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THE STATUS OF THE BUBBLER CONDENSER CONTAINMENT SYSTEM FOR THE REACTORS OF THE VVER-440/213 TYPE

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

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The primary objective of the NEA is to promote co-operation among the governments of its participating countries in furthering the development of nuclear power as a safe, environmentally acceptable and economic energy source.

This is achieved by:

- *encouraging harmonization of national regulatory policies and practices, with particular reference to the safety of nuclear installations, protection of man against ionising radiation and preservation of the environment, radioactive waste management, and nuclear third party liability and insurance;*
- *assessing the contribution of nuclear power to the overall energy supply by keeping under review the technical and economic aspects of nuclear power growth and forecasting demand and supply for the different phases of the nuclear fuel cycle;*
- *developing exchanges of scientific and technical information particularly through participation in common services;*
- *setting up international research and development programmes and joint undertakings.*

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has concluded a Co-operation Agreement, as well as with other international organisations in the nuclear field.

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made up of scientists and engineers. It was set up in 1973 to develop and co-ordinate the activities of the Nuclear Energy Agency concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations. The Committee's purpose is to foster international co-operation in nuclear safety amongst the OECD Member countries.

CSNI constitutes a forum for the exchange of technical information and for collaboration between organisations which can contribute, from their respective backgrounds in research, development, engineering or regulation, to these activities and to the definition of its programme of work. It also reviews the state of knowledge on selected topics of nuclear safety technology and safety assessment, including operating experience. It initiates and conducts programmes identified by these reviews and assessments in order to overcome discrepancies, develop improvements and reach international consensus in different projects and International Standard Problems, and assists in the feedback of the results to participating organisations. Full use is also made of traditional methods of co-operation, such as information exchanges, establishment of working groups and organisation of conferences and specialist meeting.

The greater part of CSNI's current programme of work is concerned with safety technology of water reactors. The principal areas covered are operating experience and the human factor, reactor coolant system behaviour, various aspects of reactor component integrity, the phenomenology of radioactive releases in reactor accidents and their confinement, containment performance, risk assessment and severe accidents. The Committee also studies the safety of the fuel cycle, conducts periodic surveys of reactor safety research programmes and operates an international mechanism for exchanging reports on nuclear power plant incidents.

In implementing its programme, CSNI establishes co-operative mechanisms with NEA's Committee on Nuclear Regulatory Activities (CNRA), responsible for the activities of the Agency concerning the regulation, licensing and inspection of nuclear installations with regard to safety. It also co-operates with NEA's Committee on Radiation Protection and Public Health and NEA's Radioactive Waste Management Committee on matters of common interest.

This report on the status of the bubbler condenser containment system for the reactors of the VVER-440/213 type has been prepared by Prof. H. Karwat[1] with the assistance of Dr. H.E. Rosinger[2]. It incorporates comments made by the members of the OECD Support Group on VVER-440/213 Bubbler Condenser Containment Research. Additional copies can be requested from:

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SUMMARY

VVER-440/213 Pressurized Water Reactors have a pressure-suppression containment structure called a "Bubbler Condenser" tower which can reduce the design pressure of the entire containment following a design basis accident (DBA), such as a loss-of-coolant accident (LOCA). The bubbler condenser pressure suppression system provides reduction of the LOCA containment pressure by the condensation of released steam in a water pool. World-wide there are 14 nuclear power plants of the VVER-440/213 type operating in the Czech Republic, Hungary, the Slovak Republic, Russia and the Ukraine. Four more are still under construction.

The main element of the bubbler condenser containment system is the bubbler condenser tower unit consisting of a building which contains up to 12 staggered water pools with approx. 160 gap-cap inlet openings on each pool level. The VVER-typical gap-cap system provides intensive contact between the air-steam mixture and the cold water in the pools. The gas volumes above the water levels are connected to an air trap building by one way check valves, thus separating the residual air.

The following phenomena are important to understand and assess the efficient function of the bubbler condenser containment system:

- Dynamic loading of the gap-cap system by mass flow-induced differential pressures upon occurrence of a LOCA;
- Oscillatory loading of the flat water pool trays by condensation phenomena;
- Water carry over into the air traps during the impulsive air transfer period;
- Possible limitations of the air flow from the bubbler condenser into the air traps in case of approaching sound velocities inside the check valves;
- Efficiency of the bubbler condenser tower in case of partial failure of the condensation trays or of single gap-cap systems (e.g. by-pass formation);
- Water spilling over an passive spraying.

The earlier experimental data base for the design of the bubbler condenser containment system has been reviewed. Mainly, two experimental facilities , the so-called "Reduced Bubbler Condenser Model" and the "Enlarged Experimental Model" served to confirm former design decisions. The structure-dynamic properties of the chosen gap-cap systems and of the confining walls of these structures are not well known as no studies were performed at that time with respect to the interaction between oscillatory condensation and the structure-dynamic response of the gap-cap systems and its confining structures.

Intensive discussions within the OECD Support Group on "VVER-440 Bubbler Condenser Containment Research Work" revealed the need for a supplementary proposal for a multiple gap-cap system test rig. The Czech SVUSS Research Institute has elaborated a concept which was based on the use of original bubbler condenser structural components of a nuclear power plant. Thirty-six gap-cap systems were to be tested simultaneously. This concept preserved the structural eigenfrequencies of the bubbler condenser elements to the largest possible extent. Experiments were to focus mainly on the response of the structures of the condenser elements to the oscillatory bubbler condensation process. Detailed discussions showed that thermal stratification within the bubbler condenser tower needs also to be studied. As a consequence, both concepts were combined into the "Unified Bubbler Condenser Research Project" (UBCRP) avoiding to the largest extent any duplication of experimental works.

In 1994 the European Commission (EC) asked for an additional "VVER-440/213 Bubbler Condenser Qualification Feasibility Study". The scope of this study was to again review and assess existing documents about various aspects of the bubbler condenser containment system and to draw independent conclusions as to which further experiments were really necessary. The Qualification Feasibility Study was finalised early in 1996.

The study confirmed the need for additional research in this field and asked for two separate experimental activities to be carried out within the frame of the EC TACIS/PHARE assistance programme of the European Commission. One study should focus on thermal-hydraulic processes, the second one on structure mechanic aspects, with both studies supported by analytical work. Three specifications for the experimental and analytical works have been issued. Technical proposals ("Prequalification Reports") have been submitted by potential Eastern European research institutes which are based on the afore mentioned technical specifications. They were adopted by the EC and form the basis for a future EC PHARE/TACIS-funded experimental and analytical support programme.

The OECD Support Group is fully supportive of the currently proposed EC PHARE/TACIS project to assess the reliability of the bubbler condenser system. The execution of this programme is considered as a necessary minimum to fully assess the function of the bubbler condenser tower and to assure its reliable operation in case it should be required during an accident. The proposed activities constitute a high priority issue within the frame of a nuclear assistance programme to establish an adequate level of reactor safety.

1. INTRODUCTION

There are currently eight countries operating 59 Russian-designed nuclear power reactors with 12 in various stages of construction. There are three principal reactor types: the 440 MW VVERs (Pressurised Light-Water Reactors) including the older 230 models and the newer 213 models, the 1000 MW VVERs and the RBMKs (fuel channel, graphite-moderated reactors). Significantly different safety features are found not only among the various reactor types, but also within the various generations of each type. Comprehensive safety analyses, including accident analyses, have been recognised as being of utmost importance in assessing nuclear power plant safety.

Following the break-up of the Soviet Union in 1991, major national and international organisations initiated programmes to assess and improve the safety of nuclear power plants in countries operating Russian-designed reactors. Included were bilateral and multilateral assistance programmes, co-ordinated by the G-24, among them being: the programmes of the European Commission (PHARE, TACIS), the efforts of the International Atomic Energy Agency, the nuclear safety account of the European Bank for Reconstruction and Development, and, of course, the Co-operation Programme of the OECD Nuclear Energy Agency.

The OECD Nuclear Energy Agency has undertaken technical support for all of these reactor types. This report deals exclusively with the OECD/NEA assistance to the second generation of the 440 MW VVERs, i.e., the VVER-440 model 213.

The VVER-440/213 Pressurized Water Reactors have a pressure-suppression containment structure called a "Bubbler Condenser" tower which is designed to reduce the design pressure of the entire containment following a design basis accident (DBA) such as a loss-of-coolant accident (LOCA). The bubbler condenser pressure suppression system provides reduction of the containment pressure by the condensation of released steam in a water pool and, if compared to Western BWR reactor containments, by the large free containment volume (see table2).

World-wide there are 14 nuclear power plants of the VVER-440/213 type operating in the Czech Republic, Hungary, the Slovak Republic, Russia and the Ukraine, and there are four still under construction at MOCHOVCE in the Slovak Republic. One more plant at Greifswald (Germany) has been closed down. The construction of two other plants with modified bubbler condenser containment in Cuba has been cancelled. These facilities are listed in Table 1.

Originally, the bubbler condenser pressure suppression system was considered adequate. However, subsequent detailed evaluations have identified some possible deficiencies especially for design basis accidents and for more severe accidents. The main deficiencies identified were in general related to:

- poor modelling of the accidents including design basis accidents,
- poor knowledge of integral and certain single effects,
- materials and properties of test rig structures different from prototype plants,
- absence of verified computer codes.

One of the safety concerns for the VVER-440/213 reactors relates to the ability of the bubbler condenser containment system to function satisfactorily and to maintain its integrity following certain postulated accidents and thus limit the release of radioactive material to the environment. The complicated geometry of the bubbler condenser unit, and the dependence on several moving devices and interlocks are the main doubts expressed by different specialists with regard to the design. A research programme is required:

a) to understand the interactions of the thermal-hydraulic and structure dynamic phenomena expected in the bubbler condenser system and the governing parameters,

b) to develop suitable mathematical models for relevant phenomena of this system for introduction into existing thermal-hydraulic codes, and, subsequently,

c) to verify the capabilities of the mathematical models to predict the governing parameters of interacting phenomena occurring under accident conditions.

Based on the results of such research, it should be possible to assess whether it is necessary and possible to upgrade current designs.

2. THE BUBBLER CONDENSER CONTAINMENT SYSTEM OF VVER-440/213 NUCLEAR POWER PLANTS: A GENERAL DESCRIPTION

In VVER-440/213 nuclear power plants, the complete containment system, shown in Figure 1, consists of the following main parts:

- the hermetic compartment system (Reactor Building) in which are the primary system coolant loop components. It consists of more than 40 compartments connected to the bubbler condenser tower (Bubbler Condenser),
- the bubbler condenser tower (Bubbler Condenser), which provides the passive pressure suppression, and
- the adjoining air traps (Sections 11 of Bubbler Condenser), which will hold the non-condensable gases (such as air, fission product gases) transferred from the hermetic compartment system through the bubbler condenser tower, and
- active and passive spray systems providing long-term pressure reduction.

