec 1962
SENN	Sessa Aurunca	Boiling H_2O, 2% U	150	June 1963
SELNI	Trino Vercelleze	Press. H_2O, 2.6% U	270	June 1964
(6) *Japan*				
JPDR	Tokai-Mura	Boiling H_2O, 2.5% U	11.7	Aug 1963
(7) *Sweden*				
R-3/ADAM	Agesta	Press. D_2O, nat. U	9	Jul 1963
(8) *United Kingdom*				
CALDER HALL	Calder Hall	Nat. U, graphite, CO_2	4 × 45	May 56/ Dec 1958
CHAPELCROSS	Chapelcross	Nat. U, graphite, CO_2	4 × 45	Oct 58/ Dec 1959
DFR	Dounreay	Fast breeder 45.5% U, NaK	15	Nov 1959

Name	*Location*	*Type*	*Net Output (MWe)*	*Criticality Date*
BERKELEY	Berkeley	Nat. U, graphite, CO_2	2 × 138	Aug 61/ Mar 1962
BRADWELL	Bradwell	Nat. U, graphite, CO_2	2 × 150	Aug 61/ Apr 1962
AGR	Windscale	2.5% U, graphite, CO_2	27.3	Aug 1962
HUNTERSTON	Hunterston	Nat. U, graphite, CO_2	2 × 170	Sep 63/ Apr 64
HINKLEY POINT	Hinkley Point	Nat. U, graphite, CO_2	2 × 250	May 64/ late 64
TRAWSFYNYDD	Trawsfynydd	Nat. U, graphite, CO_2	2 × 250	Sep 64/ Dec 64
(9) *United States of America*				
EBWR	Lemont	Boiling H_2O, 1.5+90% U	4.5	Dec 1956
SM-1	Fort Belvoir	Press. H_2O, 93% U	1.9	Apr 1957
SRE	Santa Susana	Graphite-sodium, 90% U + Th	5.1	Apr 1957
VBWR	Pleasanton	Boiling H_2O, 2-5% U	shut-down '63	Aug 1957
SHIPPINGPORT	Shippingport	Press. H_2O, nat. + 93% U	60	Dec 1957
DRESDEN	Dresden	Boiling H_2O, 1.5% U	208	Dec 1959
YANKEE	Rowe	Press. H_2O, 3.4% U	175	Aug 1960
PM-2A	Greenland	Press. H_2O, 93% U	1.5	Oct 1960
BORAX-5	Idaho Falls	Nucl. superheat, 5 + 93% U	2.7	Feb 1962
PM-1	Sundance	Press. H_2O, 93% U	1.0	Feb 1962
PM-3A	Antarctica	Press. H_2O, 93% U	1.5	Mar 1962
SM-1A	Alaska	Press. H_2O, 93% U	1.7	Mar 1962
SAXTON	Saxton	Press. H_2O, 5.7% U	3.3	Apr 1962
INDIAN POINT	Indian Point	Press. H_2O, 93% U + Th	255	Aug 1962
HNPF	Hallam	Sodium-graphite, 3.6% U	75	Aug 1962
BIG ROCK POINT	Charlevoix	Boiling H_2O, 3.2% U	75	Sep 1962
ERR	Elk River	Boiling H_2O, 93% U + Th	20	Nov 1962

