International Co-operation in MHD Electrical Power Generation

by Vyacheslav Chernyshev

Over the past two decades, research and development in magnetohydrodynamic (MHD) electrical power generation have been accompanied by a considerable upswing in international co-operation. The IAEA's MHD programme was launched in 1966 when it supported the initiative of OECD's Nuclear Energy Agency (NEA) to establish a joint group, which was called the Joint NEA/IAEA International Liaison Group on MHD Electrical Power Generation. This team of experts from 18 countries has been engaged in a regular exchange of scientific and technical information on MHD electrical power generation and has helped to find solutions to a variety of technological problems and to implement a number of design concepts.

The MHD Liaison Group has been instrumental in the organization of annual meetings, panels of experts on various engineering and technological problems, and international MHD conferences. There have been six international conferences on MHD electrical power generation, the first of which was held in the UK in 1962 and the sixth in the USA in 1975. Plans are now afoot for a seventh international MHD conference to be held in 1979. The MHD Liaison Group also periodically prepares and publishes status reports on research and development in the field. The most recent status report, which appeared in 1977, contains a survey of national programmes, an evaluation of the most promising lines of research and a review of future problems.

In these reports, both developed and developing countries receive up-to-date scientific information on the most important and promising aspects of direct energy conversion by means of MHD. With this in mind, the IAEA has continued to sponsor the international liaison group even at a time when the NEA could not itself do so. At present, the group is being supported by the IAEA and UNESCO.

Magnetohydrodynamic Systems

The MHD generator is an energy converter working on the principle of interaction between an electrically conducting fluid and a magnetic field (see Figure 1). Interactions of this kind were investigated by Faraday at the beginning of the 19th century. In his first work on electromagnetic induction in fluids, Faraday sought to use the earth's magnetic field to measure the flow rate of the water in the Thames river. It was not until the early 1960's, however, that the idea of a magnetohydrodynamic method for converting energy fully came into its own. Basically, an MHD generator is a device for directly converting thermal energy into electricity. There are three types of MHD cycle: open, closed and liquid-metal.

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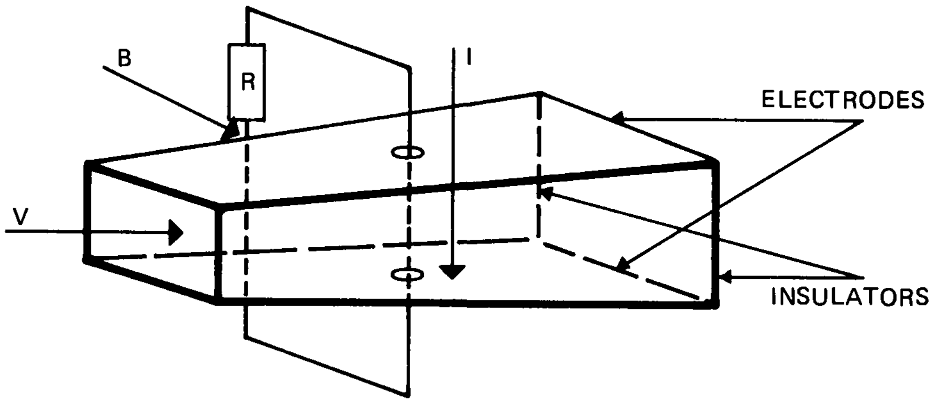


Figure 1. Schematic of MHD generator channel The flow of an electrically conducting fluid in a magnetic channel induces an electric field (intensity vector **I**), which is perpendicular to both the velocity vector **V** of the conducting fluid and the induced magnetic field vector **B**. During the flow of the fluid through the channel, a current is induced in the electric circuit with resistance load **R** The channel power for a given magnetic field increases with the velocity and conductivity of the fluid The fluid can be either ionized gases or liquid metal and is heated to a high temperature before it enters the MHD generator channel. The heat source can be a fossil fuel or a nuclear reactor.