In the case of a LOCA, the air-steam mixture generated inside the hermetic compartment system will be transferred into the bubbler condenser tower. Steam will be condensed by the staggered low-pressure water trays while the residual air will be transferred through check valves into the air trap building. The interaction of these three main parts (hermetic compartment system, bubbler condenser tower and air trap building) determines the specific low design pressure of the entire containment system which from basic principles is similar to the pressure suppression system containments of Western Boiling Light Water Reactors (BWRs).

Under design basis accident conditions, the compartments of the hermetic system (Reactor Building in Figure 1) will be loaded by local pressure differences. The pressurisation process is similar to the situation covered by the design of full pressure containments of Western PWRs. Consequently, the applicable rules and guidelines for the analyses of Western PWR containments are also relevant for the safety assessments of the VVER-440/213 hermetic compartment system. They have been proven adequate for the design, with the corresponding hydraulic codes being widely validated against experimental results obtained in nearly full-scale experimental facilities (e.g. the HDR-containment test facility) /KAR90/. Experimentally proven safety factors may cover the analytical uncertainties in the predicted loads on the hermetic compartment system (KAR89a, Wash conf).

Remarkable differences exist between the phenomena and processes which dominate the bubbler condenser containment system and those of Western pressure suppression system containments. The main element of the bubbler condenser containment system, partially shown in Figure 2, is the basic bubbler condenser unit, the so-called gap-cap inlet opening. The bubbler condenser tower consists of a building which contains up to 12 staggered water pools with more than 150 gap-cap inlet openings on each pool level. Every three levels are connected to one air trap (see also section 11 in Figure 1). The VVER-typical gap-cap system provides intensive contact between the air-steam mixture and the cold water in the water pools.

3. THE PHYSICAL PROCESSES IN A BUBBLER CONDENSER CONTAINMENT SYSTEM

It is useful to describe the physical processes occurring in the bubbler condenser unit to understand some of the potential concerns about the system and the need for additional research and development. The functional scheme of the process is illustrated by Figure 3. In the case of a postulated large break LOCA, up to a break of 500-mm diameter piping, the steam-air mixture generated within the hermetic compartment system is transferred into the bubbler condenser tower through the bubbler condenser shaft (6). It penetrates the horizontal spaces between the water trays (7), as shown schematically in Figure 4. The steam-air mixture will pass through a large number of vertical openings, the gap-cap inlet openings, to the water trays (3). These gap-cap inlet openings are lengthy rectangular gaps covered by rectangular caps forcing the steam-air flow through the water pools, i.e., the initial upward directed flow is turned 180 degrees by the caps into a downward oriented flow. The increasing pressure of the steam-air mixture below the water tray forces the steam-air mixture to reduce the water inside the cap (4) around the gap until the lower edge of the cap is reached and the steam-air mixture flows into the water pool in the water tray, distributing the steam/air flow into the water by the zig-zag shaped lower edge of the cap. The steam is condensed by the cold water in the water trays, the residual air leaves the surface of the water pool and is collected within the space above.

The gas volumes above the water levels are connected to large volumes (8) in the air trap building by one way check valves (5), which allow the air to flow into the air trap volumes preventing its backflow. This results in a reduction of the pressure in the upstream volumes (6) and (7) and the hermetic compartment system below atmospheric as soon as the residual steam has been condensed at the corresponding surfaces.

The water trays are also provided with a set of pressure-controlled check valves (1) connecting the gas volumes above the water trays with the bubbler condenser shaft (6). These valves are normally closed. They shall open if the absolute pressure in the bubbler condenser shaft falls below 0.16 MPa and the gas flow direction, governed by the pressure difference, is from the trays‘gas volumes to the shaft. The purpose of these valves is to prevent the water back flow from the trays in case of a small break LOCA. Thus, in the case of a large break LOCA, when the initial pressure exceeds the threshold pressure, the valves (1) remain closed. Due to condensation of the steam on the inner surfaces of the containment and in the water trays the pressure in the gas shaft (6) falls below that of the gas volume above the water trays (9), the air in the gas volume above the water trays begins to press on the water level, forcing the water down to return through the gap-cap inlet openings. The water begins to fall on the lower shelves of the inlet duct, gathers in the perforated baffle (2) and penetrates through the perforations into the bubbler condenser shaft (6). This leads to further steam condensation in the shaft, a continuing pressure drop and an increase in the pressure difference acting on the water trays. The water outflow through the gap-cap inlet openings increases until such time as the pressure in the gas shaft falls below the threshold pressure of the valves (1) when the pressures are practically equalised.

The uniformity of steam condensation efficiency in the bubbler condensation units has been questioned because of the shallow depth of the pool water, about 1/2 m versus the 4 to 6 m for the water pools of the Western Boiling Water Reactors, and because of the complicated geometry of the bubbler condenser unit, i.e., the gap-cap inlet openings with a narrow space for the steam-air flow at the bottom of the water trays. There are 12 levels of water trays and the thermal loading, both vertical and horizontal, of these staggered water trays must be established since the condensation of the steam is dependent on the temperature of the water in the trays. In addition, the dependence on check valves and interlocks have also raised some doubts with regard to the design.

4. CONCERNS ABOUT THE BUBBLER CONDENSER CONTAINMENT SYSTEM

Table 2 provides a comparison of characteristic features of Eastern European bubbler condenser containment systems with some Western pressure suppression system containments. A typical US facility like MARK-II and modern German KWU plants Baulinie-72 are compared to the design features of VVER bubbler condenser containment systems of PAKS (Hungary), MOCHOVCE (Slovak Republic) and Greifswald (Germany). It is evident that the drywell volume of the hermetic compartment system including the drywell volume of the gas transfer duct to the staggered water pools is relatively large compared to the drywell volume of the Western pressure suppression system. The ratio (free volume)/(thermal reactor power) is larger by a factor of 4 to 20 compared to Western BWR plants. This may explain the lower design peak pressures and smaller pressurisation rates. Moreover, the total volume of all water trays together, as related to the thermal reactor power, of the VVER-440/213 plants approximately corresponds to that of the Western BWR plants.

A total flow area of 2.5 m^2 is available between the gas room above the water trays and the air traps to transfer an air volume of up to 30,000 m^3 within a very short time. Under such circumstances, choked flow conditions could develop which may amplify the maximum transient pressurisation of the hermetic compartment system and the part of the bubbler condenser downstream the water trays. Water droplet entrainment between the water pool surfaces and the check valve entrance may increase the choking effect. Depending on the degree of the entrainment a reduction of the sound velocity of the air-water droplet mixture of 10% or more appears possible /BÖC74/. On the other hand, flow choking within the check valves would limit superficial air flow velocities through the water pools reducing possible carry over of water to the air traps, that would eventually not be available on the trays during later periods of the LOCA event.

The possibility of water hammer events caused by the condensation of air–free steam within the water pools (chugging) cannot be totally excluded /BUK89/. Chugging may occur locally at the cap exits, it is dependent on the flow rate density of the steam/air mixture and in particular on the air content of the mixture. Low mass flow density and low air content of the flow may cause chugging events with high pressure spikes, which the structures would not tolerate. However, due to the large free volume of the hermetic compartment system and the connecting corridor this is unlikely to happen. In this context, it is important to understand the local flow conditions of the 12 staggered bubbler condenser trays during the LOCA event. Dependent on the location of the anticipated rupture of a main recirculation line, a detailed analytical simulation of the hermetic compartment system which involves more than 40 compartments, might illustrate the variety of possible local air concentration transients at the gap–cap inlet openings and may indicate flow parameters for supplementary testing.

The following phenomena are important to understand and assess the efficient function of the bubbler condenser system:

- Dynamic loading of the gap-cap system by mass flow induced differential pressures upon occurrence of a LOCA
- Oscillatory loading of the flat water pool trays by condensation phenomena
- Water carry over into the air traps during the impulsive air transfer period.
- Possible limitations of the air flow from the bubbler condenser into the air traps in case of approaching sound velocities inside the check valves.
- Efficiency of the bubbler condenser tower in case of partial failure of the condensation trays or of single gap–cap systems (e.g. by–pass formation).
- Effectiveness of the passive spray and water spill over process.

Simulation methods developed for the analysis of Western pressure suppression systems have not been sufficiently verified for VVER reactors to provide reliable answers on these VVER–specific questions. Hence, the experimental investigation into the behaviour of the bubbler condenser containment systems of VVER–440/213 nuclear power stations is considered as a high priority issue.

The analytical simulation of the efficiency of the bubbler condenser containment systems needs more detailed modelling than the simulation of Western pressure suppression systems. In the early 90s, the need to modify the existing computer codes like DRASYS, developed by GRS for the simulation of the pressure suppression system of a KWU–Baulinie 69 or 72 containment, was recognised. An improved version of the DRASYS code is now available as a subroutine within the containment code RALOC, thus providing direct coupling of the detailed simulation of the hermetic compartment system with the simulation of the bubbler condenser tower /SCW96/.

The behaviour of the bubbler condenser containment system under severe accident conditions has not been addressed so far. After resolving the open questions relevant for design basis accident scenarios, the particularities of the bubbler condenser containment system of VVER-440/213 nuclear power plants under severe accident conditions may be an objective of future in-depth discussions taking into account the specific aspects of available and/or possible accident management strategies.

5. THE DESIGN ASSESSMENT OF THE BUBBLER CONDENSER CONTAINMENT SYSTEM

5.1 The Earlier Experimental Data Base to Support the Design

It was only after 1990 that some information became available concerning the early testing of the bubbler condenser containment function and the associated fluid dynamic and thermo-hydraulic phenomena expected during a loss–of–coolant accident when a schematic description of the concept and some superficial test results were published by USSR experts /BUK78/ and /BUK81/. Two experimental facilities served to finalise and confirm the design decisions: one facility involved a single gap–cap system, while the second facility consisted of several gap–cap systems in parallel.

Basic investigations were performed with the so–called "Reduced Bubbler Condenser Model". This test rig consisted of two halves of one gap–cap system of reduced length and was basically used to study the condensation efficiency under a variety of operating conditions. Temperature measurements above and below the water tray were interpreted in terms of condensation efficiencies. All experiments confirmed an efficient condensation of steam as long as the temperature of the water was sufficiently below the saturation line. Some limitation was observed if the specific steam loads in the tests exceeded 300% of the design value. Nevertheless, the test results served as the basis for the final design of the gap–cap inlet openings.

Later, an "Enlarged Experimental Model" was established to investigate the behaviour of several gap-cap systems operated in parallel and connected to an air trap simulator. Horizontal arrangements of up to 9 gap-cap systems, as well as vertical arrangements of 3 staggered double–gap-cap systems were studied. These tests were performed with flow cross sections of the gap–cap systems dimensioned on basis of the experiments with the "Reduced Model". Although the main interest in these integral experiments was the uniformity of the operating parameters of a multiple gap-cap system, the structure-dynamic properties of the gap-cap system and of the confining walls of the "Enlarged Model" were not prototypical.

