The session closed with an impromptu contribution by B.M. Vul (USSR), on recent developments in large superconducting magnets which provide a means of storage suitable for large pulses of electrical energy.

In a panel discussion on solid electrolytes the use of solids with abnormal high ionic mobility was considered. Their application is largely in facilitating electrochemical reactions between elements which are incompatible with aqueous electrolytes, a prime example being the use of β-alumina in the sodium-sulphur battery. Other uses have been proposed, such as refinement of an ionic species by electricity generation by stimulating ionic diffusion in the solid by means of a large temperature difference between two reservoirs of the appropriate liquid metal or vapour.

The properties of the one solid electrolyte being experimented with on a large scale were discussed, notably how its ionic conductivity $\sim$0.3mho cm^{-1} at 300°C was related to the existence of metastable sodium ion sites in the β-alumina lattice, and how the occupancy of such metastable sites is influenced by the occurrence of stacking faults in the lattice, together with the stabilisation of above stoichiometric concentrations by replacing some of the aluminium with a di-valent or mono-valent metal.

Thermal Storage

Of the possibilities for thermal storage in hot liquids including water, hydrates or chlorides, hot water storage seems to hold out most promise, but the capital cost of the most obvious route using pressurised vessels is still high. Possible cheaper ways include storage in the water of natural water/rock conglomerates, in lakes, in wet soil and in naturally occurring caverns filled with water. D. J. Schroeder described also storage by latent heat associated with solidification of salt solutions at near ambient temperature and highlighted $KF.4H_2O$ as a material with almost ideal properties for use in domestic solar energy heating and air conditioning systems. His high temperature molten salt storage heater for indoor domestic installations has a super-insulation jacket of controllable thermal transmittance.

Most of these methods will demand considerable development effort before entering the field of practical economic operation.

Coal Conversion

A wide range of possibilities exist for conversion of coal to liquid and gaseous secondary fuel products with important advantages to the ultimate user. Whilst discussing the UK research programme on these topics, F. Williams emphasised the range of international developments in, for example, the Lurgi and Cogas processes. Among a number of examples for the longer term, a process for solution of coal in anthracene oil with subsequent regeneration and production of a range of organic products was interesting but again much research is going to be needed to bring these ideas into practice.

W.T.E.
B.E.

Nuclear Energy

All our hopes are in nuclear energy. This statement made first by P. L. Kapitza in his opening talk was to be echoed on a number of occasions. Nobody is completely comfortable and would welcome another way out but there are no real alternatives in the foreseeable future to supply the massive increase in demand and particularly in electricity production that is needed. In A.M. Weinberg's words, it would be wrong to abandon nuclear energy by evoking other talismans. In exchange for an inexhaustible and clean source of energy, society promised to pay meticulous attention to its use. This last phrase had been used previously by Weinberg when speaking of the Faustian deal on nuclear energy but he was careful to explain on this occasion that this did not imply a devilish exchange, Faust was, after all, redeemed.

The problems are formidable it is admitted and it would be comfortable if mastering the fusion reaction was something that we could expect in the near future but it was difficult to anticipate a working fusion reactor before the end of the century and we were only too well aware how long after this it would be, before there might be reliable, economic and safe production units on the networks of the world.

Development of the LWRs

It was a reflection on the maturity of nuclear energy as Weinberg's talk was entitled, that he was able, whilst speaking essentially of the evolution of reactor systems in the United States, to be speaking effectively for everybody. Gone are the days where discussions on nuclear power were dominated by the strident claims of the protagonists of competitive systems and the market infighting of competing manufacturers. But Weinberg emphasized this should not mean that no reappraisal was necessary ; it was highly desirable that forward policies should be studied intensively and alternative strategies prepared.

It was an accident of history that had resulted in the almost universal adoption of light water reactor systems for central power production (more than 200 are currently on order) as these had initially been developed for submarine propulsion where compactness was the crucial criterion. They proved however, to be relatively cheap and reliable and when the cost of a unit of separated work fell by a a factor of ten between 1945 and 1960 to a figure of around $ 12/g(the momentum they had gathered led them inexorably onwards. But whereas some years ago the capital cost of heavy water in the D_2O systems imposed a serious financial disadvantage, it was no longer clear that the same conditions held good today.

Breeders

At a very early stage, the necessity for a breeder reactor was appreciated as uranium without breeding is not a very interesting source of energy in the long term. In the Fermi mind, breeding was synonymous with the fast breeder but Wigner had promoted the concept of the thermal breeder until the poisoning effect of fission products dominated by the ^{135} Xe cross-section of 2,6 million barns indicated that it could only work in a homogeneous system. As a result, the FBR emerged as the only contender but it is a very different animal from the one that was first envisaged ; cores are bigger, fuel elements taken to high burnups and in consequence chemical separation is done in specialized plants far away. But the FBR is not necessarily the only solution and unless it is clear that a short doubling time is vital, a light water or even heavy water breeder merits more detailed study. Liquid systems have also a lot to recommend them and Weinberg diffidently recalled the molten salt experiment which had really gone very well.

The time at which breeders were introduced on the industrial scale and the doubling time they needed to have built in depended upon your scenario for growth. In the medium term, if one was really concerned with uranium consumption, which is becoming more and more the case, it was of more than passing interest that the HWR and HTR required only about 60 % of the uranium needed by the LWR even with plutonium recycle.