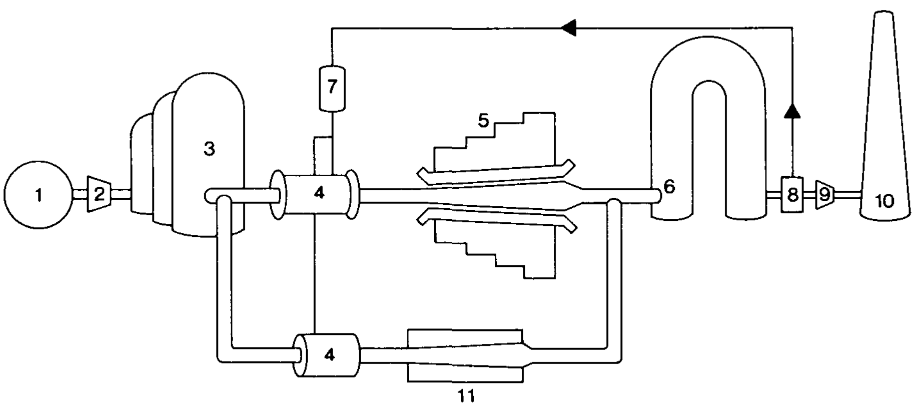
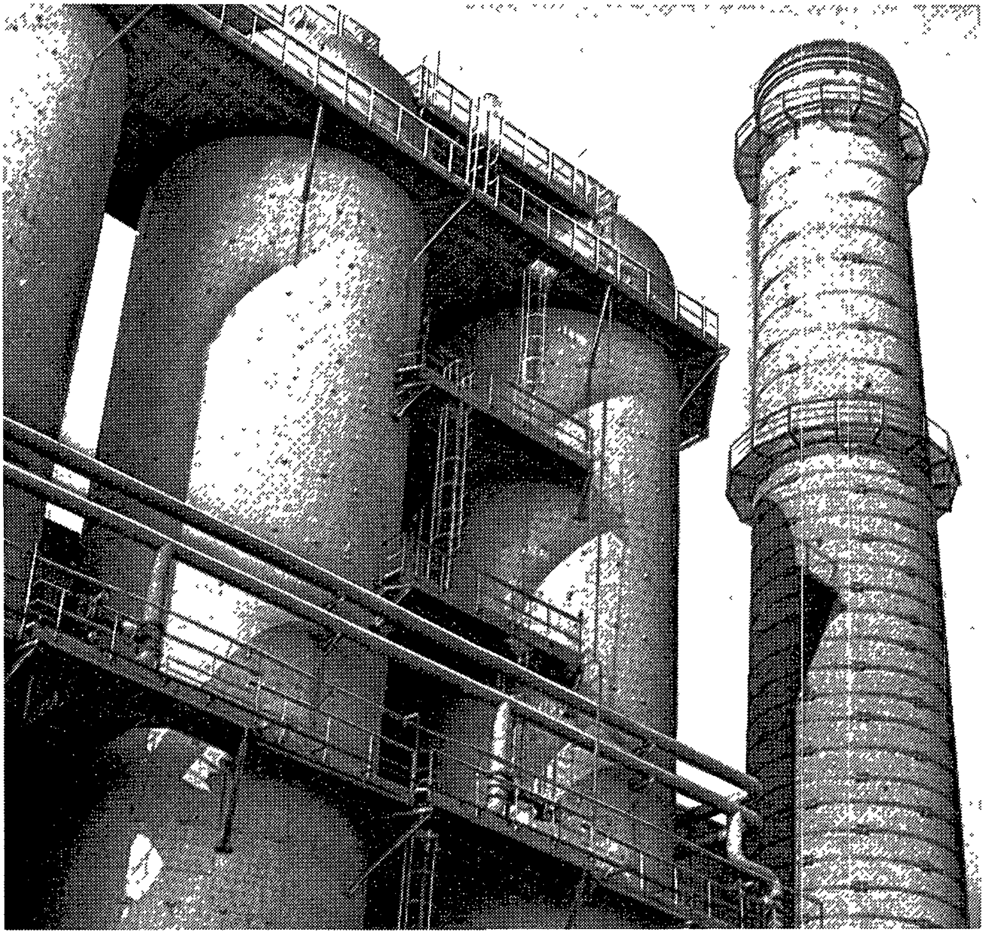


Figure 2. Schematic of U-25 MHD power facility with by-pass loop for superconducting magnet system. (1) Natural gas source, (2) compressor, (3) air preheater, (4) combustor, (5) MHD generator, (6) steam generator, (7) seeding system, (8) seed regenerator system, (9) stack exhaust blower, (10) discharge stack, (11) superconducting magnet system.

