JPRS L/10240

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Worldwide Report

NUCLEAR DEVELOPMENT AND PROLIFERATION

(FOUO 1/82)

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WORLDWIDE REPORT

NUCLEAR DEVELOPMENT AND PROLIFERATION

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CONTENTS

EAST EUROPE

CZECHOSLOVAKIA

SUB-SAHARAN AFRICA

NIGER

Briefs

SENEGAL

WEST EUROPE

FRANCE

Briefs

ITALY

CZECHOSLOVAKIA

PM-3652 NUCLEAR POWER STATION DIAGNOSTIC SYSTEM OUTLINED

Prague ENERGETIKA in Czech No 9, 1981 pp 386-392

[Article by Eng Karel Prokop and Eng Milan Novak, EGI, Dukovany Nuclear Power Station, and Eng Svatobor Stech, Dukovany Nuclear Power Station Concern: "The PM-3652 Nuclear Power Station Diagnostic System"]

[Text] Currently, industrial equipment is becoming increasingly complex and expensive. This also increases the need to assure its optimal operating condition, reliability and technical safety. These requirements can be met only if we have information on the processes taking place in the equipment and on the devices and structural members which assure proper operation. For this purpose it is essential to monitor the condition of the equipment and processes taking place in it and to provide for signaling of unsafe (i.e., extraordinary or emergency) conditions.

Modern methods for evaluating the state of processes and equipment include analysis not only of short-term average values of measured parameters, but also of changes in these parameters, for the changes brought about by a process contain important information about it. The characteristics of a dynamic process are its amplitude and frequency spectrum. In information engineering, the technique of evaluating statistical fluctuations of signals has been called "noise analysis." This method is particularly suitable for comprehensive monitoring of processes.

In continuous measurement of the characteristics of a process, we primarily monitor the occurrence and development of deviations from measurement values corresponding to normal states of the equipment. In this way, we can identify the cause of an abnormal state and detect processes of equipment damage in their initial stages. It is advantageous to use the period when the equipment is being broken in (e.g., the startup of a nuclear power station), when it is highly probable that the equipment and components are functioning correctly, to measure the characteristics of the normal state.

Analysis of the noise components of various signals, including pressure, temperature, neutron flux, vibration and the like, has led to noteworthy results in diagnosis of processes occurring in such pressure vessels as nuclear reactors and reactors in the chemical and metallurgical industries. An advantage of these methods is that they do not require direct contact of the sensor with the working medium.

To solve the problems noted above for nuclear reactors, the PM-3652 noise analysis system has been developed. This system allows diagnosis of damage to nuclear reactors and has been tested under operating conditions for several years. It includes monitoring of vibration in the reactor, its interior components and the control equipment drives; in addition, the system records the pressure values of the coolant in the reactor (pressure pulses) and the neutron flux inside and outside the reactor. The system also has instruments to locate loose components in the pressure vessel and primary circuit. All of these parameters are measured simultaneously by the PM-3652 system. Analysis of the noise components of the measured quantities (noise components of signals) makes it possible not only to obtain short-term average values but also to determine the temporal (long-term) trends of such parameters. This makes it possible to monitor possible undesirable trends in parameters, which has special importance for diagnosis of reactor states.

Purpose of the System

Measured Quantities, Measurement Locations and Sensors

For noise diagnosis in an operating nuclear reactor, the following quantities are monitored:

a. The neutron flux density in the reactor core is measured by beta emission detectors;

b. the neutron flux density outside the reactor is measured by ionization chambers;

c. the coolant pressure at the reactor inlet and outlet and at selected locations in the primary circuit is measured by piezoelectric sensors;

d. vibration of the pressure vessel, the control assemblies and the main circulating pumps is measured by piezoelectric sensors.

Choice of measurement locations is based on calculations using mathematical models. The sensors are located where computations indicate that vibration problems are likely to be indicated most clearly.

Information Content of Neutron-Flux Density Signals

Of the measured quantities listed above, neutron noise gives the most extensive information. Almost all important processes in a nuclear reactor are reflected to some degree in the time trend of neutron-flux density. Thus, evaluation of these processes becomes possible through evaluation of neutron-flux density trends, using computations based on mathematical models derived from nuclear reactor theory.

The noise composition of the neutron-flux density signals is influenced by the following effects:

a. changes in reactivity produced by vibration of components inside the reactor or by coolant inhomogeneities;

b. changes in the neutron-flux density produced by coolant inhomogeneities or changes in the thickness of the water-filled space between the reactor barrel and the pressure vessel resulting from vibration of the reactor barrel; in this case we treat the core as a neutron source and the neutron detector is outside the reactor;

c. changes in the neutron-flux denisty outside the pressure vessel resulting from movement of the core as a whole or of its individual components; this involves changes in the position of the neutron source relative to the neutron detector located outside the reactor;

d. local disturbances in the neutron-flux density inside and outside the core resulting from effects operative in a particular location, e.g., inhomogeneity of the coolant, steam bubbles, local vibration.

Information Content of Pressure Signals

On the basis of previous experience, pressure pulse measurements can be used to infer the following effects (sources of pressure pulses):

a. pressure pulses produced by the main circulating pumps; the frequency of the pulses is governed by the rotary frequency of the main circulating pump vanes and by their higher harmonics;

b. pressure pulses resulting from changes in the hydraulic resistance of the inner fixtures of the reactor; these changes result from vibration of the components inside the reactor produced by coolant flow;

c. pressure pulses resulting from the geometry of the reactor cooling circuit;

d. pressure pulses resulting from turbulence in the coolant.

Information Content of Vibration Sensor Signals

The signals from the vibration sensors include mechanical movements of the components or connecting systems to which the sensors (accelerometers) are attached. However, the sensors can also detect vibrations originating far away from them.

In order to be able to sense the most important vibration problems, we locate the vibration sensors:

a. on the pressure vessel flange where the reactor barrel is suspended, making it possible to sense horizontal and vertical movements of the barrel;

b. at suitable locations on the pressure vessel wall, e.g., in the zone of the intake and outlet connectors, in order to sense their vibrations;

c. at selected locations in the primary circuit where maximum vibration may be expected, i.e., the main circulating pumps, the steam generators, and pumps in the primary circuit auxiliary systems.

There are various sources of mechanical vibration, such as the main circulating pumps, movement of the main shutoff valves, the control-assembly drives, and coolant flow.

The sensor placement described above gives us the following main capabilities:

1. monitoring the functioning of the main circulating pumps, the main shutoff valves and the control-assembly drives;

2. detecting the existence of loose parts in the primary coolant by evaluating tapping (impact) against the walls and structural components;

3. sensing and monitoring the mechanical vibrations of structural components (e.g., seizing of bearings and the like).

Measuring Apparatus

The measuring apparatus, a block diagram of which is given in Fig 1, consists of the following components:

a. a signal sensor (detector);

b. a preamplifier located near the sensor;

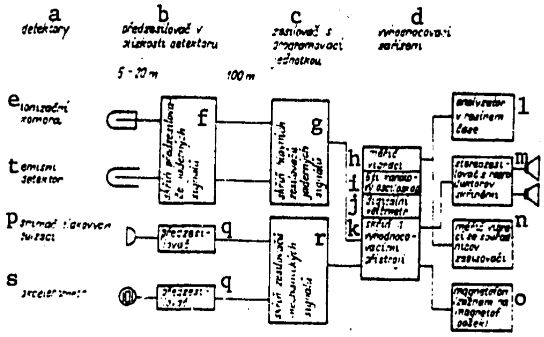
c. the connecting cable between the sensor and preamplifier;

d. the amplifier;

e. a programming unit;

f. evaluating equipment.

Fig 1. Block diagram of PM-3652 noise analysis system



Obr. 1. Blokové schéma systému šumové analýzy — PM 3652

Key:

a. Detectors
b. Preamplifier close to detector
c. Amplifier with programming unit
d. Evaluating equipment
e. Ionization chamber
f. Nuclear signal preamplifier box
g. Main nuclear signal amplifier box
h. Vibration meter
i. Six-channel oscilloscope
j. Digital voltmeter
k. Box containing evaluating equipment
l. Real-time analyzer
m. Stereo amplifier and speakers in housing
n. Vibration meter and coordinate plotter
o. Tape recorder (recording on magnetic tape)
p. Pressure pulse sensor
q. Preamplifier
r. Mechanical signal amplifier box
s. Accelerometer
t. Emission Detector

The main technical problem in noise analysis is separation of relatively low-level noise (0.01-2 percent) from the average values of the main signal. In the subsequent stage, the problem is amplification and transmission of the signal so that the desired signal stands out clearly against the background interference. These requirements are met by means of preamplifiers whose design allows a signal to be transmitted over a relatively large distance without losing its quality.