Safety

There was thus every reason to rethink our forward programmes in terms of an energy strategy but nuclear debates these days tended to be dominated by the safety question, the $\infty \times 0$ syndrome which occupied so many of the headlines. In spite of the fact that more data has been compiled on the effects of radioactivity than any other potential pollution (Eklund), accident probabilities were given much more extensive study in such documents as the Rasmussen report, and three international organizations were concerned with safety studies, there seemed to be a disproportionate fear on the part of the general public. It was interesting to compare the attention devoted to possible reactor accidents calculated as 1 in 10^8 for 100 operating reactors. Failure of the Sacramento dam would mean the death of some quarter of a million people and the probability of failure could be estimated to within an order of magnitude of 1 in 10^3, but this generated no public fear.

Weinberg expressed the view and nobody contested this, that the waste disposal problem is sufficiently well understood and in any ordinary human terms is safe enough — an expression which of course means different things to different people and results in different standards being adopted in different countries. The absence of the need for containment of LWRs in the Soviet Union is just one example. It was easier to scare than unscare but he believes that the hazards associated with nuclear energy are no greater than with other energy producing systems. It will of course be extremely hard to clean up any mistake and the possibility of the diversion of nuclear material was a major preoccupation. However, we have lived with the storage of vast quantities of nuclear explosives since the war, so far safely, and in any case we cannot unlive this fact of life and there is no way of eliminating it. What we needed to do within our overall energy strategy was to pay continuous and careful attention to detail at both the organizational level and at the level of detailed engineering. An increase in the power availability of the current series of water reactors from the present 60 % to 70 % or more would make a contribution to energy supplies well worth having.

Hybrid systems

As our needs for an energy more transportable than electricity grow, so nuclear engineers must be turning their attention to applications other than central station generation. Total systems have to be considered such as the one put forward by K.B. von der Decken in which an HTR is used in an EVA generator to reform from a methane feed, CO and hydrogen which is piped to the load centre and there in an ADAM converter, power and heat is produced whilst the methane is regenerated. The only waste product is water and one has the possibility of locating the primary heat source — the reactor — in a guarded nuclear park where all the nuclear activities are concentrated.

Fusion

For those who hoped to see fusion an imminent solution to our energy problems there was but cold comfort from the fusion experts fresh from the Lausanne conference which was reviewed by C. M. Braams.

The hopes for laser fusion have gone from years to decades as the processes for magnetic confinement did some ten years or more ago. No laser exists with the power needed by orders of magnitude or the right frequency. Moreover the realisation of the DT reaction by any system is going to be difficult enough and the DD is just a mirage on the horizon. In the DT reaction, some 80 % of the energy is liberated as fast neutrons and 20 % as alpha particles. This means one has immediately radiation problems with the tritium not least of which will be its extraction from molten lithium and huge material problems associated with the fast neutron flux. Moreover the abundance of lithium is not significantly greater than uranium.

Laser heating

Sketching the elementary physics of laser fusion, A.M. Prokhorov pointed out that to raise the temperature of a DT spherical pellet to fusion temperatures, some 10^9 J/g is needed. If the heating is to be accomplished in a time shorter than the inertial confinement time, the rate of heating works out at 5.10^{15} W/cm² which means that with the laser pulses of 10 KJ and 2.10^{-10} s long now becoming available, pellets of 10^{-5} g could be heated.

If however, we are to have nuclear heating (by the α particles produced) and so some semblance of a self-sustained reaction the condition $\varrho\, r = 0.3$ g/cm² must be fulfilled where ϱ is pellet density and r is pellet radius. Today we can only aspire to a figure for $\varrho\, r$ of $0.5.10^{-2}$ g/cm² and we must either push the laser energy up towards 1GJ or dramatically increase the density by a compression technique. Such compression can in principle be obtained by bombarding with a rising energy density, but losses due to evaporation would be $\cong$ 90 % and we should still finish with only 5 % burn up. Moreover we have very little experience of compression behaviour. Computer simulation indicates we should extract as much energy as is in the laser beam but as the laser efficiency is of the order of only 1 % this is far from good enough.

One possibility that has been suggested is to use the neutrons liberated in a laser triggered cloud of micro-particles as an irradiation source for a sub-critical fission assembly but it is difficult to see the economic justification for such a technique.

Tokamaks

In the Tokamak reactors, the time for heating is of the order of seconds and it is this slow energy transfer that has given the impetus to the study of laser and relativistic beam heating. Nevertheless the system is being vigorously pursued, the latest device to be proposed being Jet (EN, vol 6 n° 4) a machine regarded as the best experimental Tokamak so far, but it is essentially a physics experimental tool and will not attain fusion energies.

Mirrors

One good piece of news that had been reported at Lausanne (at least from the point of view of the physics) was the successful suppression of instabilities in a mirror machine at Livermore, by the injection of low energy plasma. A theoretical prediction had been made that the cause of the instabilities was the loss of low energy plasma during the heating cycle and if this could be stopped, or compensated, the plasma should remain stable. Confirmation of this prediction is a considerable encouragement that real progress is being made in understanding the physics of these processes and it is evident that this must remain the primary goal for some years to come.

E.N.S.