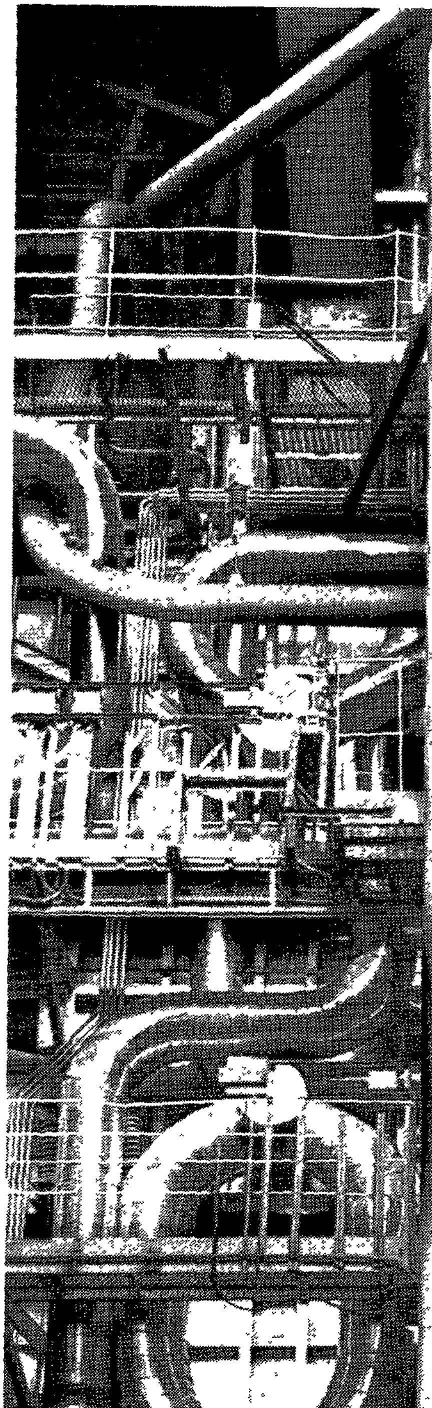


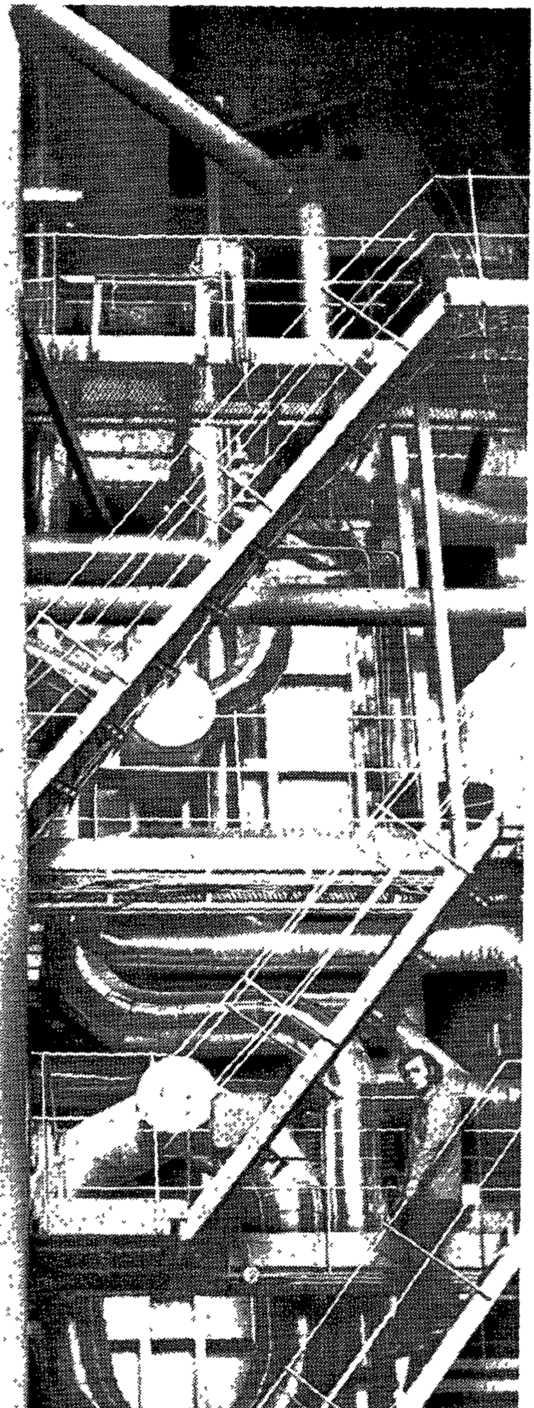
Air preheater of the U-25 facility at the High Temperature Institute of the USSR Academy of Sciences