Sensors

Available information on the number and location of sensors varies. A survey of these data is given in Tables 1, 2 and 3, which show the numbers of individual types of sensors according to references 1, 2 and 4. Fig 2 has been developed according to the latest information [3, 4] supplemented with data from reference 5; it shows the measurement locations in the primary circuit. The five sensors located in the volume compensator [5] are, according to reference 4, a special arrangement which was used only during the startup period. Currently, the volume compensator at the Bruno Leuschner nuclear power station has no sensors (units 3 and 4), but it is planned to equip this important part of the primary circuit with some sensors in units 5 and 6. However, no specific data are available. The location of sensors in the reactor can be seen from Fig 3.

Table 1. Sensors and their locations (data from technical information on PM-3652 system [1]).

Sensor	Number	Location
Emission detectors	30	Core
KS-30/1 vibration sensors	1	Base of pressure vessel
	4	Plane of bottom of pressure vessel, spaced at 90°
	4	Plane below level of pressure vessel connections, spaced at 90°
	4	Plane of pressure vessel flange, spaced at 90°
	3	Main circulating pumps (one sensor per pump)
	2	Control-assembly drives
UDE-150e pressure pulse sensor	1	Pressure vessel: coolant intake
	1	Pressure vessel: coolant outlet
	2	Between main shutoff valve and main circulating pump

Table 2. Survey of sensors (data according to reference 2)

Sensors	
30	Self-powered neutron-flux detectors in groups of five in six channels inside the reactor vessel
10	Ionization chambers for measuring neutron flux, in groups of two with different sensitivities in five channels in the water jacket surrounding the reactor vessel. The high-sensitivity detector is used during startup and the low-sensitivity detector during power production
1	Piezoelectric vibration sensor on base of pressure vessel
4	Piezoelectric vibration sensors on surface of vessel below the core
4	Piezoelectric vibration sensors on surface of vessel above the core
4	Piezoelectric vibration sensors on surface of vessel between pipe connections
4	Piezoelectric vibration sensors on flange of vessel
2	Piezoelectric vibration sensors on control-assembly tubes
3	Piezoelectric vibration sensors on outlets of the three circulating pumps
2	Piezoelectric pressure fluctuation sensors on outlet piping of two circulating pumps
1	Piezoelectric pressure fluctuation sensor on vessel near one intake connection
1	Piezoelectric pressure fluctuation sensor on vessel near one outlet connection

Table 3. Survey of sensors used in units 3 and 4 of Bruno Leuschner nuclear power station (data according to reference 4)

Type of sensor	Number of sensors in:	
	One unit	Two units
Self-powered (emission) detectors	60	120
Ionization chambers	6	12
Pressure pulse sensors	8	16
Vibration sensors	52	104
Total number of sensors	126	252

Special attention must be devoted to transmission of signals from the sensors to the preamplifiers and to the design of the preamplifiers themselves. It must be assured that during signal transmission over a relatively long path there will be no undesirable attenuation or distortion resulting from interference in the signal path.

Emission Detectors

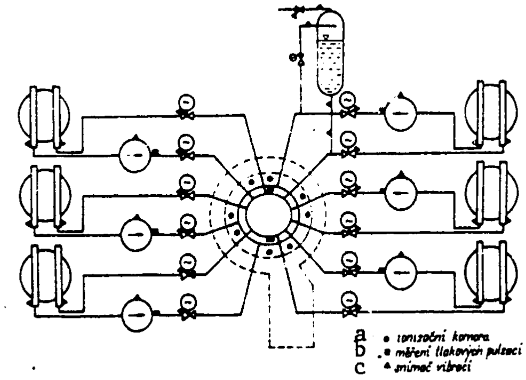
Neutron-flux density in the reactor is measured by beta-emission detectors. Rhodium detectors 200 mm long are located at 5 vertical levels, in guide tubes.

Detection of local changes in the neutron-flux density requires measurement at a relatively large number of points in the reactor core.

Fig 2. Measurement locations in primary circuit (for information purposes)

Key:

a. Ionization chamber
b. Pressure pulse measurement
c. Vibration sensor

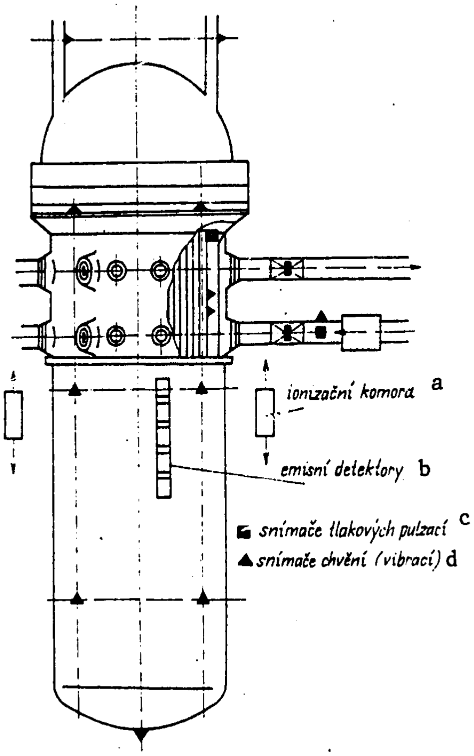


Obr. 2. Měřicí místa v primárním okruhu (informativní údaje)

Fig 3. Location of sensors on reactor

Key:

a. Ionization chamber
b. Emission detectors
c. Pressure pulse sensors
d. Vibration sensors



Obr. 3. Umístění snímačů na reaktoru

The instantaneous detector current value is used for noise analysis: the transfer factor for the noise signal is:

$$K_{\phi} = 3 \times 10^{-21} \text{ [amp-sec-cm}^2\text{/particle]}$$

The signal is fed from the detector to a preamplifier located close to it, and from there to the main amplifier.

Ionization Chamber

The neutron-flux density in the space around the reactor is measures by ionization chambers located in the biological shield. The ionization chambers are movable vertically along the core zone.

The transfer factors are:

$$K_{\phi} = 6 \times 10^{-15} \text{ [amp-sec-cm}^2\text{/particle] (power range);}$$

$$K_{\phi} = 10^{-12} \text{ [amp-sec-cm}^2\text{/particle] (startup).}$$

The signals from the ionization chambers are fed to preamplifiers located close to them and from there to the main amplifiers.

Vibration Sensors

Piezoelectric sensors capable of measurement in a range from 2 Hz to 10 kHz are used as vibration sensors. The transfer factor is:

$$Bq = 20 \text{ [pC/g]}$$

The signals from the vibration sensors are fed to preamplifiers located close to them.

Pressure-Pulse Sensors

Pressure pulses at the reactor intake and outlet and at various locations in the primary circuit are measured by pressure-pulse sensors.

The transmission factor is:

$$Bq = 350 \text{ [pC/MPa]}$$

With an average working pressure in the vicinity of 12 MPa, the sensors can register pressure pulses down to $\Delta p = 2$ kPa.

Preamplifiers

The preamplifiers increase the power level of the measured signal, thus allowing it to be transmitted over some distance; otherwise there would be undesirable attenuation and distortion. The preamplifiers must be located as close as possible to the sensors or detectors, i.e., within 5 to 20 meters.

Preamplifiers for Nuclear Signals

The preamplifiers (current amplifiers) for the measurement signals of emission detectors and ionization chambers are located, along with the power supplies for the emission detector channels, in the preamplifier box, close to the reactor. The signal input and output leads are joined to the box by connectors so that the box can be disconnected when working with the reactor.

Vibration and Pressure-Pulse Signal Preamplifiers

These are symmetrical discharge amplifiers whose transfer factors are so chosen that the output signal for vibration (acceleration) is 100 $mV/m/sec^2$ = 1 V/g; for the pressure-pulse sensor output signal it is 2 V/MPa.

Main Amplifiers

The main amplifier unit consists of two boxes containing not only the amplifiers themselves, but modular components for power supply, signal labeling, signal division (splitting the signal into short-term average values and noise components, amplification of noise components to a common level) and channel selection. All modular components and functional groups, inserted units, chassis and boxes are standardized. This design allows effective use of spare parts and rapid repair.

Main Nuclear Signal Amplifier Box

This box contains modular components of the main and dividing amplifiers for processing the signals from the emission detectors, with two limiting value signals (positive and negative limiting values) and modular signal labeling components.

The group of channels carrying emission-detector signals from the preamplifiers which is chosen for evaluation may be selected manually. The signals from the ionization chambers are amplified and monitored for values in excess of the limits. Compensating and integrating amplifiers allow further processing of the ionization chamber signals. An adjustable integrating amplifier is used to integrate the signals from several ionization chambers when the reactor is at low power and to determine average values of location-dependent effects.