Name	*Location*	*Type*	*Net Output (MWe)*	*Criticality Date*
HUMBOLDT BAY	Eureka	Boiling H_2O, 2.6% U	50	Feb 1963
CVTR	Parr	Press. D_2O, 1.5 + 2.0% U	17	Mar 1963
PNPF	Piqua	Organic, 1.9% U	11.4	June 1963
ENRICO FERMI	Lagoona Beach	Fast breeder, 25% + nat. U	60.1	Aug 1963
EBR-2	Idaho Falls	Fast breeder, 49% + nat. U, Na	16.5	Nov 1963
NPR	Richland	0.9% U, graphite, H_2O	776	Dec 196[a]
PATHFINDER	Sioux Falls	Nucl. superheat, 2.2 + 93% U	58.5	Nov 1964
BONUS	Punta Higuera	Nucl. superheat, nat. + 3% U	16.3	Apr 1964
(10) *Union of Soviet Socialist Republics*				
APS	Obninsk	5% U, graphite H_2O	5	May 1954
SIBERIAN	Troitsk	Nat. U, graphite, H_2O	600 (6×100)	Sep 58/ Dec 62
URAL I.	Beloyarsk	Nucl. superheat, 1.3% U	94	Sep 1963
WWER I.	Novo Voronezh	Press. H_2O, 1.5% U	196	Dec 1963
TES-3	Obninsk	Press. H_2O, enr. UO_2	1.5	1961
ARBUS	Melekes	Organic, 36% UAl_4 + Al	0.75	June 1963

POWER REACTORS UNDER CONSTRUCTION

Name	*Location*	*Type*	*Net Output (MWe)*	*Criticality Date*
(1) *Belgium*				
SENA	Chooz[b]	Press. H_2O, 3.1% U	266	1965
(2) *Canada*				
CANDU	Douglas Point	Press. D_2O, nat. U	200	1965

[a] *Reactor critical, power generation scheduled for late 1965 or early 1966.*

[b] *Electricity production is equally shared between Belgium and France; the reactor is located in France.*

Name	*Location*	*Type*	*Net Output (MWe)*	*Criticality Date*
(3) *Czechoslovakia*				
HWGCR	Bohunice	Nat. U, D_2O, CO_2	150	1970
(4) *France*				
EDF-3	Chinon	Nat. U, graphite CO_2	375	1965
EL-4	Monts d'Arrée	Enr. U, D_2O, CO_2	80	1966
EDF-4	Saint Laurant des Eaux	Nat. U, graphite, CO_2	480	1967
(5) *Germany, Federal Republic of*				
AVR	Jülich	Pebble bed, 20% U, graphite He	13.2	1965
KRB	Gundremmingen	Boiling H_2O, enr. U	237	1966
MZFR	Karlsruhe	Nat. U, press. D_2O	50	1965
KWL	Lingen	Boiling H_2O, fossile superheat, enr. UO_2	250	1968
KBWP	Obrigheim	Press. H_2O, 3% UO_2	283	1968
(6) *India*				
TARAPURA	Tarapura	Boiling H_2O	2 × 190	1967
(7) *Japan*				
TOKAI-MURA	Tokai-Mura	Nat. U, graphite, CO_2	158	1965
(8) *Netherlands*				
GKN	Dodewaard	BWR ("direct cycle")	47	1968
(9) *Spain*				
ZORITA DE LOS CANES	Zorita de los Canes	Press. H_2O	140	1968
(10) *Sweden*				
R-4/EVA	Marviken	Boiling D_2O, nat. U	200	1968
(11) *Switzerland*				
LUCENS	Lucens	1% U, D_2O, CO_2	7.5	1965
(12) *United Kingdom*				
DUNGENESS	Dungeness	Nat. U, graphite, CO_2	2 × 275	1964/65
SIZEWELL	Sizewell	Nat. U, graphite, CO_2	2 × 289	1965
OLDBURY	Oldbury	Nat. U, graphite, CO_2	2 × 300	1966