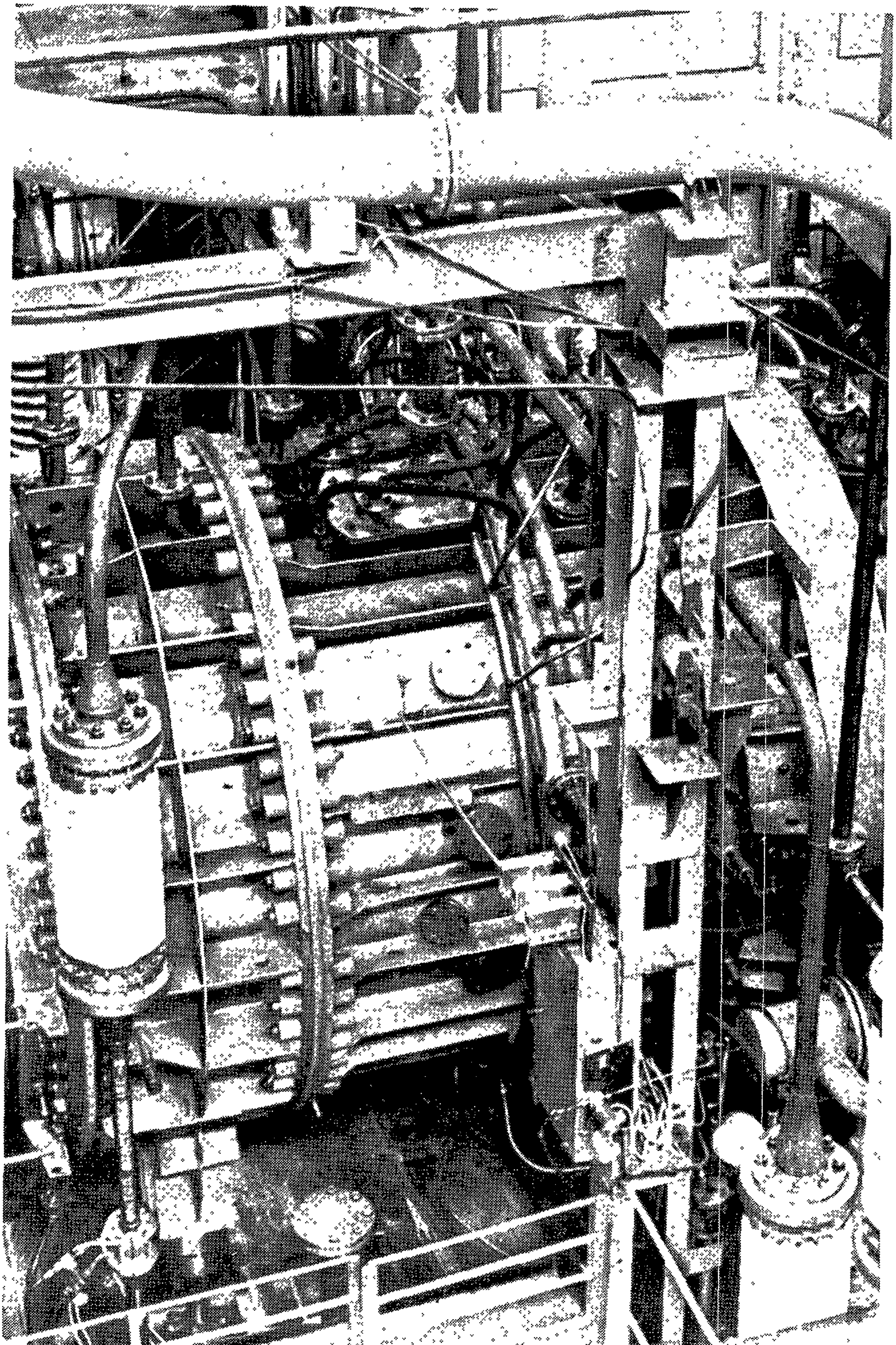
In the open cycle, the products of combustion of fossil fuel, seeded to improve ionization, are released into the atmosphere after passage through the MHD system. The closed cycle presupposes continuous circulation of the working gas through a closed circuit. In this case, the heat source may be an ultra-high-temperature gas-cooled reactor, and a seeded inert gas can be used as the working fluid. The liquid-metal MHD system could use as a working fluid the liquid-metal from a fast-neutron reactor. The main difficulty with such systems is creating a flow of liquid with a high enough velocity.

From both the physical and engineering standpoints, the possibility of an MHD system operating in a closed or liquid-metal cycle has been firmly established. However, the potential use of these cycles in large-scale power stations has not yet been developed to the same extent as open-cycle systems.

Steam generator at the U-25 facility ▶







Control panel of the U-25 MHD facility.

An assessment of the development of power generation in the more advanced countries of the world shows that in the coming years (up to the year 2000) the bulk of their electricity will be furnished by conventional power stations burning organic fuel. Inasmuch as expenditure on fuel at the present time amounts to 50—55% of the total outlay on electricity generation (and will increase), one of the most important problems in power engineering is to improve the thermal efficiency of power stations, while reducing the thermal pollution of the environment.

Seen from this point of view, the magnetohydrodynamic method of electric power generation based on the open cycle is one of the most promising methods for directly converting heat energy into electricity and will help to improve the economic viability of thermal power stations. It is expected that first-generation MHD power stations will have an efficiency of about 50%, while for the second generation the figure will go up to 60%. Even at the stage where first-generation MHD stations are introduced, the specific fuel consumption could be reduced by 20—30% and the coolant water consumption could drop by a factor of 1.5 compared with normal thermal power stations.

◀ Combustor at the U-25 facility.

The U-25 MHD Facility

In the early 1970's the High Temperature Institute of the USSR Academy of Sciences constructed the first large MHD pilot facility, the U-25, which has successfully supplied electricity to the Moscow grid. The U-25 (see Figure 2) contains all the main components of future industrial power stations that will make use of an MHD generator.