The compensating amplifier allows precise measurement of deviations in the average values of the ionization chamber signals; these are used to determine the effectiveness of the control assemblies as a function of their position.

Main Mechanical Signal Amplifier Box

The main amplifier box contains amplifiers equipped with signals indicating that limiting values have been exceeded; these amplifiers are used to process signals from vibration and pressure-pulse sensors, which can be tapped with earphones or loudspeakers. In addition, the box contains modular signal labeling and power supply components.

Evaluation Equipment

The PM-3652.13 evaluation equipment consists of the following devices:

a. a six-channel oscilloscope;

b. a digital voltmeter;

c. a universal device for vibration measurement consisting of an oscilloscope, an indicator, a narrow-band analyzer, a control unit for processing the signal and a graph plotter;

d. a measurement point selector;

e. an output panel for a computer;

f. an output for a magnetic tape recorder;

g. a signal labeling unit.

Technical Data

Dimensions of box (meters):

preamplifier box 0.6 x 2.1 x 0.6;

main amplifier box 0.8 x 2.0 x 0.6;

evaluation equipment box 0.8 x 2.0 x 0.6.

Sensors, Preamplifiers and Amplifiers

A survey of the transfer factors and output signals of preamplifiers and amplifiers for various types of sensors is given in Table 4.

The OPD 280 U Six-channel Oscilloscope

This is a slow-speed oscilloscope:

sensitivity	0.5 V/cm
input impedance	5 megohms
input frequency	0-10 kHz
screen diagonal	280 mm.

The Q-1206.010 DC Digital Voltmeter

Measurement range	1 microvolt-1 kV (six ranges)
Maximum sensitivity	1 digit per microvolt

Table 4.

Tab. 4

Měřená veličina 1	Typ snímače 2	Snímač Přenosový faktor Rozsah frekvencí 3	4 Předzesilovač		Zesilovač 7	
			přenosový faktor 5	výstupní signál 6	přenosový faktor 5	výstupní signál 6
zrychlení 10	KS 30 1	Bq = 20 pC/g 2 Hz ... 10 kHz	50 mV/pC	1 V/g	V = 316 V = 100 V = 31,6 V = 10 V = 3,16 V = 1	316 V/g 100 V/g 31,6 V/g 10 V/g 3,16 V/g 1 V/g
tlak 11	QDE 150e	Bp = 350 pC/MPa 0,1 Hz ... 10 kHz	5,7 mV/pC	2 V/MPa	V = 316 V = 100 V = 31,6 V = 10 V = 3,16 V = 1	632 V/MPa 200 V/MPa 6,3 V/MPa 2 V/MPa 0,63 V/MPa 0,2 V/MPa
hustota toku neutronů (in-core) 12	beta-emisní detektor 13	$K_\Phi = 3.10^{-18} \frac{Ascm^2}{částice}$ 14	10 V/µA 3,3 V/µA 1 V/µA	$3.10^{-11} \frac{Vscm^2}{částice}$ 15 $10^{-11} \frac{Vscm^2}{částice}$ $3.10^{-12} \frac{Vscm^2}{částice}$	V = 100	$3.10^{-11} \frac{Vscm^2}{částice}$ $10^{-11} \frac{Vscm^2}{částice}$ $3.10^{-12} \frac{Vscm^2}{částice}$ 15
hustota toku neutronů (out-core) 16	ionizační komora KNK 57 M 17	$K_\Phi = 6.10^{-15} \frac{Ascm^2}{částice}$ 14	10 V/µA 1 V/µA 0,1 V/µA 0,01 V/µA	$6.15^{-8} \frac{Vscm^2}{částice}$ 15 $6.10^{-9} \frac{Vscm^2}{částice}$ $6.10^{-10} \frac{Vscm^2}{částice}$ $6.10^{-11} \frac{Vscm^2}{částice}$	V = 316 V = 100 V = 31,6 V = 10 V = 3,16 V = 1	$18{,}9.10^{-6} \frac{Vscm^2}{částice}$ $6.10^{-11} \frac{Vscm^2}{částice}$ 15
hustota toku neutronů (out-core) 16	ionizační komora KNK 56 17	$K_\Phi = 10^{-12} \frac{Ascm^2}{částice}$ 14	10 V/µA 1 V/µA 0,1 V/µA 0,01 V/µA	$10^{-5} \frac{Vscm^2}{částice}$ 15 $10^{-6} \frac{Vscm^2}{částice}$ $10^{-7} \frac{Vscm^2}{částice}$ $10^{-8} \frac{Vscm^2}{částice}$	V = 316 V = 100 V = 31,6 V = 10 V = 3,16 V = 1	$3.16.10^{-8} \frac{Vscm^2}{částice}$ $10^{-8} \frac{Vscm^2}{částice}$ 15

Key:

1. Measured quantity
2. Type of sensor
3. Sensor, transfer factor, frequency range
4. Preamplifier
5. Transfer factor
6. Output signal
7. Amplifier
8. Transfer factor
9. Output signal
10. Acceleration
11. Pressure
12. Neutron-flux density (in-core)
13. Beta-emission detector
14. Amp-sec-cm^2/particle
15. Volt-sec-cm^2/particle
16. Neutron-flux density (out-core)
17. Ionization chamber

Vibration-Measuring Instrument

Section powered from electrical

System (11031)	220V/110V
External source--battery	12 V

11 163 Narrow-Band Analyzer

Frequency range	0.2 Hz-20 kHz
Relative bandwidth	3%, 10%, 30%

11 018 High-Pass Filter

Limiting frequency	16-500 Hz (switchable by half octaves)

11 025 Indicator Unit

Indicator	Effective, positive and negative peak (maximum) value
Frequency range	1 Hz-15 kHz

11 028 Oscilloscope

Frequency Range	2 Hz-15 kHz
Time base speed	300-0.03 msec/cm (tangential)
X: horizontal sensitivity	20 mm/volt
Y: vertical sensitivity	8.5 or 22-75 mm/volt

Real-Time Analyzer (External Device)

Frequency range	20 Hz-20 kHz
Measurement capability	Instantaneous, peak (maximum) value
Filter and broadband channels	30 channels by thirds of an octave 5 broadband channels
Input resistance	100 kohm

Location of Devices

The spatial arrangement and location of the sensors and preamplifiers is described in the section on measuring apparatus and in Tables 1, 2 and 3. For servicing reasons, it is recommended that the amplifier boxes and evaluating equipment boxes be located close to the computer used for signal analysis.

Survey of Instruments Included in Noise-Analysis System

Name	Type
Sensors	
Vibration sensor	KS 30/1
Pressure pulse sensor	QDE-150e
Emission detector (ED)	
Ionization chamber (IK)	
Connector cable	5700/20

PM 3652.10 Nuclear Signal Preamplifier Box

Emission-detector signal amplifier	4386-110
Ionization chamber signal preamplifier	4386-120
SR-13 stabilizer	4882-13
Transformer	T 1388
Section powered by electrical system	3301-24
Plug-in unit with blower	
Power system connection panel	
Lamp and fuse panel	
Connector panel	

4386-335 Mechanical Signal Preamplifier

Preamplifier connecting block

PM-3652.11 Nuclear Signal Main Amplifier Box

Main emission-detector signal amplifier	4386-210
Compensating amplifier	4386-221
Compensating amplifier	4386-222
Integrating amplifier	4386-219
Separating amplifier: ED and signaling labeling	4386-211
Separating amplifier: IK and IK channels	4386-225
Main amplifier of IK signal	4386-330
Relay unit	4386-48401
Signal labeling unit switch	4386-215
Signal labeling unit matrix C	4386-485
Modular power supply	3204/15
Modular power supply	3307/15
Power system connection panel	
Power supply control unit	
Program panel (manual program selector)	
Output signal panel	
Ionization chamber power supply	4486-50

PM 3652.12 Mechanical Signal Amplifier Box

Main mechanical signal amplifier	4386-330
Signal labeling switch	4386-215B
Signal labeling unit matrix C	4386-485L
Amplifier for earphone	4832-03A
Modular power supply	4882-33
Modular power supply	4837-20
Modular power supply	4387-31
Switch panel (monitoring)	
Output signal panel	
Rectifier and filter unit	
Transformer	
Power supply cable panel	
Programming unit	4386-340

PA 3652.13 Evaluating Instrumentation Box

Six-channel oscilloscope	OPD 280/U
Digital voltmeter	G 1206.010
Vibration meter	
Box	110 12 (BG 401)
Power system section	11031 (SM 61)
Oscilloscope	11028 (SM 50)
Indicator unit	11025 (SM 40)
Narrow-band analyzer	11163 (SM 32)
Control unit	PM 3310 (SM 71)
High-pass filter	11018 (SM 23)
Signal labeling unit	
Measuring location selector	
Panel for output to computer	
Panel for output to recording device	
Panel for connection to power system	
Modular power supply (5V/6A)	
Modular power supply	3307/15

Evaluating Instruments

Real-time analyzer	01012
Stereo amplifier	HSV 921
Speaker box	B9301

Note: The technical design of the system allows an increase in the number of measuring locations.