Other separate effects tests were carried out to understand the formation of water swell levels and some later tests indicated also the possibilities of oscillatory condensation and air–free steam condensation (chugging). However, these tests were done with gap systems of reduced lengths for a different condenser system of the IGNALINA nuclear power plant /ANT83, KUZ84, KUZ88/. The coupling of oscillatory condensation modes with the structure dynamic response of the gap–cap systems was not studied in detail by neither experiment.

Outside the former Soviet Union, an important test rig to study bubbler condensation was built at the research establishment in BECHOVICE near Prague (now named "SVUSS "Statni Vyzkumny Ustav pro Stavbu Stroju). This test facility still exists, consisting of a pressure vessel to simulate a scaled transient blowdown event, a simplified model of the hermetic compartment system without internal structures and two half–segments of a typical gap–cap arrangement with slightly reduced dimensions modelling the bubbler condensation unit /SIP91/. A sketch of the BECHOVICE facility is shown in Figure 5. The air space above the water pool is connected to an additional container simulating the air trap. The relative volume ratios representing the hermetic compartment system, the water inventory and the air space above the water level have largely been preserved by a so–called "volume–scaled" test arrangement. In order to allow for the typical time-transients of an integral experiment, a volume–scaled blowdown process was specified resulting in a reduction of the required blowdown rates proportional to the reduced number of gap-cap units of the prototype containment (approximately 1800 or more).

Mechanical pressurisation loads on the bubbler condenser structures under design basis accident conditions were studied by Polish experts within an aerodynamic test rig. The experiments were performed at the Technical University of Warsaw to obtain qualitative and quantitative information, in particular on the flow velocity and pressure history, to further support the strength analyses of the containment structures /SZU88/. The study served to generate the additional data required for an independent Polish safety assessment of the ZARNOWIEC nuclear power plant project in the late 1980s.

The model of the reactor containment was linearly scaled 1:54, representing the internal configuration of the reactor compartments and of the bubbler condenser tower encompassing all relevant equipment (e.g. the reactor pressure vessel, the steam generators, and water shelves of the condenser tower). Loading of the containment model was simulated experimentally as a transient process by releasing compressed air. Measurements were performed for two versions of the bubbler condenser tower – a basic configuration, as proposed by the original Soviet design, and a modified configuration with the perforated shielding plate at the entrance to the condenser tower. The experimental results provided important qualitative information concerning the expected pressure and flow velocity transients of the prototype plant and raised the first doubts about the adequacy of the structural design of certain parts of the bubbler condenser containment system. /SZU88/.

Another large multi-stage test facility was initiated in the 1980s at ZUETES in Zugres (Ukraine), but it was never finished and put into operation. The test rig consisted of three large steel containers with an elevation of approximately 30 m and volumes of 270 m^3 each. The three steel containers are interconnected by pipes and were supposed to model the hermetic compartment system (drywell), the bubbler condenser arrangement (wetwell) including the gas shaft, and the air trap. The original goals envisaged with this test facility were:

- to serve for code varification purposes by large scale testing
- to obtain large scale integral confirmation about findings observed earlier from experiments with the "Reduced Model" and the "Enlarged Model".

The primary interest was the uniformity of the thermal loading of a larger test arrangement under typical LOCA conditions.

5.2. *Recent IAEA Studies*

During the last several years the IAEA has published a series of reports describing the background and characteristic design features of VVER-440/213 Nuclear Power Plants /IAE95/IAE94/. In this context the mechanical strength of some existing bubbler condenser containment systems was also reassessed /IAE95a/. This work was undertaken to assist operators in the reevaluation of the bubbler condenser performance and to identify the need for supplementary experimental studies to better understand the specific problems of the bubbler condenser.

The analyses showed that the mechanical design of certain parts of the bubbler condenser is unsatisfactory and there might be a danger of metal structure failure under certain DBA conditions (such as the instantaneous double ended guillotine break of the largest pipe in the reactor coolant system resulting in local pressure differences of approximately 30 kPa). Subsequent calculations, applying specific guidelines developed for the evaluation of the bubbler condenser metallic structures /IAE94a/, reiterated earlier concerns and confirmed the need for strengthening some parts of the bubbler condenser structures.

A subsequent peer review /IAE 95b/ confirmed these findings. Although in most cases the predicted stresses are only slightly higher than admissible ones, there are also elements and joints for which expected loads will be many times larger than allowed for the structures. The calculations were performed using simplified and conservative approaches. More exact best-estimate calculations are expected to result in smaller stress values. However, where the predicted stresses may be 10 or even 60 times larger than admissible, the need for local improvements became evident. As a result of these analyses, some integral structural tests were proposed for containments of certain nuclear power plants.

Most of the analyses were performed for thermo-hydraulic processes of importance under initial DBA conditions. The effects of possible condensation oscillations and/or poolswell were not studied by the IAEA-sponsored analyses. In this respect the IAEA-experts supported the execution of new large scale experiments to confirm that those phenomena not yet investigated during the earlier testing by the "Reduced Model" and by the "Enlarged Model" would not endanger the integrity of the condenser structures. If performed properly, such experiments would also help to quantify the degree of conservatisms inherent to the mechanical strength analyses for the postulated DBA conditions.

Based on above mentioned studies on the design and on the operational experience with VVER-440/213 reactors an IAEA document was released, which gives ranking to the identified generic safety issues according to their safety significance /IAE 95c/. The document is presently used to facilitate the development and execution of plant specific safety improvement programmes. It also serves as a basis for reviewing the implementation of the requested improvements. Amongst several other problems five generic containment related issues have been identified and ranked (high ranking degree means high safety significance):

- Bubbler condenser strength behaviour, maximum pressure difference of steel structures under LOCA (Ranking III)
- Bubbler condenser thermodynamic behaviour (Ranking II)
- Containment leak rates (Ranking II)
- Maximum pressure differences on walls between compartments of hermetic boxes (Ranking II)
- Peak pressure in containment and activation of subatmospheric pressure after blowdown (Ranking I)

The ranking of the containment-related issues underlines the need for supplementary and confirmatory analyses and experiments.

6. THE UNIFIED BUBBLER CONDENSER RESEARCH PROJECT (UBCRP)

The OECD Nuclear Energy Agency, under the OECD Centre for Co-operation with Economies in Transition (CCET), is carrying out a programme of co-operation with the Central and Eastern European Countries (CEEC) and the New Independent States (NIS) of the former Soviet Union. This Co-operation Programme is based on the areas of its traditional strength and is carefully supervised and co-ordinated to ensure that the activities complement or are supplementary to those of other international organisations.

Through the activities of the OECD Support Group on "VVER-440 Bubbler Condenser Containment Research Work" and of the NEA Secretariat, the OECD has been an active supporter of the work on the bubbler condenser containment research with emphasis on the thermal-hydraulic-related issues of the bubbler condenser unit. The OECD has fostered co-operation between the various interested parties, and has been supportive of the research facilities in Eastern Europe to obtain funding through the PHARE/TACIS programme of the European Community.

The genesis of the OECD Support Group on "VVER-440 Bubbler Condenser Containment Research Work" had its formal beginning at a multi-lateral symposium on Safety Research for VVER-Reactors in Cologne, Germany, 7-9 July, 1992. The symposium recommended that a concerted effort be undertaken to study the dynamic behaviour of the bubbler condenser containment system of VVER-440/213 reactors under design basis and severe accident conditions, and that an international working group be formed to evaluate a list of priorities of still unresolved safety concerns, i.e., open items, relevant fof the dynamic behaviour of the bubbler condenser containment system. The evaluation was to identify which items could be studied in existing test facilities and which items would require new or redesigned test rigs.

A multilateral working group was created in 1992 to review the available experimental evidence and to specify further necessary tests. The group firstly established a list of the physical phenomena that should be studied experimentally to answer some modelling shortcomings or to answer some deficiencies uncovered in trying to analyse the bubbler condenser containment system. The group also established whether the physical phenomena should be experimentally studied in detail by separate effects tests or by integral tests.

The group assessed the possibility of using the small-scale test facility at BECHOVICE for some of the single separate effects experiments and confirmed it suitable for generating code validation data within the limits of the given design.

During its Annual Meeting held in Paris in December 1993, the OECD/NEA Committee on the Safety of Nuclear Installations (CSNI) endorsed a common French/German proposal to establish a link between the multilateral VVER–440 Bubbler Condenser Research Working Group already existing /KAR95/ and the overall CSNI programme. The major aim was to concentrate and amplify technical consultation by sharing experiences accumulated in NEA Member countries during earlier work related to the understanding of BWR pressure suppression systems /M.o.M4/. It was expected that additional Western experts would join the OECD Support Group on "VVER–440 Bubbler Condenser Containment Research Work". Countries eventually participating in this group were the Czech Republic, France, Germany, Hungary, Italy, the Russian Federation, the Slovak Republic, the Ukraine, and the United States of America. So far, nine meetings have been organised to discuss and conclude on an agreed research programme.

6.1 The Main Goals of the Unified Bubbler Condenser Research Project (UBCRP)

A well balanced research proposal was developed to avoid duplication of efforts. The "Unified Bubbler Condenser Research Project" (UBCRP) was elaborated to cover the identified supplementary research needs encompassing the small scale BECHOVICE test rig, the innovative NABUCCO test concept and, to a limited extent, the unfinished ZUETES test rig /BAL94/.

The technical issues addressed, the required methods for testing, and the existing analytical simulation capabilities of available computer codes are summarised in Table 3.

The suitability of existing and new test facilities to address the open technical issues is summarised in Table 4. In summary:

- The small BECHOVICE test rig could be used for separate effects tests shedding more light into the details of the gap-cap clearing process and the pool swell event.
- The ZUETES test rig could confirm the uniformity of thermal loading conditions of the vertically staggered trays.
- The horizontal section of the NABUCCO test rig should yield data on the mechanical response of the bubbler condenser tower structures to oscillatory condensation phenomena.

6.2 The Possible Involvement of Existing test Facilities

An early aspect of the Unified Bubbler Condenser Research Project (UBCRP) specification was the utilisation of the existing small scale BECHOVICE test rig and of the uncompleted large multi–stage bubbler condenser test rig at the Thermo-Electric Research Center ZUETES.

Conceptually, the ZUETES test rig was considered to become an important bubbler condenser test facility. In total 27 gap–cap systems, designed with original flow cross sections, could be operated simultaneously. Figure 6 provides a peripheral impression of the test facility. Sufficient energy would be available at ZUETES to either execute integral blowdown experiments or well controlled separate effects tests. The dimensions of the three typical containment component models, in particular the model for the hermetic compartment system, would facilitate an evaluation of an inhomogeneous air-steam distribution inside the hermetic compartment system.