The fuel selected for the U-25 facility is natural gas. Combustion takes place in oxygen-enriched air that is preheated to 1200°C. To improve the conductivity of the plasma, use is made of a seed (alkaline metal) which is cycled to the combustor. The plasma flow, which has a temperature of over 2500°C, generates an electric current in the MHD generator channel inside the field of the electromagnet. Inverters convert the direct current from the MHD generator into alternating current. The facility is controlled by a computer.

After passing through the MHD generator, the plasma gives up its heat in a steam generator and the steam is used in the secondary circuit steam power plant. Before the heat-depleted plasma is discharged into the atmosphere, the seed is extracted and recycled to the combustor.

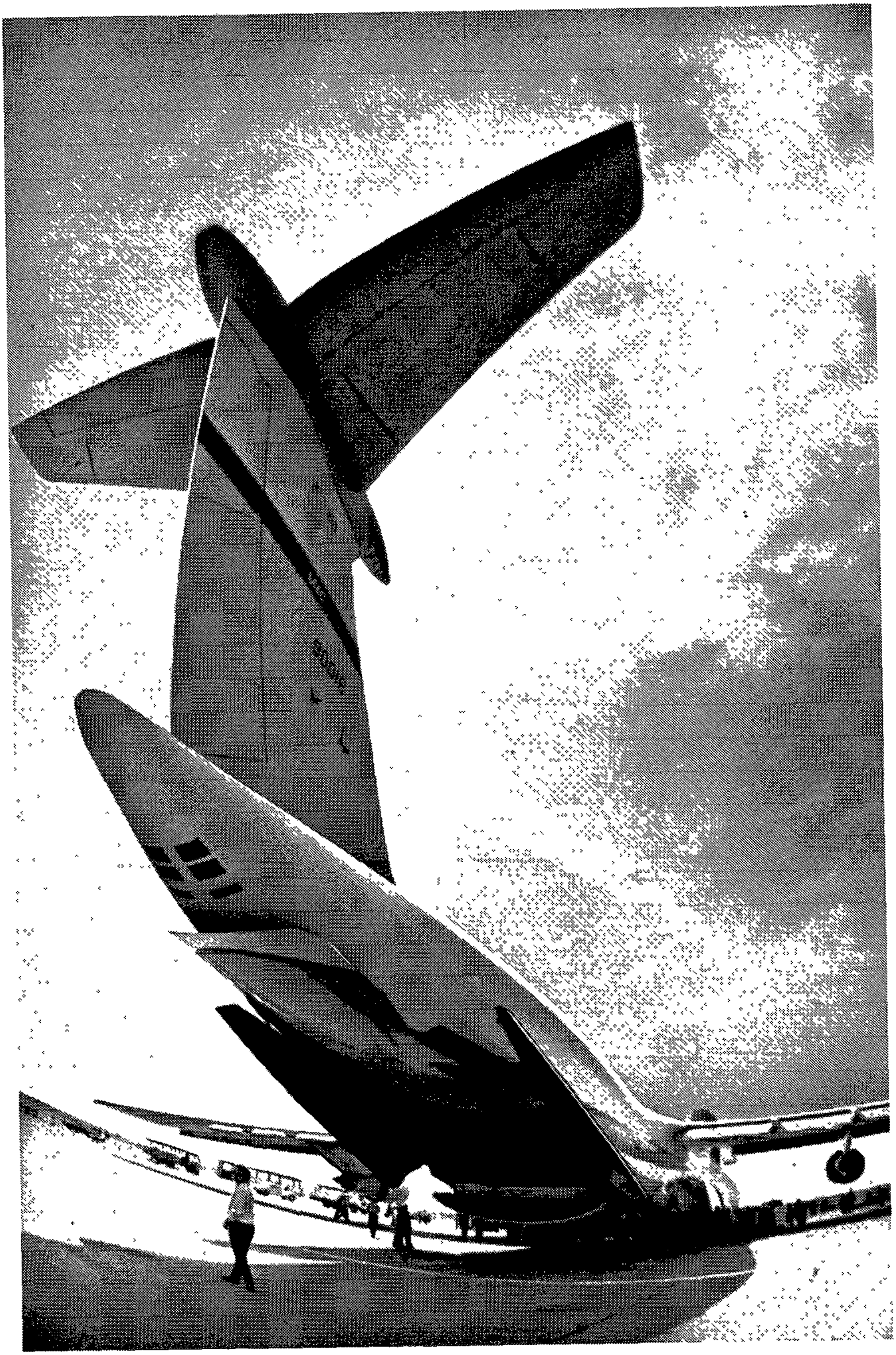
In the combustor of the U-25 facility, the thermal load in the flow chamber reaches 70×10^6 kcal/m^3.h, which is approximately 300 times higher than is achieved in the best modern steam boilers. The characteristic feature of the MHD generator combustor is that it operates under a very high potential — 5 kW in the U-25. Work is still going on to select the most suitable type of MHD generator channel for the U-25 device so as to ensure continuous channel operation over a prolonged period and at rated power.