System Capabilities

The noise-measurement analysis system has the following features and capabilities:

1. It has multiple uses in nuclear engineering and the chemical and metallurgical industries.

2. It allows monitoring of the operating condition of equipment which is not equipped with measuring and regulating systems.

3. It gives timely signals of changes in an operating process or the occurrence of damage to machinery and equipment. It can be used to evaluate the probable cause of damage, and thus makes it possible to prevent breakdowns and emergency conditions in process equipment.

4. It provides data for planning of inspections and repairs, and can be used to plan the necessary scope of work during planned equipment stoppages. This raises equipment maintenance to a qualitatively higher level.

5. Equipment repairs can be limited and the interchange system can be used for smaller radioactive components.

6. It allows the detection and location of loose parts. This prevents major damage to equipment, excess shutdowns of the power station and the resulting loss in power produced.

7. It processes and evaluates signals from vibration, pressure, temperature and neutran-flux density sensors, and can conduct frequency and time analysis of the measured values.

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CZECHOSLOVAKIA

DIRECT CONVERSION OF NUCLEAR ENERGY TO ELECTRICITY DISCUSSED

Prague ENERGETIKA in Czech No 9, 1981 pp 393-399

[Article by Eng Jiri Racek, Electrical Engineering Faculty, VUT [Technical Institute], Brno: "Methods of Direct Conversion of Nuclear Energy to Electrical Energy"]

[Text] Types of Direct Conversion of Energy to Electricity

The main sources of energy for the production of electricity can be divided into the following groups:

--the energy of solar radiation;

--chemical energy;

--hydraulic energy;

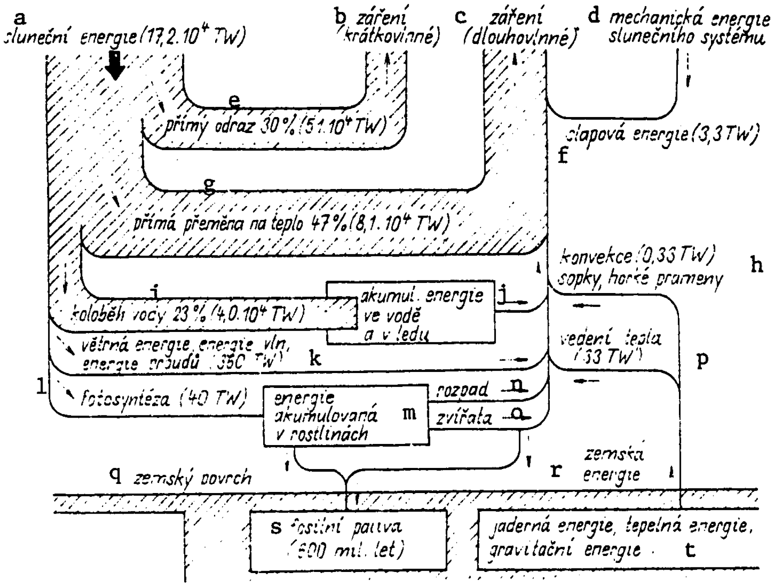
--geothermal energy;

--nuclear energy.

The energy of solar photons heats and illuminates the earth and is converted into the kinetic energy of marine currents, wind in the atmosphere and waves on water surfaces, into the gravitational potential energy of clouds and streams of water, and into the energy accumulated in plants. We may consider chemical energy (particularly fossil fuels) as solar energy accumulated in the depths of the earth in the course of its geological development. In the broad sense, then, we may include all of these energy sources in the category of solar energy.

The natural flow of geothermal energy is fed by two sources, namely heat accumulated in the depths of the earth and heat newly created within the earth, primarily by natural radioactive processes. In practice, it is frequently difficult to distinguish between use of the natural flow of geothermal energy and use of the stored heat.

The energy balance is shown in more detail in Fig 1.



Obr. 1. Schéma energetické bilance Země

Fig 1. Energy balance of the earth.

Key:

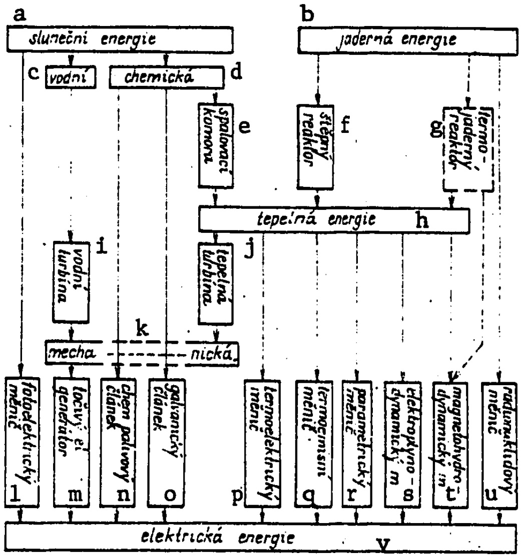
a. Solar energy
b. Radiation (short wave)
c. Radiation (long wave)
d. Mechanical energy of the solar system
e. Direct reflection
f. Hydraulic energy
g. Direct conversion to heat
h. Convection: volcanoes, hot springs
i. Circulation of water
j. Accumulated energy in water and ice
k. Wind energy, wave energy, energy of currents
l. Photosynthesis
m. Energy accumulated in plants
n. Decay
o. Animals
p. Conduction of heat
q. Surface of the earth
r. Energy of the earth
s. Fossil fuel (600 million years)
t. Nuclear energy, thermal energy, gravitational energy

There are various ways of producing electrical energy from the sources described above. At the end of the 1950's there was a surge of interest throughout the world in direct conversion of energy into electricity. The term "direct conversion" began to be applied to methods of obtaining electrical energy which did without moving components such as turbines. A systematic survey of the main energy conversion methods is given in Fig 2.

Fig 2. Survey of the main methods of conversion of various forms of energy to electricity.

Key:

a. Solar energy
b. Nuclear energy
c. Water power
d. Chemical energy
e. Combustion chambers
f. Fission reactor
g. Thermonuclear reactor
h. Thermal energy
i. Hydraulic turbine
j. Heat turbine
k. Mechanical energy
l. Photoelectric converter
m. Rotary electrical generator
n. Chemical fuel cell
o. Galvanic cell
p. Thermoelectric converter
q. Thermionic converter
r. Parametric converter
s. Electrohydrodynamic converter
t. Magnetohydrodynamic converter
u. Radionuclide converter
v. Electrical energy



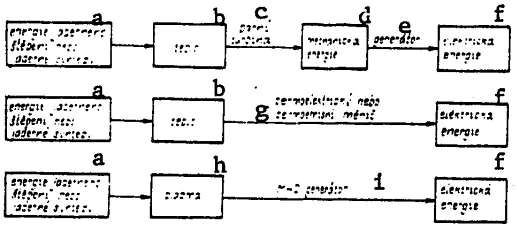
Obr. 2. Přehled hlavních způsobů přeměn různých forem energie na energii elektrickou

Among the forms of direct conversion of energy to electricity, solar energy is used as the source primarily in solar batteries and chemical fuel cells. Almost all other methods of conversion of energy to electricity use nuclear energy as the source. Some methods of producing electrical energy from the energy of nuclear fission or fusion are shown schematically in Fig 3.

Fig 3. Processes for producing electrical energy from the energy of nuclear fission or fusion.

Key:

a. Energy of nuclear fission or fusion
b. Heat
c. Steam turbine
d. Mechanical energy
e. Generator
f. Electrical energy
g. Thermoelectric or thermionic converter
h. Plasma
i. MHD generator



Obr. 3. Posloupnosti procesů při výrobě elektrické energie získané z energie jaderného štěpení nebo energie jaderné syntézy

Of the methods for direct conversion of energy to electricity which have been described, magnetohydrodynamic (MHD) and thermionic conversion are considered the most suitable for large-scale power production in the near future.

Magnetohydrodynamic Conversion of Energy

The operation of MHD generators is based on the same principle as that of inductive generators, with the essential difference that in the MHD generator it is an electrically conductive fluid (plasma or liquid metal), instead of a solid conductor, which moves in the magnetic field.