The OECD Support Group re-evaluated the original goals for the ZUETES test facility, namely to obtain large-scale integral confirmation on findings observed earlier from experiments with the "Reduced Model" and the "Enlarged Model". However, due to interruption of the construction, the installation of instrumentation and the design of a new comprehensive data processing system had not been carried out. It would have required considerable financial commitments. Furthermore, a detailed evaluation of the structural dynamic properties of the existing system was considered indispensable to definitively assess the suitability of the existing ZUETES test facility. Most likely, a complete redesign of the test rig, including new instrumentation, would have been necessary to resolve these problems. Hence, within the frame of the UBCRP it has been recommended to restrict the further utilisation of the ZUETES test rig for checking the spatial uniformity of the thermal loading conditions of a system of staggered water trays and to study the spatial and local effects of the passive spray system.

Video records of some more recent experiments within the small BECHOVICE test rig in 1990 indicated the existence of oscillatory condensation modes. (In general, the frequency of typical condensation oscillations is dependent on geometric conditions characterising the experimental set-up as well as the full size plant arrangement.) Recognising the importance of oscillatory condensation phenomena for the structural integrity of the bubbler condenser containment system, the OECD Support Group recommended a series of supplementary separate effects tests to be carried out in the BECHOVICE facility (see also Figure 5). Such experiments were to study :

- the impact of the hydraulic and geometric characteristics of single condenser units under different flow conditions on frequencies and amplitudes of oscillatory condensation
- the water expulsion from the condenser and the influence of pressure gradients on the mechanism of water carryover or siphon flow
- condensation effectiveness depending on various factors
- the influence of water carry-over on the flow resistance of check-valves.

On the recommendation of the OECD Support Group, the NEA has also sponsored and co-funded an evaluation of some available measurement techniques and their applicability to the Unified Bubbler Condenser Research Project. The small-scale BECHOVICE experimental apparatus was used to test different types of measurement devices from the point of view of accuracy, reliability, and price to select the most convenient measurement devices. For this stage of the project, the evaluation concentrated on steam content measurements, strength and wall displacement measurements, visual observations and velocity measurements. Participation from FZR (Research Centre Rossendorf) and Hochschule für Technik and Wirtschaft, Dresden was beneficial as these are organisations specialised, respectively, in two-phase flow measurement techniques by means of needle-shaped probes, and special fluidic gauge for the determination of air-steam mixtures. The experiments yielded valuable insights into the suitability of the proposed measurement principles. Most methods which were studied proved their applicability under bubbler condenser operating conditions, although some devices may require additional development and/or should be replaced by other devices /SUC95/.

6.3 The Innovative NABUCCO Test Rig Concept

Neither the BECHOVICE test rig nor the unfinished large ZUETES test facility were designed to preserve the structure dynamic properties of the prototypic gap–cap systems and of the important confining structures (e.g. tray side walls, the flat bottom pool and ceiling plates) of the bubbler condenser. Hence, a comprehensive investigation into the possible interactive coupling of oscillatory condensation modes with the dynamic response of a multi gap-cap system arrangement and the associated structures would have required considerable modifications of these facilities. During its early meetings, the OECD Support Group assessed that their total reconstruction would not be cost beneficial and concluded that it would be necessary to have a new design concept of a multiple gap-cap system test facility.

Responding to these findings, the Czech National Research Institute for Machine Design (SVUSS) has developed a technical concept, titled the NABUCCO-Project, based on the utilisation of the original structures of the MOCHOVCE nuclear power plant. The proposed new test rig concept was to be based on the installation of 4 original condenser elements, each consisting of 9 stainless steel gap/cap systems. The elements would be arranged in 2 levels with 2 elements at each level. In total, 36 gap-cap systems could be simultaneously tested. The advantage of this concept was seen in the preservation of structural eigenfrequencies of the bubbler condenser elements to the largest extent possible, including relevant sections of confining tray structures. The envisaged experiments were to primarily focus on the response of the mostly plane structures of the condenser elements to the early pressurisation and to the subsequent oscillatory processes of bubbler condensation. Possible onset of resonance effects between condensation oscillations and the eigenfrequencies of involved structures was of particular interest.

A general sketch of the proposed NABUCCO design is given in Figure 7 showing the horizontal extension of the gap/cap system arrangement. The vertical cross section of the concept is shown in figure 8 indicating the spatial arrangement of the pressure reservoir, the hermetic compartment system simulation and the bubbler condenser arrangement. The distance between the trays has been preserved as well as the elevation of the check valve outlet relative to the nominal water level of each tray as evident from Figure 8[1]. Once, the main goals of the envisaged experiments had been agreed, the entire instrumentation concept was subject to a thorough discussion by the OECD Support Group. The needs for code validation purposes had to be assessed against the technical possibilities of the test rig. Exchange of experience with Western experts which in former times performed pressure suppression system tests was extremely beneficial for the specification of an adequate instrumentation concept.

6.4 Analytical Support

Several years of supplementary code development and validation work was considered necessary to simulate particular aspects of the bubbler condenser containment behaviour /ARN92/. Like in other fields of thermo-hydraulic research, the direct extrapolation of experimental results to full-size commercial facilities is difficult if not even impossible. Validated computer codes must be made available to analyse and interpret experimental data. Finally such codes shall predict the safety properties of the full-size bubbler condenser containment system.

One meeting of the OECD Support Group was devoted to evaluating the needs for the analytical support work for the analysis of the bubbler condenser containment system /M.oM.6/ . In an earlier version of the United Bubbler Condenser Research Project, it had been suggested that 16 different codes would be used to evaluate the behaviour of the bubbler condenser containment system. This meeting clarified the capabilities, verification, availability and documentation of these various codes. The presentations revealed considerable differences in the capabilities of the codes to address phenomena relevant for the analytical support of the United Bubbler Condenser Research Project. Several codes would require considerable additional development efforts before they could simulate the phenomena important to the project. The recommendation was to give priority to the codes which were readily available to perform the required analyses.

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[1] Legend on Figures 7 and 8 intentionally omitted.

7. THE EUROPEAN COMMISSION PHARE/TACIS PROJECT

The Unified Bubbler Condenser Research Project (UBCRP) reached a state of maturity in 1994 which allowed a global estimation of the financial support necessary to execute the entire programme. "UBCRP" would have needed a total funding of between $US 8.4M and 11.0M. It was hoped that the entire Unified Bubbler Condenser Research Project would be rapidly sponsored by the European Commission within the frame of its Nuclear Safety Support Programmes PHARE and TACIS.

In early 1995, ENAC/Siemens was awarded the contract for the "VVER 440-213 Bubbler Condenser Qualification Feasibility" by the European Commission. This was a PHARE project with PAKS (Hungary) as the main partner, with DUKOVANY (Czech Republic) and BOHUNICE (Slovak Republic) as co-beneficiaries. The scope of this project was for the contractor to review and assess all existing documents about the different aspects of the bubbler condenser containment of VVER-440/213 and to draw conclusions as to which further experiments were necessary. The OECD Support Group was an active (invited) participant at the first of the European Commission-sponsored meetings on the Bubbler Condenser Qualification Feasibility Study called by ENAC, Budapest, 4-5 April 1994. At this meeting, the OECD representative provided the documentation in the form of reports and minutes of all meetings produced by the OECD Support Group. In addition, the OECD submitted a proposal for the review to be carried out by the OECD Support Group after completion of the Qualification Feasibility Study by the contractor.

The Qualification Feasibility Study was finished early in 1996 /ENA96/. The study confirmed the need for additional research in this field and specified two separate experimental programmes to be executed within the frame of the TACIS/PHARE assistance programme of the European Commission. One programme would serve to study the thermal-hydraulic phenomena and the associated structure dynamic interactions on basis of a prototypical bubbler condenser configuration for the Hungarian PAKS nuclear power plant. The technical concept of this programme has some similarity to the NABUCCO test concept developed earlier by the OECD Support Group.

A second programme would verify the structural integrity of certain components of the bubbler condenser steel structures under DBA-typical conditions. It will be closely linked to the prototypical structures of the DUKOVANY and/or BOHUNICE nuclear power plants and may be considered as a first experimental response to the findings of the above-mentioned IAEA-sponsored structural assessments.

Later on, and supplementary to these two specifications, a third specification has been drafted and added to the Terms of Reference for the Bubbler Condenser Experimental Qualification Project /TOR96/. Analytical studies were requested which should be supported by a number of small-scale separate effects tests. These studies would mainly serve to facilitate the final design of the larger multi-systems test rig and provide assistance in the interpretation of its future experimental results.

Technical proposals ("Prequalification Reports") have been submitted by potential Eastern European Research Institutes which were based on the above mentioned technical specifications resulting from the Qualification Feasibility Study. These proposals have been submitted to and adopted by the EC. They are considered as the main basis for the future PHARE/TACIS-funded experimental and analytical Bubbler Condenser Containment support programme.

The Electrogorsk Research and Engineering Center for Nuclear Power Plant Safety (EREC) near Moscow (Russia), the Power Equipment Research Institute (VUEZ) in Levice (Slovak Republic) and

SVUSS in Bechovice (Czech Republic) were selected as local Eastern subcontractors to perform a considerable part of the engineering work. The submitted technical proposals closely followed the specifications issued by EC. The general structure of the PHARE/TACIS project is shown in Figure 9.

The specification for the EREC works addresses primarily items which in the frame of UBCRP were associated with the NABUCCO proposal. The Qualification Feasibility Study considered a single 2x9 gap-cap element arrangement (see Fig.10) as sufficient to address the open questions of the condensation tray behaviour. The proposed test rig is to a certain extent similar to the NABUCCO concept. Preservation of the mechanical properties of the tray and the gap-cap systems, closely linked to the existing configuration of the PAKS Nuclear Power Plant as one of the beneficiaries of the PHARE/TACIS project, resp. the use of original structures has been requested by the specification. Existing differences between the structural design of the bubbler condenser trays of the PAKS plants and those of the Czech and Slovak plants (DUKOVANY, BOHUNICE and MOCHOVCE) as well as of ROVNO and KOLA should be assessed by the contractors to warrant the general applicability of the expected test results.

Several characteristic volume and/or flow area ratios have been taken into consideration to preserve similarity to full size plants, or at least preserve the typicality of the test rig arrangement and its mode of operation. Some supplementary scaling studies will be necessary and performed for the correct interpretation of experimental results addressing the transient mixing of the released steam with the air initially present in the hermetic compartment system.

The necessary analytical support will be covered by the third component of the common PHARE/TACIS project. The items requiring analytical activities are again comparable to those described by the UBCRP report. Scaling and interpretation of test results are the primary objectives. Suitable codes to serve this purpose will be used in the frame of the project to meet the analytical needs reconfirmed by the Feasibility Study.