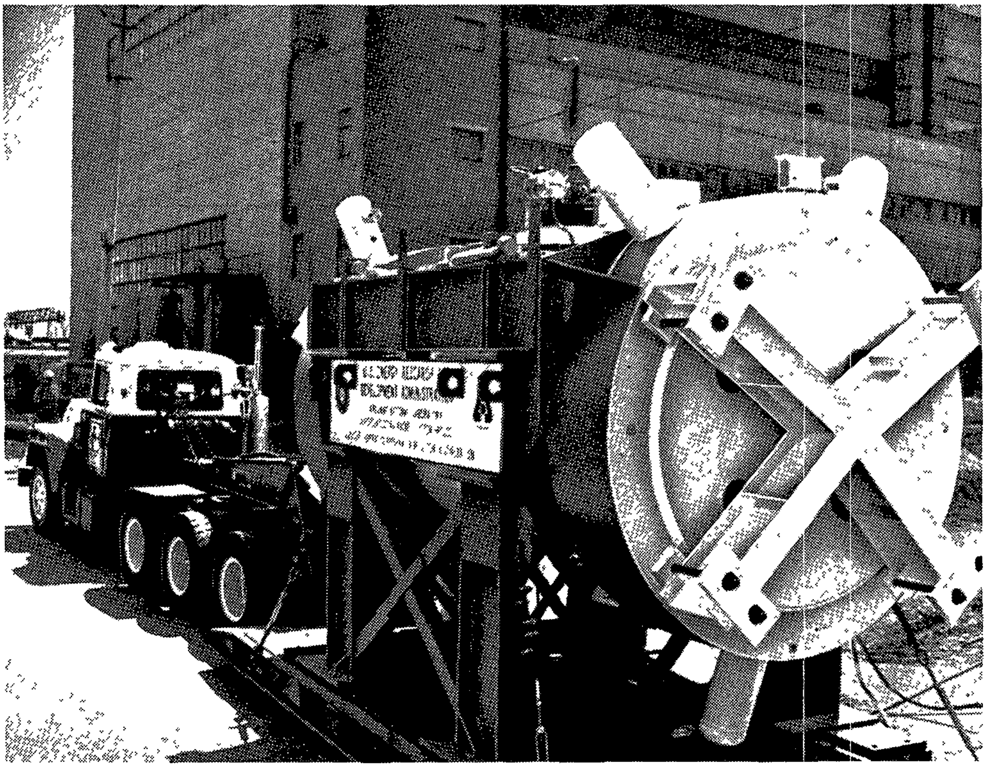
The principal design parameters for the U-25 have already been attained (see Table 1). The broad range of research performed with this facility has made it possible, even at the present stage, to begin construction of a pilot 500-MW MHD power station unit for industrial purposes. It should be pointed out that, for large-scale production, MHD power stations can operate under base-load, intermediate, or peak-load conditions.

Table 1: Main characteristics of the U-25 MHD facility

— Power (MW)	20.4
— Fuel	natural gas
— Oxidizer	air + O_2
— Oxygen enrichment (% of volume)	45
— Preheated air temperature (°C)	1250
— Inlet temperature (°C)	2600
— Mass flow rate (kg/$)	50
— Ratio of seed to full gas weight (%)	1
— Inlet pressure (atm)	3.5
— Velocity of flow (m/s)	1000

U.S. Air Force Galaxy C5 at Sheremetyevo airport (Moscow) delivering a superconducting magnet built by the Argonne National Laboratory. ▶