A simplified diagram of an MHD generator is given in Fig 4. The electrically conductive material flows through a channel in the form of an expansion nozzle of rectangular or square cross section. Two opposite walls parallel to the magnetic field B are electrically conductive and form the electrode system; the other two walls are nonconductive. The active part of the MHD generator (in which the electrodes are located) is in a magnetic field, with the pole pieces of the magnet located above and below the nonconductive walls.

Electrical energy is obtained from the MHD generator by converting some kinetic energy and some potential energy. The transfer of energy from the flow of working medium to the external load circuit results from a complex process of interactions between electrically charged particles and the external magnetic field and between charged and neutral particles.

The current density of a flowing gas moving with a velocity $\vec{v}$ in a magnetic field of flux density $\vec{B}$ is

$$j = (\vec{E} + \vec{V}\vec{X}),$$

where $\vec{E}$ is the electric field intensity under universal external load resistance and σ is the conductivity of the working gas. Because the electric field intensity during free passage is $\vec{E}_0 = -\vec{v}\vec{X}$, we can use the load factor K, defined as the ratio of the electric field intensity under load to the intensity in free passage, i.e.,

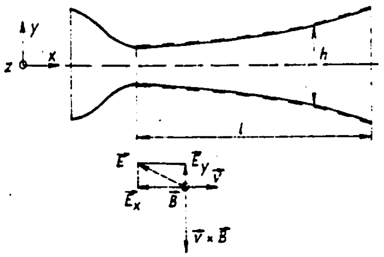
$$K = \frac{E}{E_0} = \frac{P}{P + \frac{j^2}{\sigma}}$$

to express the specific electric power of the MHD generator, provided that the vectors of velocity $\vec{v}$, magnetic flux density $\vec{B}$ and electric field intensity $\vec{E}$ are mutually perpendicular:

$$P = \sigma v^2 B^2 (1-K) K.$$

For given values of σ, v and B, the power output is at a maximum at $K = 0.5$. If the magnetic flux density is greater than about 1.5-2 T, the Hall effect begins to become important, and instead of a Faraday-type MHD generator we have a Hall-type generator.

Fig 4. Arrangement of a Faraday-type MHD generator and directions of the principal vectors.



Obr. 4. Schematické uspořádání magnetohydrodynamického generátoru Faradayova typu a směry hlavních vektorů

As can be seen from the last equation given, the electrical conductivity of the working substance is an extremely important quantity. An inert gas is electrically conductive only if it is at least partially ionized. Accordingly, it is heated to a high temperature, 2000-3000° K, at which a low-temperature plasma is produced. In order to increase the electrical conductivity, a certain quantity of an easily-ionized alkali metal such as potassium or cesium (ionization potential of Cs $\sim$ 3.89 V, of K $\sim$ 4.34 V) is added to the plasma. Even in this case, the electrical conductivity of the low-temperature plasma is rather low, on the order of 10 S/m. In order to make σv^2 reach the required value, the working medium must be accelerated to high speeds, on the order of 1,000 m/sec. This is generally done in a nozzle.

The electrical conductivity of liquid metals is high, on the order of 10^6 S/m^{-1}, and accordingly it is unnecessary to accelerate them to high speeds. They are accelerated in an injector by a current of their own vapor, with which the liquid metal mixes, producing a two-phase mixture. The liquid phase is the magnetohydrodynamic working medium and also the energy source, while the vapor phase is the thermodynamic working medium during injection.

The working medium may flow in an open or closed cycle.

In the open cycle, the working medium flows from the heat source, (combustion chamber) through the MHD channel, the steam generator and the separator, to the atmosphere. In this case the working medium is the gas produced by combustion, with an ionizing additive.

Closed cycles, in which the working fluid moves in a closed circuit, can be divided into:

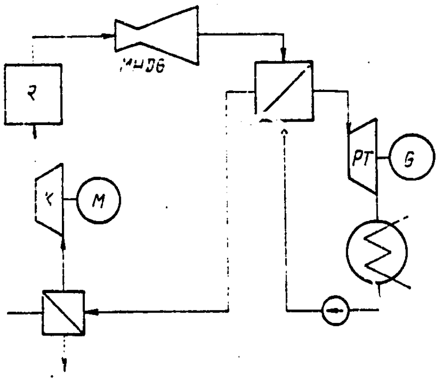
--cycles using plasma (inert gas), in which the heat source may be, for example, a high-temperature nuclear reactor (Figs 5 and 6) or a controlled thermonuclear reactor; combustion of fossil fuels may also be used, with the heat being transferred to the working medium in a neat exchanger;

--the liquid metal cycle, in which the heat source may be a breeder reactor (Fig 7), a high-temperature gas-cooled reactor, a coal-burning fluidized bed and the like.

Fig 5. Closed circuit MHD system with high-temperature reactor and steam turbine

Key:

R.	high-temperature reactor
MHDG.	magnetohydrodynamic genator,
PT.	steam turbine,
G.	generator,
K.	compressor,
M.	motor.



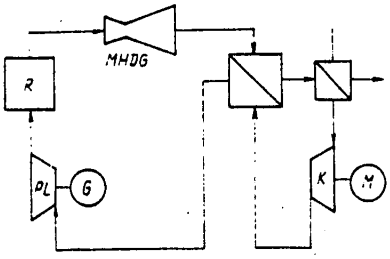
Obr. 5. Magnetohydrodynamický uzavřený oběh s vysokoteplotním reaktorem a s parní turbínou

R - vysokoteplotní reaktor; *MHDG* - magnetohydrodynamický generátor *PT* - parní turbina; *G* - generátor; *K* - kompresor; *M* - motor

Fig 6. Closed circuit MHD system with high-temperature reactor and gas turbine

Key:

R.	high-temperature reactor
MHDG.	magnetohydrodynamic generator,
PL.	gas turbine,
G.	generator
K.	compressor,
M.	motor.



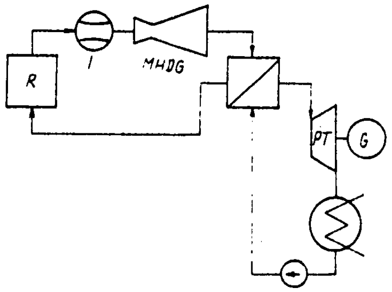
Obr. 6. Magnetohydrodynamický uzavřený oběh s vysokoteplotním reaktorem a s plynovou turbínou

R - vysokoteplotní reaktor; *MHDG* - magnetohydrodynamický generátor; *PL* - plynová turbina; *G* - generátor; *K* - kompresor; *M* - motor

Fig 7. Closed-circuit magnetohydrodynamic system with sodium-boiling water reactor, injector and steam turbine

Key:

R.	sodium-boiling water reactor (may be replaced by heat exchange connected to high-temperature reactor
I.	injector
MHDG.	magnetohydrodynamic generator
PT.	steam turbine
G.	generator



Obr. 7. Magnetohydrodynamický uzavřený oběh se sodíkovým varným reaktorem, s injektorem a s parní turbínou

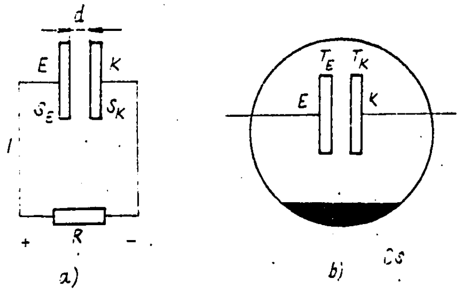
R - sodíkový varný reaktor (může být nahrazen výměníkem tepla připojeným na vysokoteplotní reaktor); *I* - injektor; *MHDG* - magnetohydrodynamický generátor; *PT* - parní turbina; *G* - generátor

In the case of nuclear heat sources, where for safety reasons only the closed cycle can be used, the situation is more complex than for nonnuclear open-cycle sources. When we consider these possibilities we find considerable discrepancies in the required working parameters, i.e., temperature and pressure, for the nuclear reactor and the MHD generator, which must be taken into account in the design process.

Thermionic Energy Conversion

Thermionic energy conversion makes use of thermionic emission of electrons from the surface of a heated metal. The basic structure of a thermionic converter (TEM) consists of a set of two electrodes, an emitter E and a collector K. The linear dimensions S_E and S_K of their surfaces (generally $S_E = S_K$) are much greater than the distance d between the electrodes. A schematic diagram of a TEM is given in Fig 8.

Fig 8. Thermionic converter: a, with load circuit; b, cesium diode.