The test specification for the work to be performed at VUEZ covers the experimental qualification of the bubbler condenser mechanical structures, specifically the DUKOVANY and BOHUNICE structural configuration. Static pressure differential tests have been requested to simulate the initial pressure build up in the bubbler condenser which may occur in a transient with a rate of less than 1 bar/s thus neglecting dynamic effects. The purpose of this test programme is to verify the structural integrity of the pressure retaining boundary of the bubbler condenser trays under quasi static differential pressure as expected during the first moments of a postulated Design Basis Accident. The tests will be performed by pressurising the test facility in small steps not larger than 0.01 MPa. The first step shall be at 90% of the yield strength of the pressure retaining boundary. Afterwards, the pressure shall be increased in steps of approximately 1/10 of the test pressure until the required maximum test pressure has been reached.

These proposed static structural tests aim to address some essential shortcomings identified by analytical assessments performed on behalf of the comprehensive IAEA activity. All these studies came to conclusions that part of the bubbler condenser structure stresses as predicted by strength analyses would exceed admissible values at distinct points and certain structures may fail in case of a large break loss-of-coolant accident (DBA-type accident).

The work to be performed at SVUSS complements the thermal-hydraulic and fluid-structure interaction tests proposed by EREC. A set of small scale experiments shall be defined to support and complete the investigations in the multi gap-cap system arrangement at EREC. The existing test rig at BECHOVICE will be used after some reconstruction.

In addition, analytical activities shall be contracted to SVUSS to perform pre-test analyses, support the selection and positioning of instrumentation and perform post-test analyses. As specified in /TOR96/ computer codes selected for this task shall have the potential to analyse in detail the processes and phenomena decisive for the understanding of the thermal-hydraulic and fluid-structure interaction tests expected from the above mentioned EREC and SVUSS working programmes.

The need for additional integral large scale confirmatory tests (the original driving force to construct the ZUETES facility) was not confirmed by the Feasibility Study. Non-uniformity of flow rates and flow properties over the bubbler condenser tower height (stratification in vertical direction) and the spatial and integral effects of the passive spray system were the main objectives of some supplementary tests proposed within the frame of the UBCRP project to be either executed at ZUETES or by a modified NABUCCO test section (see also section 6.2 of this report). The Feasibility Study concluded that the aspects of the structure dynamic behaviour of the trays of the originally envisaged ZUETES test programme could be studied by parametric testing in the EREC test facility. The possibility of vertical stratification upstream of the tray system and the phenomena associated to the passive spray system could be studied in a future supplementary test programme if the need would continue to exist.

8. RECENT UTILITY INVESTIGATIONS

Some containment-related issues are of specific importance for the commissioning and future licensing of the MOCHOVCE nuclear power plant. In view of the delayed execution of the EC-funded PHARE/TACIS project, the problems which have been ranked as of high safety significance by IAEA have been addressed meanwhile by the utility to demonstrate adequacy of the proposed improvements by additional own studies. Very recently, dynamic and static pressurisation experimental programmes have been carried out with pressurisation rates up to 150 kPa/s and up to a differential pressure level of 30 kPa in a specific experimental set-up in the Tlmace (Slovak Republic) laboratories involving eight original gap/cap systems in a one-level arrangement with reinforced structures typical for the MOCHOVCE plant improvements. These tests have been performed to verify the pressure induced loads during the initial phase of a loss of coolant accident until completion of the gap/cap clearing process to respond to the IAEA recommendations /IAE95c/ for structural improvements of the bubbler condenser system. First results of this activity have been communicated on occasion of a public Nuclear Society Information Meeting held in Levice (Slovak Republic) in November 1997 (NUSIM 97). Non-reversible plastic deformations of the cap sheet and the tray stiffeners have been reported/FRE97/. Static testing under gradually increased overpressure also resulted in plastic deformation of walls and some elastic deformations of bottom and ceiling sheets. Details of the testing conditions and of the obtained experimental results have not become available during the NUSIM97 meeting. Pending full assessment of these tests, the utility expects the functional capability of the bubbler condenser to be demonstrated.

Additional experimental and analytical activities in connection with the commissioning of the MOCHOVCE reactor were devoted to study some thermodynamic aspects of the bubbler condenser in the small-scale BECHOVICE test facility. These separate effects test type investigations were aimed:

- to provide information on conditions for steam condensation oscillations possibly endangering the bubbler condenser structures,
- to study pool swell and water carry over through the DN 500 check valves to the air traps, and
- to check the functionablity of the DN 250 valves during the gap/gap clearing process.

Some results have been shown, some of which are again confirming the oscillatory nature of the condensation process inside this small test arrangement/RJE97/. A thorough assessment of these tests is advised upon availability of a full test report to better streamline the future execution of the PHARE/TACIS sponsored bubbler condenser qualification project. Particular attention should be devoted to study the potential for resonance effects between the steel structures and oscillatory condensation processes in a larger test arrangement.

9. CLOSING REMARKS

The OECD, through its Nuclear Energy Agency, sponsors the OECD Support Group on "VVER-440 Bubbler Condenser Containment Research Work" that has reviewed the earlier research performed to support the design and operation of the bubbler condenser containment system of VVER-440/213 nuclear power reactors. The Group has identified the main issues that must still be addressed and concluded that additional confirmatory research is needed.

The NEA's Unified Bubbler Condenser Research Project (UBCRP) and the European Commission's "VVER 440-213 Bubbler Condenser Qualification Feasibility" concluded that the execution of a bubbler condenser experimental programme must be considered as a necessary minimum to fully assess the functioning of the bubbler condenser tower and to assure its reliable operation in case it should be required during an accident. Confirmation of the reliability of the bubbler condenser containment system would improve the confidence in the safe operation of VVER-440/213 reactors. The proposed activities constitute a high priority issue within the frame of a nuclear assistance programme to establish an adequate level of reactor safety. The OECD Support Group is fully supportive of the currently proposed EC PHARE/TACIS project to assess the reliability of the bubbler condenser system.

Inclusion into the activities of the Nuclear Energy Agency with its CSNI Committee was very beneficial in assuring the most efficient exchange of international experience when executing this type of research. Expertise accumulated with the work on BWR-oriented pressure suppression system behaviour in Western countries will continue to assist the execution of similar experiments for the bubbler condenser containment system in the future.

The OECD Support Group on "VVER-440 Bubbler Condenser Containment Research Work" will continue to keep abreast of the status of the EC PHARE/TACIS project, and assess the results, both analytic and experimental, coming from the appropriate research programme. In doing so, the OECD Support Group will endeavour to use the available resources effectively and to avoid duplication of effort.

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/M.o.M.8/ Prague (February 1996)
/M.o.M.9/ Levice (May 1997)

Table 1: VVER-440/213 Nuclear Power Plants Equipped with Bubbler Condenser Containment Systems

FACILITY	**COMMERCIAL OPERATION**	**UNIT**	**COUNTRY**
KOLA	12/82 12/84	/3/ /4/	RUSSIA
PAKS	8/83 11/84 12/86 11/87	/1/ /2/ /3/ /4/	HUNGARY
DUKOVANY	8/85 9/86 5/87 12/87	/1/ /2/ /3/ /4/	CZECH REPUBLIC
ROVNO	9/81 7/82	/1/ /2/	UKRAINE
BOHUNICE MOCHOVCE	5/85 3/86 under construction under construction under construction under construction	/3/ /4/ /1/ /2/ /3/ /4/	SLOVAK REPUBLIC
GREIFSWALD	shutdown	/5/	GERMANY

Table 2: Some Design Characteristics Of Nuclear Power Plants With Pressure Suppression Systems

		PEACH BOTTOM	**LIMERICK**	**GRAND GULF**	**KRÜMMEL**	**GUND-REMMINGEN**	**MOCHOVCE**
TYPE OF CONTAINMENT		GE-MARK I	GE-MARK II	GE-MARK III	KWU-BL69	KWU-BL72	VVER-440/213
DESIGN OVERPRESSURE	BAR	3.9	3.85	1.05	3.5	3.3	1.5
THERMAL POWER	MWt	3293	3293	3833	3800	3800	1375
FREE CONTAINMENT VOLUME	m^3	8100	11400	44300	7600	14500	48210
FREE VOLUME/THERMAL POWER	m^3/MWt	2.46	3.46	11.3	2	3.82	35
WATER VOLUME	m^3	3480	3530	3850	3700	3100	1360
WATER VOLUME/THERMAL POWER	m^3/MWt	1.06	1.07	1.01	0.97	0.818	0.99
NUMBER OF CONDENSER PIPES/ GAP-CAP SYSTEMS	-	74	106	78 (horiz.)	72	64	1800

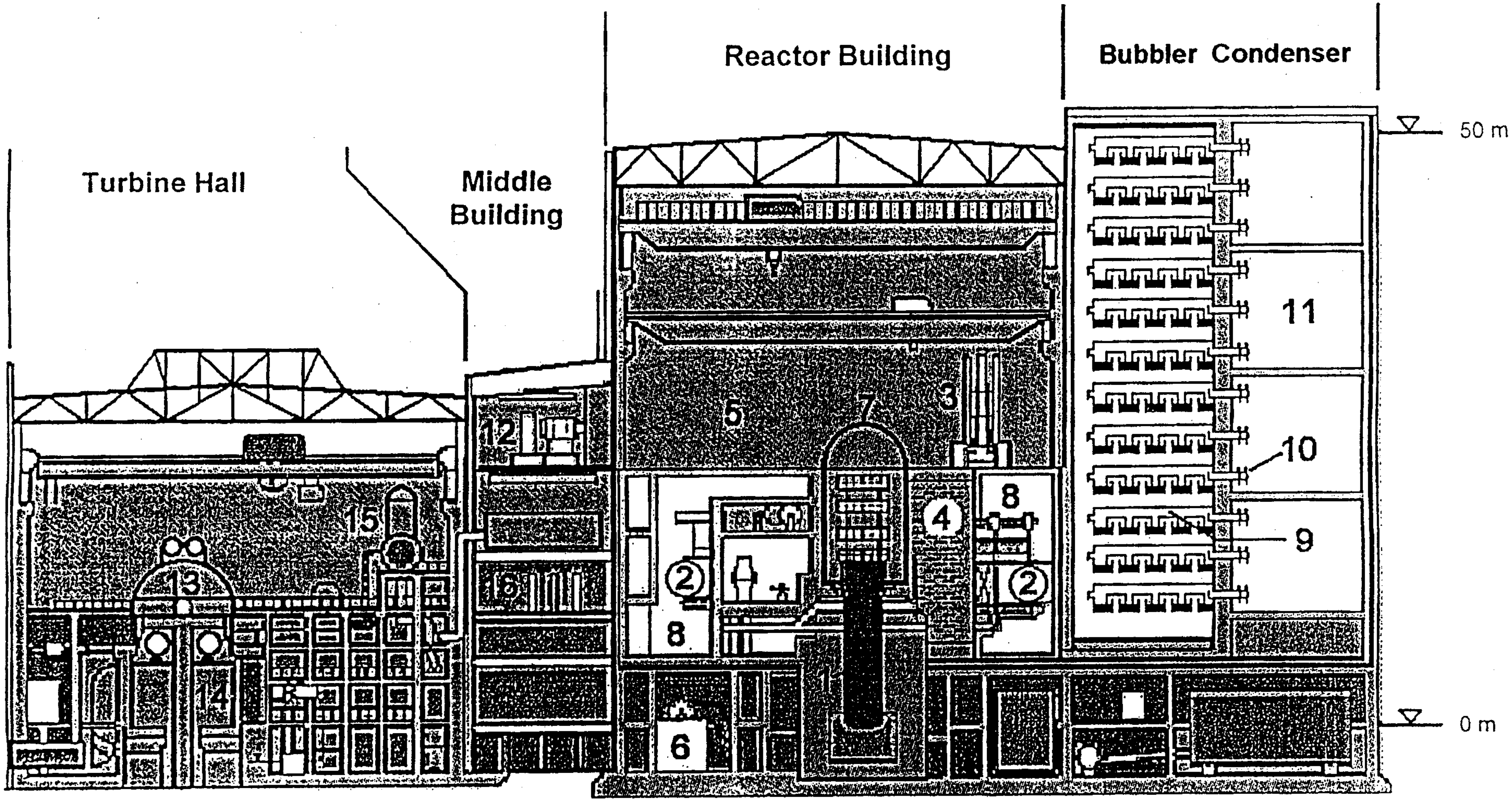
Table 3: General Overview On Main Technical Issues Of Phenomena Processes, Required Methods Of Testing And Coverage By Analytical Simulation