Name	*Location*	*Type*	*Net Output (MWe)*	*Criticality Date*
SGHWR	Winfrith	1.4% U, D_2O, boiling H_2O	93	1967
WYLFA	Wylfa	Nat. U, graphite, CO_2	2 × 590	1968/69
(13) *United States of America*				
EGCR	Oak Ridge	2.5% U, graphite, He	21.9	1965
HTGR	Peach Bottom	93% U + Th, graphite, He	40	1965
LACBWR	Genoa	3.4% U, boiling H_2O	50	1965
SAN ONOFRE	Camp Pendleton	3.6% U, press. H_2O	375	1967
CONNECTICUT YANKEE	Haddam Neck	3-4% U, press. H_2O	462	1967
JERSEY CENTRAL	Oyster Creek	Boiling H_2O	515	1968
(14) *Union of Soviet Socialist Republics*				
VK-50 (Ulyanovsk)	Melekes	Boiling H_2O, 1.5% U	50-75	1965
WWER-II	Novo-Voronezh	Press. H_2O, 1.5% U	365	1965
URAL-II	Beloyarsk	Nucl. superheat, 1.3% U	200	1965
BN-350	Shevchenko (Caspian Sea)	Fast breeder, 23% UO_2 + Pu, Na	350	

AIDS TO GREATER EFFICIENCY

Non-destructive testing methods can point the way to improvements in the design and efficiency of the nuclear power stations of the immediate future. Important developments in these methods, and a widening of their applications on the industrial scale, were foreseen at the Symposium on Non-Destructive Testing in Nuclear Technology, organised by the Agency in Bucarest, Romania, from 17 to 21 May 1965.

Non-destructive testing techniques such as radiography and ultrasonics have many advantages ; particularly in the nuclear field they avoid the need for taking samples of the materials for examination and analysis and it is often even possible to make accurate tests without any contact with the material. Non-destructive methods are used for many purposes such as to detect flaws, check dimensions, such as thickness of tube walls and determine the location and distribution of uranium fuel in a fuel element.

One of the chief lines being pursued in improving the efficiency of power reactors is to increase the heat output from the core. Thus, existing boiling water reactors produce 28 kilowatts of heat per litre of core volume, and the objective is to bring this up to 45 to 60 kilowatts. This means that a great deal of heat must be removed smoothly and evenly all the time that the reactor is operating; there must be no failure of materials or components under highly exacting conditions. Another important approach is to increase the burn-up of the fuel elements. Earlier gas-graphite reactors were built on the assumption that a burn-up of 3000 megawatt-days per ton would be achieved, but already fuel is being offered with a guaranteed burn-up of 4000 megawatt-days, and this is expected to rise to 4500 megawatt-days thanks to new fuel designs. Again, there must be no rupture or distorsion of the fuel element.

Speakers at the symposium stressed that non-destructive methods did far more than reveal flaws. They could provide a wealth of information about the physical structure and condition of materials, and the effects of fabrication processes. Non-destructive testing in nuclear technology used to be of interest mainly in research and development, but the symposium made it clear that these techniques are already being applied full-scale on the industrial production line. A number of papers referred to the use of automation, and some of the applications have been of interest beyond the nuclear industry. Thus, an automatic system designed for industrial testing of reactor fuel elements in continuous production has also been applied to light sheet metal.

Most of the established non-destructive tests have been concerned with detection of defects, and this has had the unforeseen unfortunate effect of imposing restrictive boundaries to such testing, according to D.W. Ballard (USA). He forecast the development of much wider applications of non-destructive methods in the future; they could help in the design stage, for example, in the attainment of higher strength-to-weight ratios.

For a ship propulsion reactor system, the best zircalloy tubing must be selected. A. van der Linde (Netherlands) said that the proposed system would provide 22 000 shaft horsepower for a ship of 65 000 tons. The reactor core is required to provide 1 200 days of operation at full power, and the majority of the fuel rods in the reactor will have temperatures of 335 to 345°C. A careful control is necessary to ensure that the tubes will withstand such conditions ; ultrasonic testing showed unequivocally that tubes supplied by one manufacturer were much better than those supplied by two others. A uranium fuel element described in a paper by R. Deknock (Belgium) consists of six cylindrical tubes one inside the other, with a gap of only about 3 mm between the tubes. Cooling water flows through the gap and it must not be obstructed by any slight distortion or misplacement of the cylinders. Ultrasonic methods have been devised to provide the necessary stringent checks.

Many other instances were given of the rapidly-widening contribution of non-destructive methods to process and quality control and to design improvements.