Obr. 8. Schéma termoemisního měniče
a) se zatěžovacím obvodem, b) cesiová dioda

In terms of the nature of the space between the electrodes we distinguish vacuum converters and gas-filled converters. The purpose of the gas atmosphere is to facilitate ionization in the interelectrode space, thus decreasing losses in the passage of electric current between the emitter and collector; the atmosphere generally used is cesium vapor, which is the easiest to ionize.

This electrode system is analogous to the design of vacuum or gas-filled diode tubes, whose cathode and anode correspond to the emitter and collector of the TEM. Like the cathode of the diode tube, the emitter of the TEM is at a high temperature, producing an electrical current by thermal emission of electrons.

A thermionic converter containing cesium vapor is generally called a "cesium diode"; a diagram is given in Fig 8. It consists of a closed bulb containing electrodes E and K, at whose coldest point is a container of liquid cesium; the temperature T_{Cs} of the cesium uniquely determines the (saturated) cesium vapor pressure p_{Cs}.

The emitter temperature ranges from 1,500° to 2,200° K, and the collector temperature may be as high as 1,000° K. To achieve a low-voltage arc discharge requires a high cesium vapor pressure ($p_{Cs} \approx 0.13-1.30$ kPa), which corresponds to a temperature $T_{Cs} \approx 550-650°$ K. The distance d is generally 0.2-0.3 mm.

The high operating temperature imposes extraordinary requirements regarding the material and insulation of the electrodes. Accordingly, such refractory metals as Mo, Nb, W and Re are used for the electrodes.

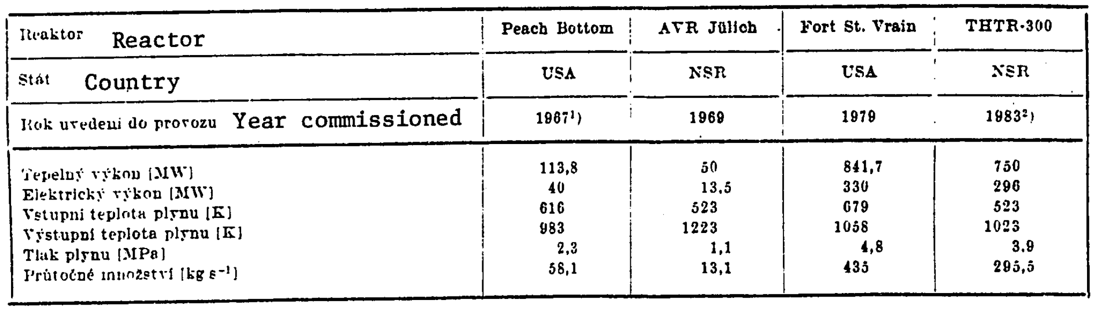
Nuclear Sources Under Consideration for Direct Conversion of Energy

A high-temperature gas-cooled reactor (HTGR) is a graphite-moderated helium-cooled reactor. The high temperature of the coolant exiting from the reactor is of interest not only for direct use in manufacturing processes or for combination of the high-temperature reactor in a direct cycle with a gas turbine, but also in terms of the possibility of using the HTGR as a heat source is closed-cycle magnetohydrodynamic systems (figs 5 and 6).

Basically there are two types of HTGR: a reactor with hexagonal fuel elements and one with spherical fuel elements. Electrical power stations with capacities of 300 MW of each type are in operation or under construction (Table 1).

Table 1. Main parameters of operating and under-consturction nuclear power stations with high-temperature gas-cooled reactors.

Tab. 1. Hlavní parametry provozovaných a budovaných jaderných elektráren s vysokoteplotními plynem chlazenými reaktory



Reaktor Reactor	Peach Bottom	AVR Jülich	Fort St. Vrain	THTR-300
Stát Country	USA	NSR	USA	NSR
Rok uvedení do provozu Year commissioned	1967¹)	1969	1979	1983²)
a Tepelný výkon [MW]	113,8	50	841,7	750
b Elektrický výkon [MW]	40	13,5	330	296
c Vstupní teplota plynu [K]	616	523	679	523
d Výstupní teplota plynu [K]	983	1223	1058	1023
e Tlak plynu [MPa]	2,3	1,1	4,8	3,9
f Průtočné množství [kg s⁻¹]	58,1	13,1	435	295,5

¹) demontován v roce 1974

²) plánované zahájení komerčního provozu

Key:

a. Heat output (MW)
b. Electrical output (MW)
c. Intake gas temperature (°K)
d. Outlet gas temperature (°K)
e. Gas pressure (MPa)
f. Mass flow (kg/sec)
g. West Germany
1) Disassembled in 1974
2) Planned beginning of commercial operation

The temperature of the gas in a high-temperature gas-cooled reactor is limited by specific requirements imposed by the nuclear fuel.

Development of this type of reactor has proceeded the farthest in the United States and West Germany. The prototype reactor of the Peach Bottom nuclear power station (United States), with an output of 40 MW, was extremely successful from the beginning of commercial operation in 1967 until planned disassembly in 1974.

The overall operating characteristics of the Peach Bottom HTGR were particularly satisfactory in terms of fuel and of power plant requirements. There were no major equipment malfunctions. In addition, there was excellent agreement between calculated and actual core characteristics, which confirmed the methods used and provided a reference data base for use in large power stations with HTGR's.

In 1979, commercial operation of a 330 MWe nuclear power station with an HTGR reactor was begun in Fort St. Vrain (United States). A number of difficulties were experienced during startup, but they were not in essence caused by an erroneous design concept, so that it may be expected that the advantage of this type resulting from the high outlet temperature of the helium will make itself felt with time. The Fort St. Vrain station is planned as a demonstration unit for systems and components of the type, to be used in power stations with large HTGR's.

The AVR prototype high-temperature reactor in Julich (FRG), with a capacity of 13.5 MW, has been in operation since 1969. The spherical bed concept is attractive because it is suitable for high temperatures. This prototype reactor achieves an output temperature of 950° C, while in the present state of development the output temperature of a prismatic-core design is fully 100° lower. This reactor is expected to be in operation until at least 1983. A power-station version with a capacity of 300 MW is being built at Schmehausen.

Operating experience with HTGR reactors at high temperatures is now being acquired. Experience with a 330 MW unit and experience in constructing power stations with advanced gas-cooled reactors (AGR) indicate the difficulty involved in achieving the intended objectives. The advantages of the high output-gas temperature do not particularly manifest themselves in increased steam parameters, but are the basis for the high efficiency of a cycle including a gas turbine and MHD generator.

The concept of a gas-cooled fast-breeder reactor (GFBR) uses the core of a helium-cooled fast-breeder reactor to achieve a high reproduction coefficient in a gas-cooled system. The operating pressure in the primary circuit will be about 9 MPa, allowing a rather high power output per unit volume.

Gas-cooled breeder reactors have been under consideration for many years, but the combination of high pressure and high output per unit volume has posed difficult safety problems. These problems have been satisfactorily solved by development of a reactor pressure vessel made of prestressed concrete.

The development of gas-cooled fast-breeder reactors makes considerable use of experience from the operation and development of gas-cooled thermal reactors. Some aspects can be taken over directly into gas-cooled breeder reactors (for example, construction preparation and design approaches, quality assurance techniques and research and development methods). Information on helium technology will be derived from the high-temperature reactor programs and from operating experience with these reactors. The fuel for the GFBR is similar to that of sodium-cooled fast breeder reactors.

Development of a GFBR with a capacity of 300 MW has been proceeding in the Soviet Union. Prototype GFBR's with capacities of 600 MW are being proposed in Western Europe and the United States.

With regard to the safety of GFBR reactors, it is generally agreed that they may be treated in exactly the same manner as gas-cooled thermal reactors. The main difference is the high power output per unit volume of the GFBR core and the requirement for removal of excess heat.

However, solution of the overall problem of gas-cooled fast breeder reactors is lagging rather far behind work on liquid-metal-cooled breaders.

It is also necessary to say a few words about the matching of reactors to MHD generators. To cut investment expenditures on gas-cooled reactors it is necessary to achieve the highest possible power density, which requires a high coolant pressure. In MHD generators, on the other hand, a lower operating temperature increases the electrical conductivity and thus the possibility of obtaining high generator output. Ultimate optimization of this equipment will depend on the relative expenses of the two main components, i.e., the reactor and the MHD generator.

Liquid-metal-cooled fast-breeder reactors (LMFBR) are also under consideration as sources of heat for liquid-metal MHD systems. The operating temperatures would range from 950° to 1,300° K, only slightly higher than the operating temperatures planned for breeder reactors of this type. Fig 7 is a diagram of an MHD generator with an LMFBR reactor.

Initial ideas of the time required to develop commercial models of power-producing breeder reactors have been considerably altered as a result of the extraordinary technical demands involved.