Processes/Phenomena	**Main Technical Issue**	**Required Methods of Testing**	**Coverage by Existing Analytical Simulation Methods**
Gap/Cap Clearing	Mechanical Loading of Water Trays during Initial Pressurization	Confirmatory Integral Experiments Necessary	Adjustements to Cope with Gap/Cap Geometry required
Pool Swell	Possible Water Entrainment into Air Traps	Confirmatory Separate Effects Tests desirable	Reasonable
Oscillatory Condensation and Chugging	Possible Resonance between Oscillatory Frequencies and Structural Eigenfrequencies	Large Scale Response Tests of Gap/Cap Elements necessary	So far Modelling Concept not applicable
Thermal Efficiency of Trays	Local and Integral Steam Condensation Efficiency	Confirmatory Tests on Efficiency Distribution necessary	Well
DN500 Check Valve Flow to Air Traps	Behaviour of Flow Resistance and Water Entrainment	Separate Effects Tests desirable with Confirmatory Integral Testing	Reasonable
Activation of Passive Spray	Thermal Effectiveness within Shaft	Integral Test necessary	Improved Model Concept necessary
DN250 Valve Behaviour	Limits of DN250 Valve Activation	Separate Effects Tests sufficient	Well

Table 4: Suitability of Existing and New Test Facilities to Address Relevant Bubbler Condenser Phenomena/Processes

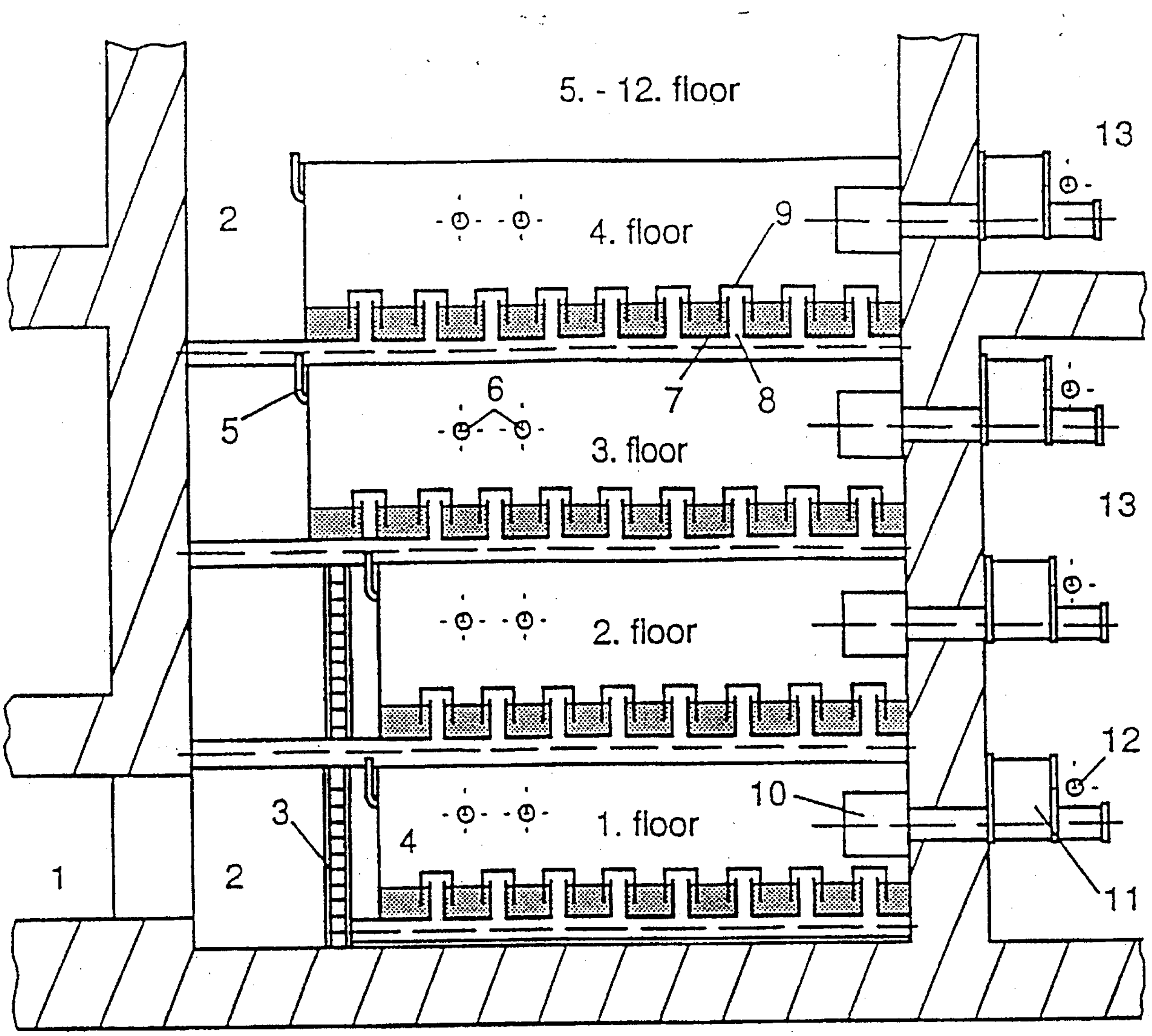
Phenomena/Processes	**Bechovice Small Scale Test Rig**	**NABUCCO Horizontal Section**	**ZUGRES**	**NABUCCO Vertical Section**
Gap/Cap Clearing	++ for SET	o for IT	+ for IT	(+ for IT)
Pool Swell	++ for SET	+ for IT on large trays	++ for IT vertical distribution	(+ for IT) vertical
Oscillatory Condensation and Chugging	? (structural properties)	++ for IT (use of original tray elements)	- (structural properties)	+ for IT if structural properties preserved
Thermal Efficiency of Staggered Trays	-	-	++ for IT	+ for IT
DN 500 Check Valve Behaviour	o	o	o	o
Activation of Passive Spray	-	-	+ for IT	+ for IT
DN250 Valve Behaviour	?	?	?	?

++ well suited + suited o limited - not suited ? questionable SET Separate Effects Tests IT Integral Tests



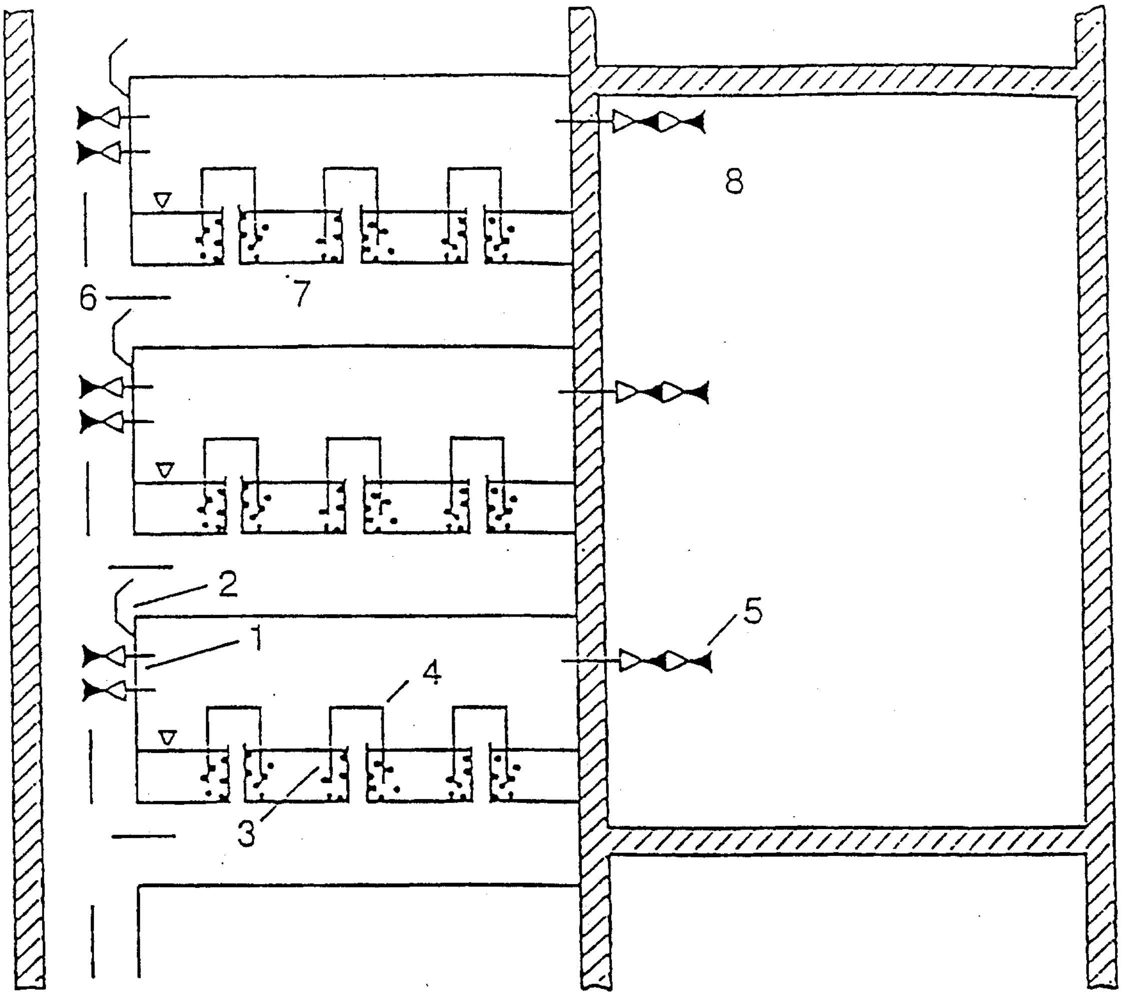
1. Reactor pressure vessel, 2. Steam generator, 3. Refueling machine, 4. Spent fuel pit, 5. Reactor hall, 6. Make-up feedwater system, 7. Protective cover, 8. Confinement system, 9. Bubbler condenser trays, 10. Check valves, 11. Air traps, 12. Intake air unit, 13. Turbine, 14. Condenser, 15. Feedwater tank with degasifier, 16. Electrical instrumentation and control compartments