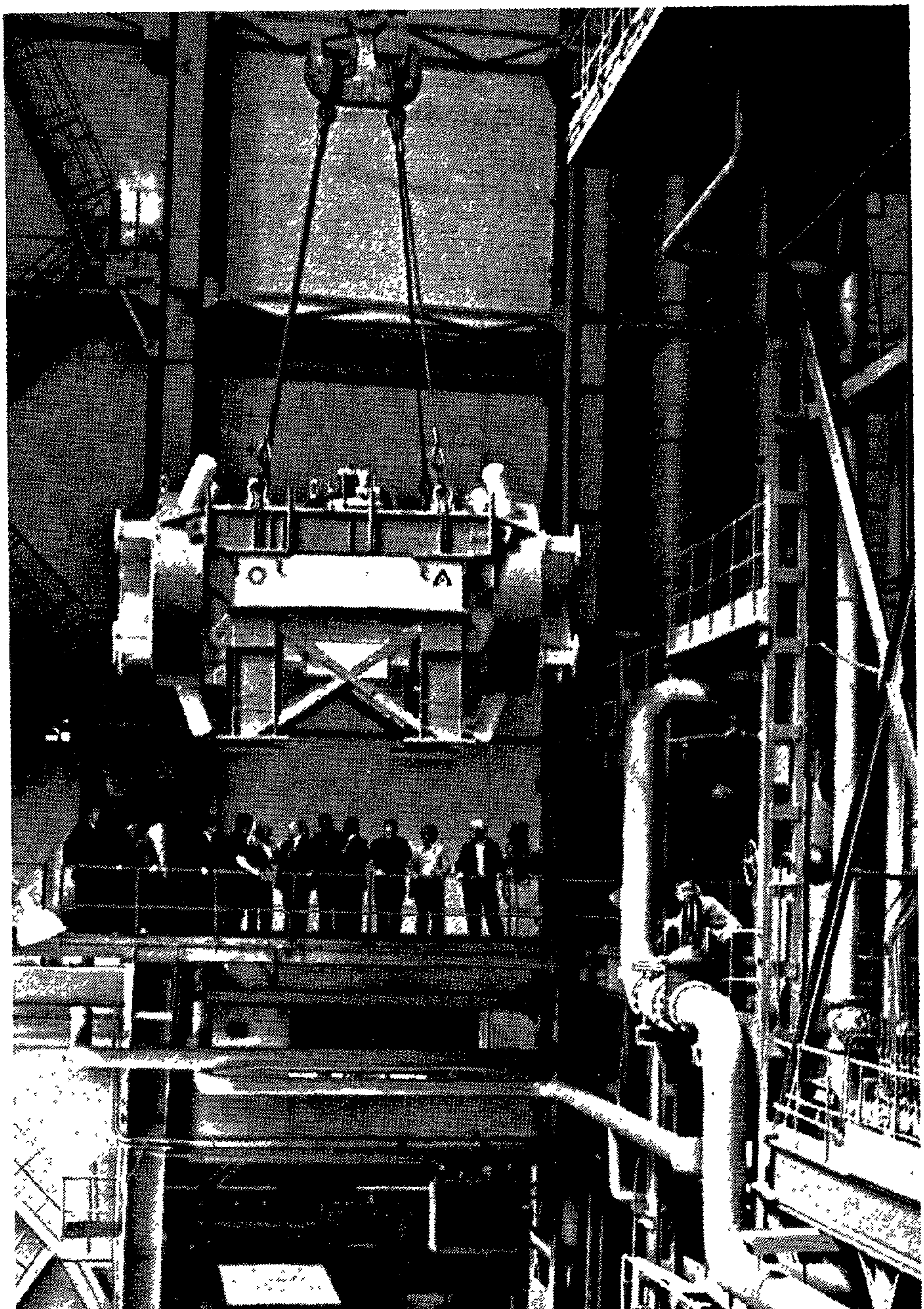
Delivery of superconducting magnet to the U-25 MHD power facility

International Co-operation

There are many examples of international co-operation in the field of MHD electrical power generation. For instance, the co-operation agreement between the Nuclear Research Institute in Poland and the Saclay Nuclear Research Centre in France led to the construction of a high-temperature air heater (up to 1200°C). A bilateral agreement on the construction of a coal gasification system was recently concluded between Poland and the USA.

There is a multilateral co-operation programme on MHD electrical power generation between the socialist countries within the framework of the Council for Mutual Economic Assistance (CMEA). The Government of India with the support of the USSR has decided to set up a 15 MW thermal research facility to study the engineering problems involved in an open-cycle MHD system based on coal gasification. A good illustration of the development of international co-operation based on the MHD Liaison Group is the joint Soviet-American programme on the design and construction of industrial MHD power plants, this work has been progressing fruitfully since 1974. Because the U-25 facility contains all the principal elements of an industrial MHD power station, it offers the American experts an opportunity to test large MHD components under working conditions. For their part, the Soviet experts

Installation of the superconducting magnet in the by-pass loop of the U-25 facility ▶