The Soviet Union, France, the United Kingdom, West Germany, Japan and the United States currently are in the forefront of fast-breeder reactor development. Small nuclear power stations with experimental prototype breeder reactors having capacities of 20 to 40 MW have been in operation for more than 15 years in these countries. Experience obtained in the operation of the first generation of experimental fast-breeder reactors is being used as a basis for design and construction of nuclear power stations with second-generation fast-breeder reactors having capacities in the vicinity of 250 MW. Three prototype power stations with such reactors have already been in operation for several years, while a fourth was put into operation in April 1980 (Table 2).

The Soviet BN-350 prototype fast-breeder reactor (Shevchenko) was first connected to the power grid in 1973. It has a capacity of 135 MW and in addition produces 5,000 tons of desalinated water an hour. Operation of the reactor to date has provided valuable operating experience, including experience with repair procedures involving disconnection of the main sodium piping and cleaning the products of reaction between sodium and water or air from the steam generators and circuits. Experience has indicated the possibility of constructing commercial nuclear power stations with such fast-breeder reactors.

The French Phenix prototype reactor (Marcoule) has been in operation since 1974. Technical data obtained during startup, operation and refueling have confirmed the design assumptions.

The British PFR prototype reactor (Dounrey), went critical in 1974, and first provided electricity for the power grid in 1975. The behavior of the core, which uses a PuO_2-UO_2 mixed oxide fuel, and of the equipment and the primary and secondary sodium circuits were in accordance with design calculations.

Table 2. Main parameters of prototype and demonstration nuclear power stations with liquid-metal-cooled fast-breeder reactors.

Tab. 2. Hlavní parametry prototypových a demonstračních jaderných elektráren s rychlými reaktory chlazenými tekutým kovem

Reaktor Reactor	BN-350	Phénix	PFR	BN-600
Stát Country	SSSR b	Francie a	Velká Británie	SSSR b
Rok uvedení do provozu Year commissioned	1973	1974	1977	1980
c Tepelný výkon [MW]	1000	590	600	1470
d Elektrický výkon [MW]	350[1])	250	230	600
e Teplota sodíku na výstupu z reaktoru [°C]	500	563	562	550
f Teplota páry [°C]	435	516	538	505
g Tlak páry [MPa]	5,0	16,3	16,2	14,0
h Vsázka [t]	1,05 (U—235)	4,3	4,1	1,26 (U—235)
i Vyhoření [TJ kg^{-1}]	4,0	6,5	5,3	7,0
j Druh reaktoru	smyčkový k	bazénový 1	bazénový 1	bazénový 1

[1]) 135 MW a 5000 tun odsolené vody za hodinu

Key:

a. France
b. USSR
c. Heat power (MW)
d. Electric power (MW)
e. Temperature of sodium at exit from reactor, °C
f. Steam temperature, °C
g. Steam pressure (MPa)
h. Charge (tons)
i. Burnup (TJ/kg)
j. Type of reactor
k. Loop type
l. Pool type
1) 135 MW and 5,000 tons of desalinated water per hour

Each of these three operating prototype LMFBR's (BN-350, Phenix, PFR) has encountered the well-known problems of lack of tightness in the steam generators and intermediate heat exchangers, but the reactors themselves have worked exceptionally well. All three have achieved record availability coefficients of 80-90 percent over the long term, and their operators say that the stations are easy to control. Each of the three stations has clearly shown its capability for safe operation at two-thirds power while repairs are being made on one of the three circuits. Another common feature of the three stations is the extremely low radiation doses received by operating personnel. Currently, radioactive leakage is almost too low to measure.

A fourth nuclear power station with such a fast-breeder reactor was put into operation at Beloyarsk in 1980. The BN-600 reactor had higher operating characteristics, i.e., sodium temperature, steam parameters, heat output, burnup, and length of time between refueling operations, than the BN-350, and also differed from the latter by its integral (pool type) primary circuit design (like the Phenix and PFR reactors). This made it possible to demonstrate even more thoroughly the advantages or shortcomings of integral design compared with loop design.

Currently, two more nuclear power stations with fast-breeder reactors are under construction, namely Super phenix (France; output 1,200 MW) and the SNR (West Germany; 280 MW). The construction of others is planned in the United Kingdom (CDFR; 1,250 MW), Japan (MONJU; 250 MW), West Germany (SNR-2; 1,300 MW), the Soviet Union

(BN-1600; 1,600 MW) and the United States (CRBR; 350 MW). The main characteristics of the planned first commercial fast-breeder reactors is shown in Table 3.

Table 3. Main characteristics of demonstration nuclear power stations with large fast-breeder reactors.

Tab. 3. Hlavní charakteristiky demonstračních jaderných elektráren s velkými rychlými množivými reaktory

Reaktor Reactor	Super Phénix	CDFR	SNR-2	BN-1600	Projekt USA
Stát Country	Francie a	Velká Británie b	NSR c	SSSR d	USA
e Tepelný výkon [MW]	3000	3230	—	4000	3800
f Elektrický výkon [MW]	1200	1250	1300	1600	1500
g Teplota sodíku na výstupu z aktivní zóny [°C]	542	540	550	530—550	535—565
h Teplota páry [°C]	490	486	500	490—510	480—510
i Tlak páry [MPa]	18,0	16,0	16,5	14,0	15,0
j Vyhoření [TJ kg⁻¹]	8,6	8,6	9,9	7,0	8,6—13,0
k Uspořádání	integrální l	integrální l	smyčkové m	integrální l	smyčkové m

Key:

a. France
b. United Kingdom
c. West Germany
d. USSR
e. Heat output (MW)
f. Electrical output (MW)
g. Temperature of sodium exiting from core (°C)
h. Steam temperature (°C)
i. Steam pressure (MPa)
j. Burnup (TK/kg)
k. Design
l. Integral
m. Loop type

As shown in Fig 7, high-temperature gas-cooled reactors with heat exchangers may also be used as nuclear heat sources for liquid-metal MHD systems.

The speed of commercial incorporation of the fast-breeder and high-temperature reactors is difficult to estimate at present, and will vary from country to country; but they are eventually certain to find extensive use.

It is advantageous to use cylindrical electrodes for nuclear thermionic converters: an outer collector, with the emitter inside it, and the nuclear fuel undergoing fission inside the emitter. A group of cylindrical TEM physically arranged end to end and electrically connected in series creates a single thermionic nuclear rod. A large number of such rods are inserted into the reactor and form part of the core; this arrangement is called the internal arrangement. An external arrangement of nuclear TEM is also possible with cylindrical electrodes; the emitters are heated by circulation of liquid metal or by a liquid metal-metal vapor system in high temperature piping.

Series-producible components and systems for nuclear converters have been designed and prepared for production, and plans for nuclear thermionic reactors with outputs on the order of 10 to 100 kW have been developed.

The first thermionic electrical generator connected with a nuclear reactor was built in the Soviet Union in 1970 and designated the TOPAZ thermionic reactor.

The thermionic fuel rods, containing several cylindrical cesium diodes arranged end to end, are located radially in the reactor in an nonuniform arrangement so as to achieve a uniform temperature distribution.

Nuclear or isotope TEM have also been built and used as low-level power sources in a number of special instances, such as in space research. Higher-power units are also under preparation.

Conclusion

Even though the technical problems of MHD generator systems using nuclear reactors as heat sources have not yet been fully solved, the results obtained in research on HTGR and LMFBR reactors allow an optimistic view of prospects for using closed-cycle MHD systems with nuclear reactors for the production of electrical energy. The high-temperature characteristics of MHD systems with HTGR reactors make such equipment more suitable for the production of electrical energy than the other alternatives (nuclear reactors connected with steam or gas turbines), since MHD generators, like nuclear reactors, can achieve high unit capacities (hundreds of megawatts). In addition, as a result of their high efficiency, they have considerably lower waste-heat losses than standard nuclear power stations.

The development of liquid metal MHD systems has reached a stage at which larger units have been built or are under construction. Tests of such equipment are yielding more precise data on the processes that take place in them. The main advantages of MHD generators using liquid metal is their ability to operate at low temperatures. However, there is no propulsion method available which allows the flow of liquid metal to be accelerated with low energy losses.

Another possible source of heat for such systems which we have not yet considered in detail is thermonuclear reactors. The use of controlled thermonuclear reactions as a source of energy is still in the developmental stage. Scientific findings gained thus far can be used as the technical basis for future thermonoclear reactors. Thermonuclear reactor technology requires more research, and it will first of all be necessary to demonstrate the physical principles involved. Although the construction of a commercial reactor of this type is still far off, many countries are currently devoting research to the problem.