FIGURE 1: THE VVER-440/213 REACTOR CONTAINMENT SYSTEM WITH BUBBLER CONDENSER AND AIR TRAP BUILDING



1 - channel connecting bubbler condenser with hermetical compartment system
2 - gasshaft
3 - protection wall
4 - gasroom
5 - perforated sheet for passive spraying
6 - valves Ø 250 between gasshaft and gasroom with interlocking mechanism
7 - tray
8 - gap
9 - cap
10 - inlet protection duct
11 - check valves Ø 500 (in series)
12 - damper device of check valves Ø 500
13 - air trap

FIGURE 2: GAP/CAP SYSTEM ARRANGEMENT ON STAGGERED WATER TRAYS



1 Pressure relief damper, 2 x NB 250 parallel
2 Perforated sheet for water sparging
3 Pressure suppression pool
4 Deflection hood
5 Check valves, 2 x NB 500, in series
6 Inlet shaft, pressure suppression pool
7 Inlet duct to pressure suppression pool
8 Air trap

FIGURE 3 : DETAILS OF THE GAP/CAP SYSTEM ARRANGEMENT CONNECTING TO THE AIR TRAP

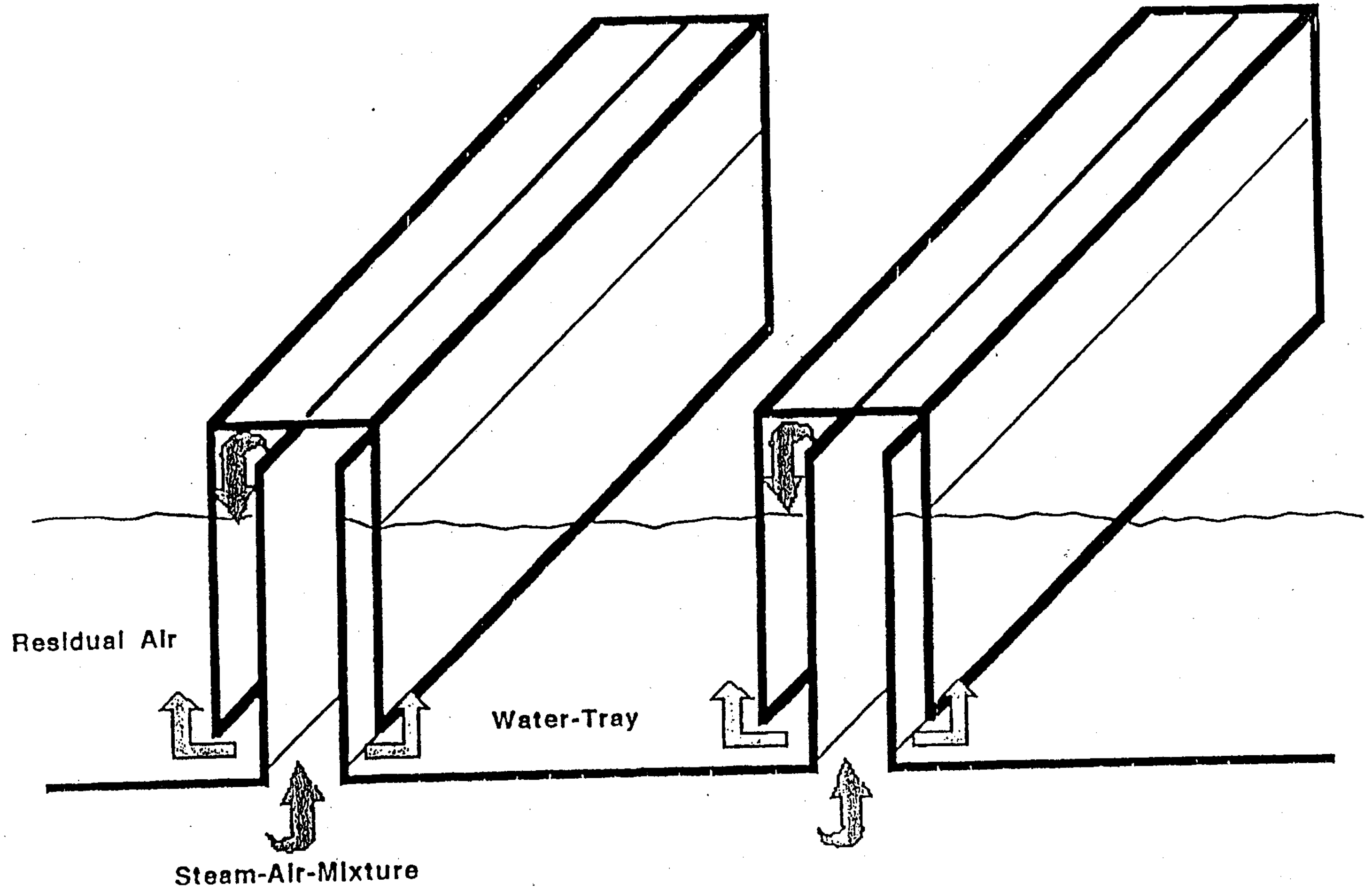


FIGURE 4 : FUNCTIONAL SCHEME OF THE GAP/CAP CONDENSATION SYSTEM

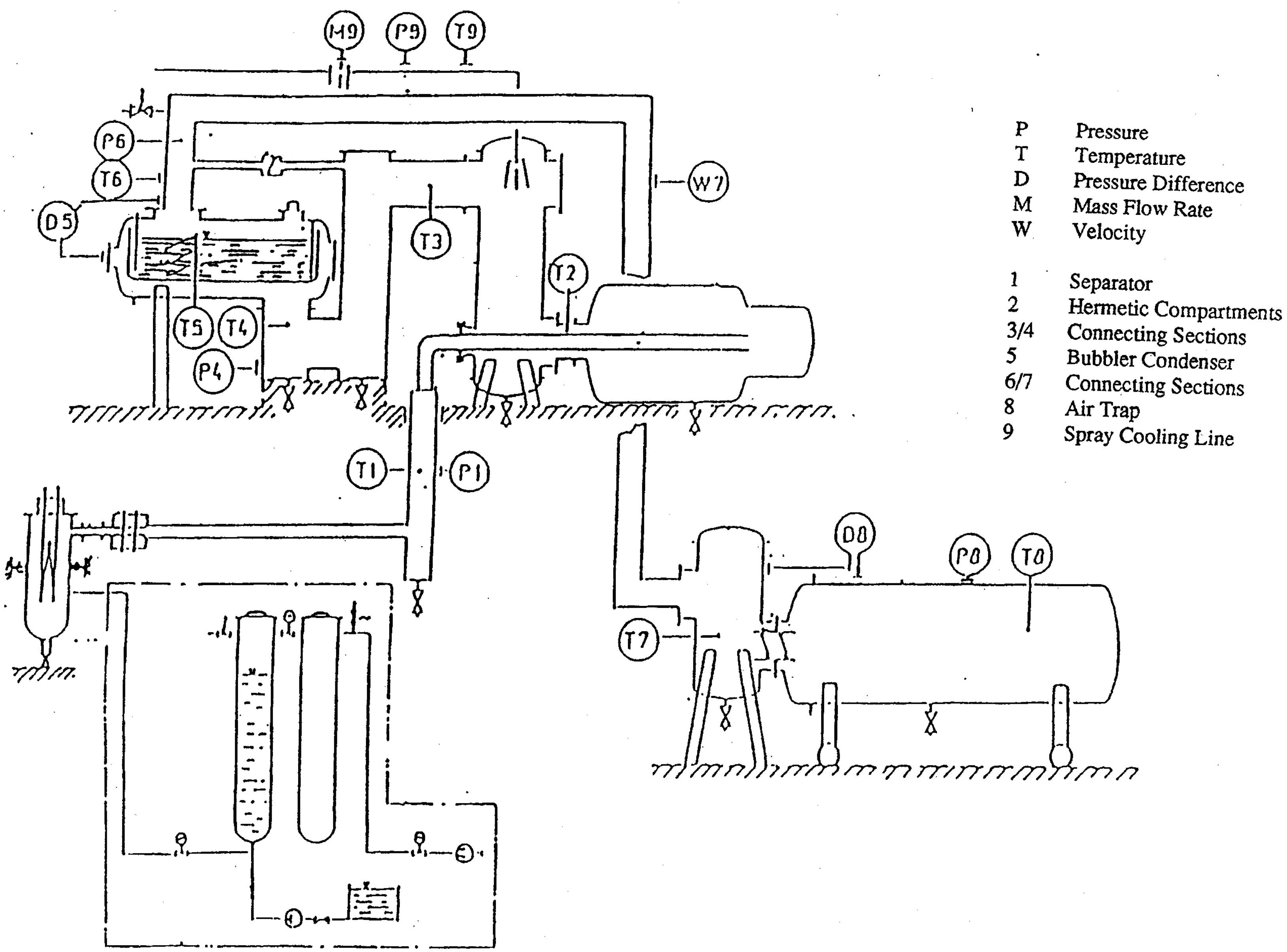


FIGURE 5: SCHEME OF THE EXISTING SVUSS BUBBLER CONDENSER TEST RIG
(2 HALVES OF A FULL-SIZE GAP/CAP SYSTEM)