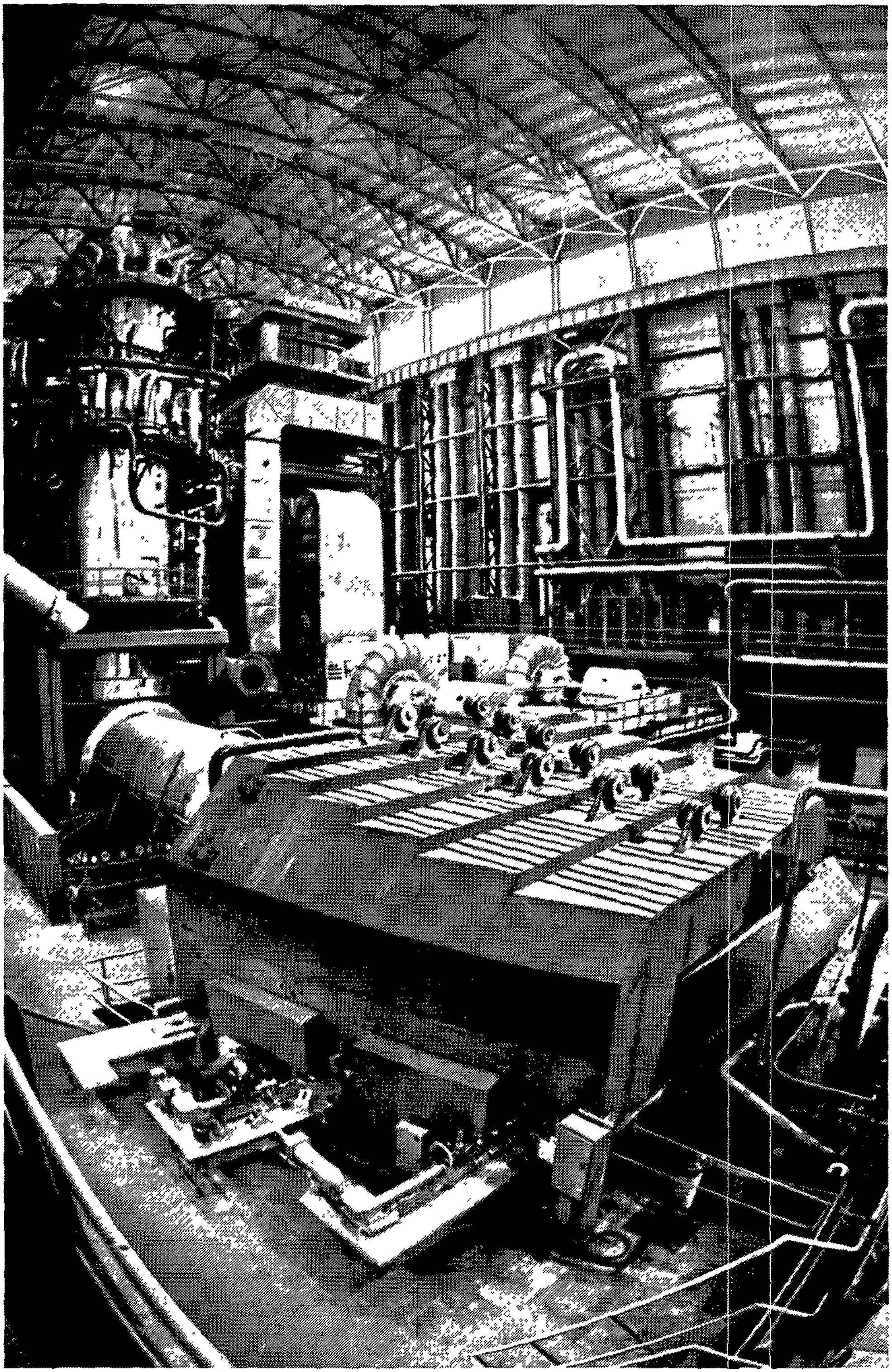


Table 2: Main characteristics of the large superconducting magnet system built by the Argonne National Laboratory for the by-pass loop of the U-25 facility.

Dimensions: Hot inlet: 40 cm diameter, Hot exit: 60 cm diameter, Overall length: 4.2 m

Magnetic field H_0/H maximum: $\frac{6.3\ T}{5\ T}$

I(conductor)/I(overall): $\frac{4.2 \times 10^3\ A/cm^2}{2.6 \times 10^3\ A/cm^2}$

$E = 20 \times 10^6\ I$

Thermal flux ($W_s[W/cm^2]$): 0.83

Helium volume/conductor volume: 0.36

are interested in studying American-designed MHD-plant components, especially large superconducting magnet systems and the operation of MHD generators that burn coal.

A major contribution to the joint USSR-USA co-operative programme was the installation in 1977 of a large American superconducting magnet system in a by-pass loop of the U-25 facility. The superconducting dipolar magnet was built by the Argonne National Laboratory and flown to the USSR (see photos). The principal characteristics of the magnet are shown in Table 2.

Over the next few years, there are plans for a joint Soviet-American study of a broad range of problems with the MHD generator using strong electric and magnetic fields (electric fields of up to 3 kV/m and magnetic induction up to 5 T). The outcome of this research will be of particular importance in the design and improvement of the main units of MHD generators to be used in industrial power stations.

Conclusion

The long-term activity of the International MHD Liaison Group supported by the IAEA and UNESCO, together with the various research and engineering programmes for international co-operation in the development of MHD, highlight the huge potential of this technology for the generation of electrical power in the future.

◄ The Soviet U-25 MHD pilot facility In the foreground is the 2000-tonne magnet system in the first loop