Thermionic conversion of energy to electricity, too, has thus far failed to achieve extensive practical utilization because of excessive technical requirements resulting from the high operating temperature of the emitters. Low-power converters (most often isotope types) have been built for space research purposes and in cases where expense is a secondary consideration.

Recently, research on thermionic converters has focused on both flame-type converters and thermionic nuclear reactors--of course for the purpose of large-scale power production, where they would help to considerably increase the degree of utilization of fuel.

Physical and technological research on direct energy conversion has produced sufficient results that individual conversion methods may be investigated further and the design and technical aspects worked out. Developmental experience thus far has been encouraging, but new proposals and requirements are also emerging, particularly involving the development of processes and new materials which thus far have been unfamiliar in engineering.

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8480
CSO: 5100/3006

NIGER

BRIEFS

PRESIDENT ON FRENCH URANIUM NEGOTIATIONS--Niger's head of state, Col Seyni Kountche, said on 7 November that, in his opinion, the initial negotiations with France on the price of uranium for 1982 indicate that there will be an "upturn" compared to 1981, when there was a significant drop in the uranium revenues. When he returned to Niamey, the Nigerien head of state said, referring to French-Nigerien cooperation, that he was also pleased to see that the Joint Commission, which met right after the French-African Conference in Paris, had come up "with satisfactory decisions in areas which are given top priority by Niger." [Text] [Paris MARCHES TROPICAUX ET MEDITERRANEENS in French No. 1879 13 Nov 81 p 2887] [COPYRIGHT: Rene Moreux et Cie Paris 1981] 8796

CSO: 5100/5607

AGREEMENT ESTABLISHING NUCLEAR MATERIALS COMPANY APPROVED

Paris MARCHES TROPICAUX ET MEDITERRANEENS in French No 1879 13 Nov 81 p 2878

[Text] On 12 September, Senegal's JOURNAL OFFICIEL published Decree No 81-658 of 6 July 1981 which approves the agreement establishing the General Company for Nuclear Materials (COGEMA).

When this agreement was signed, the COGEMA held an exclusive exploration license covering an area of 19,300 square kilometers in Eastern Senegal. This license had been renewed on 27 November 1978 by Decree No 79-881 of 25 September 1979 and the company had invested 900 million CFA francs in exploration operations in Senegal.

According to the terms of the agreement, the COGEMA is committed to invest at least 150 million CFA francs in exploratory borings during the first year of the period covered by the present agreement.

If this period of exploratory borings yields successful results, the COGEMA will proceed with additional investments of about 500 million CFA francs moving to a development stage involving boring operations and, ultimately, mining work.

If this development stage is crowned by success, the COGEMA will spend around 300 million CFA francs on a feasibility study.

If the findings of the feasibility study warrant mining operations in one or more uranium deposits, the COGEMA will be allowed to constitute a mining company.

The COGEMA will bring into that company the total sum of its investments prior to the time when the company is formed at the discount value assigned to these investments at that time in accordance with applicable tax regulations and duly authorized by Senegal's minister of economy and finance.

The mining company will be the recipient of articles of agreement in accordance with the legislation contained in the Investment Code and providing that its investment program meets the criteria required by that code for approval. These articles of agreement will be signed before any capital formation starts.

The value-added tax based on the pithead value of the output sold will be at the rate of 5 percent and this rate can be readjusted by agreement between the government and the COGEMA.

The operative provisions will fall within the legal tax system in force when that agreement is signed, with a scheduled tax on industrial and commercial profits of 33.33 percent based on the aforesaid tax system and subject to the following specifications: 100 percent amortization of exploration expenses; if amortization is deferred, it can be carried over from one fiscal year to the next without time limit; possible losses, which are not due to the amortization and which were incurred prior to the fiscal year when production reaches its rated capacity, will be allowed to be carried over for 3 more years after that level of production is reached.

The articles of agreement must also guarantee that the mining company has the right to transfer capital and its revenues and they must include a provision allowing the COGEMA to have first option to buy the company's output. The company must sell to the COGEMA at the price being offered in the world market for similar commodities and subject to approval by the company's board of directors. If the COGEMA is not the only shareholder, this right of first option to buy will be exercised on a pro rata basis according to the COGEMA's shares in the company.

8796
CSO: 5100/5607

FRANCE

BRIEFS

NUCLEAR RESEARCH DISCUSSIONS--"Top secret" discussions [are taking place] between France and Algeria concerning the establishment of a nuclear research center at Ain Oussera (near Algiers). Algerian [nuclear] technicians will also be trained in France. [Text] [Paris PARIS MATCH in French 18 Dec 81 p 44] [COPYRIGHT: 1981 par Cogedipresse S.A.]

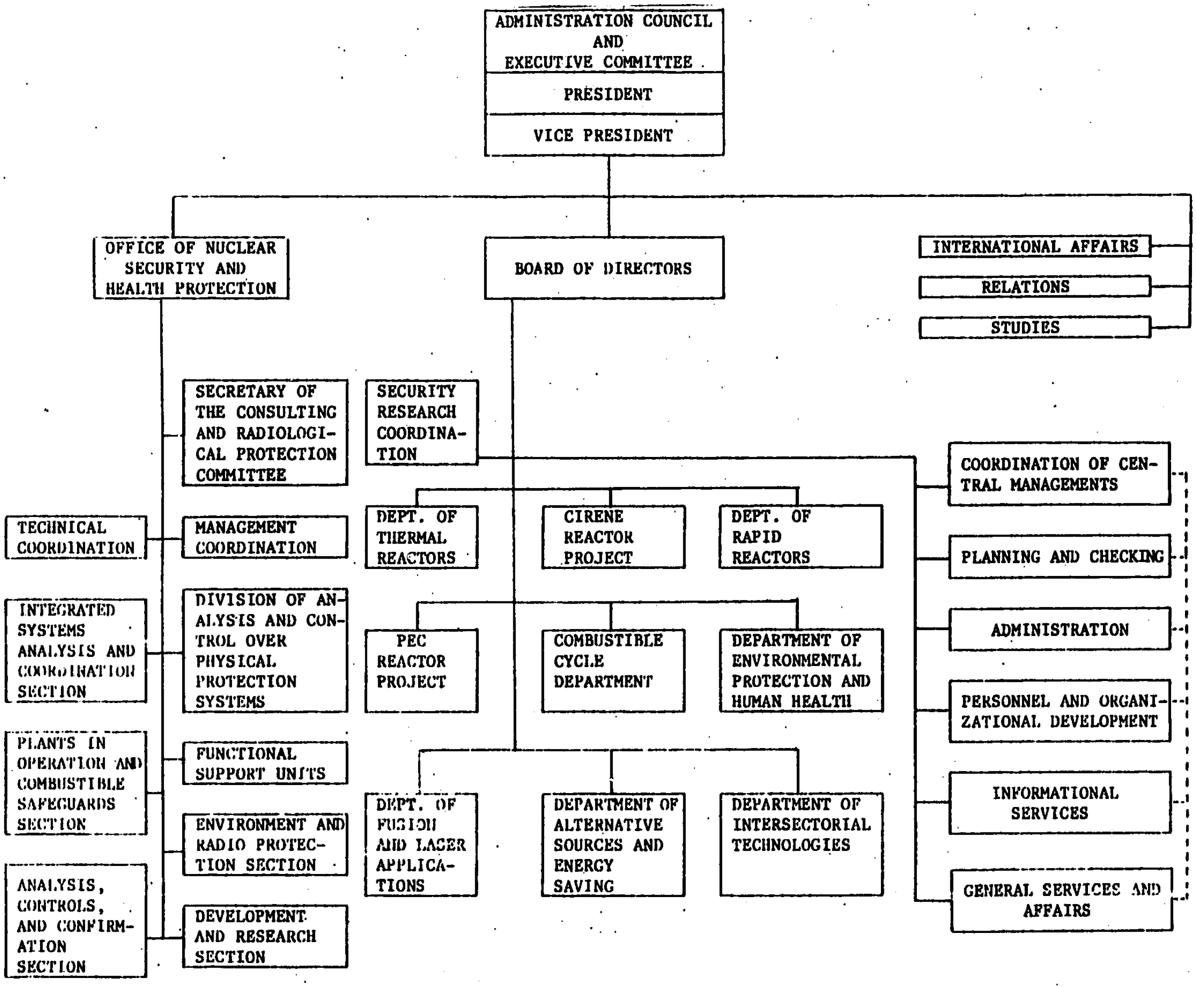
CSO: 5100/2064

ITALY

NEW ORGANIZATION OF NATIONAL NUCLEAR ENERGY COMMITTEE

Rome ATOMO E INDUSTRIA in Italian 1 Sep 81 p 5

[Text]



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