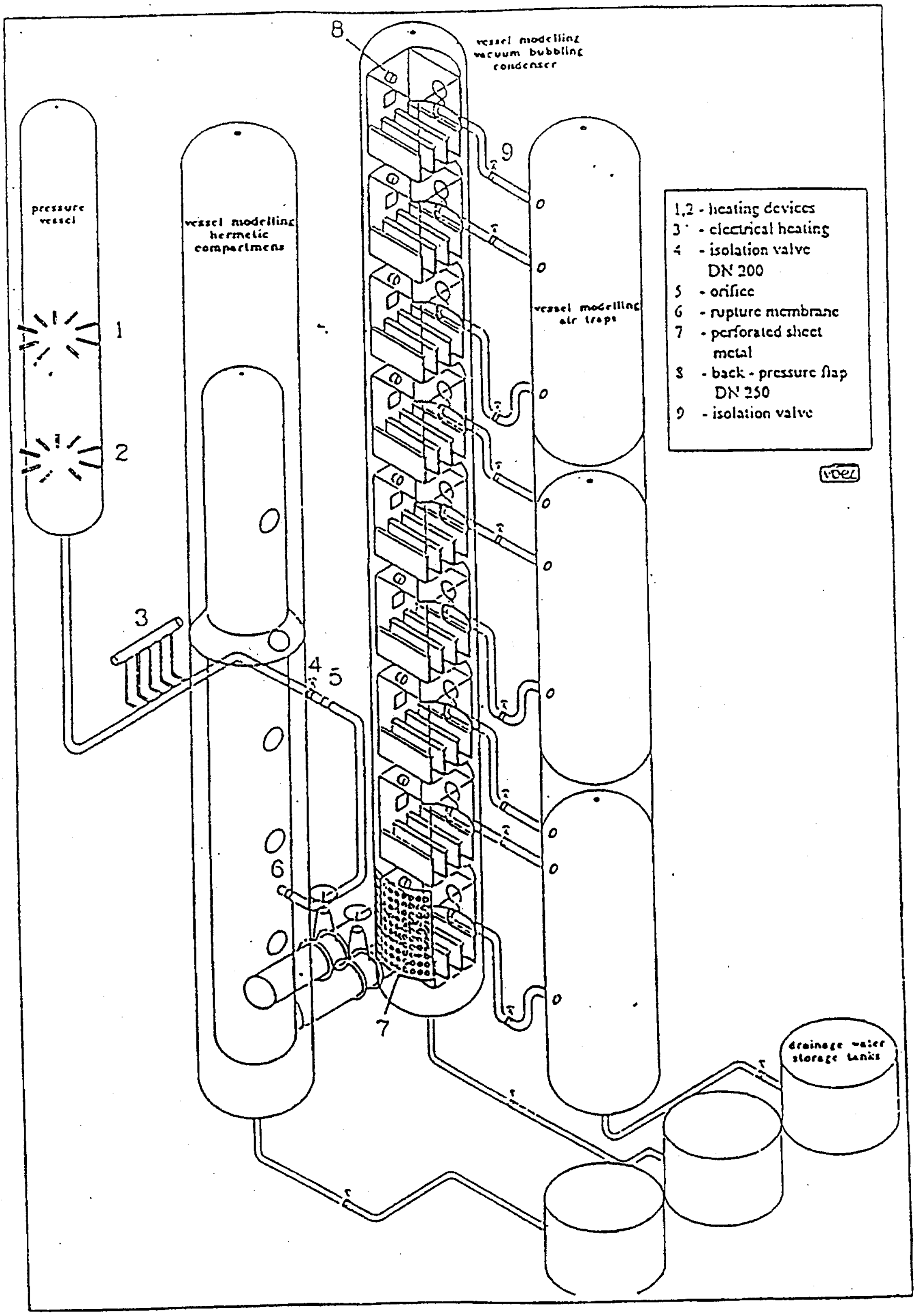


FIGURE 6: PERIPHERAL VIEW ON THE LARGE-SCALE ZUGRES BUBBLER CONDENSER MODEL

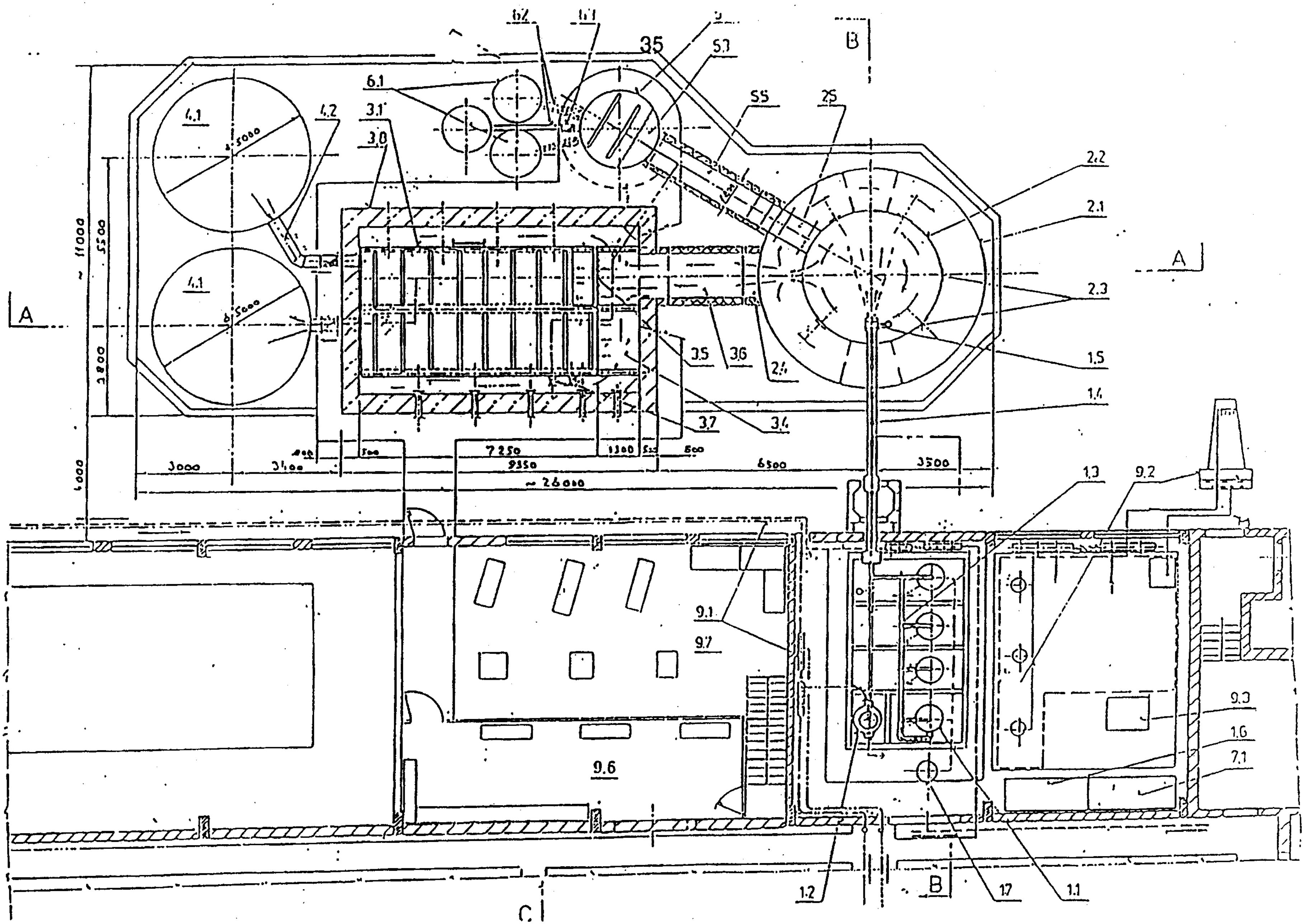


FIGURE 7: HORIZONTAL CROSS SECTION OF THE NABUCCO TESTING CONCEPT

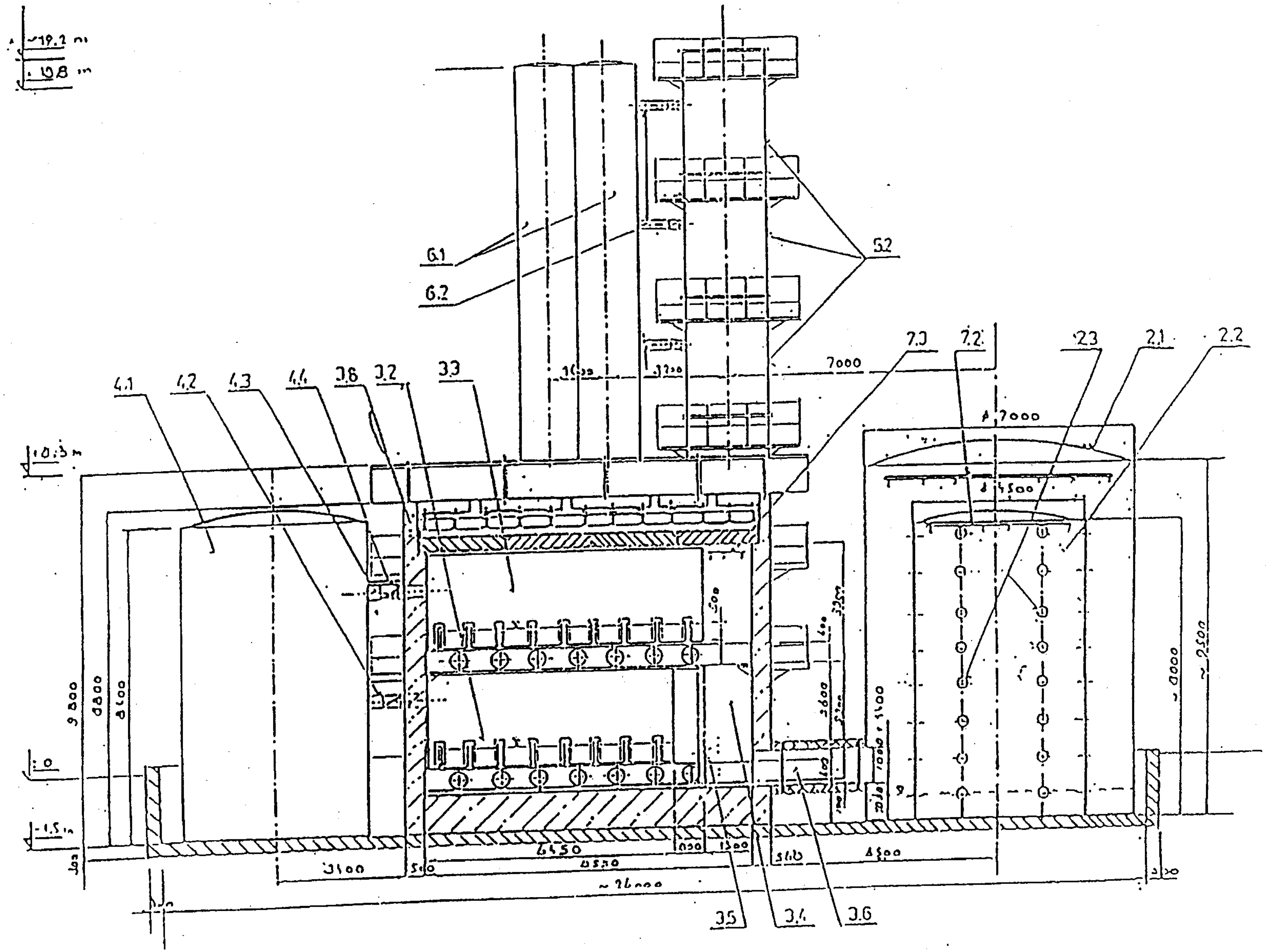


FIGURE 8: VERTICAL CUT THROUGH THE NABUCCO TEST RIG CONCEPT

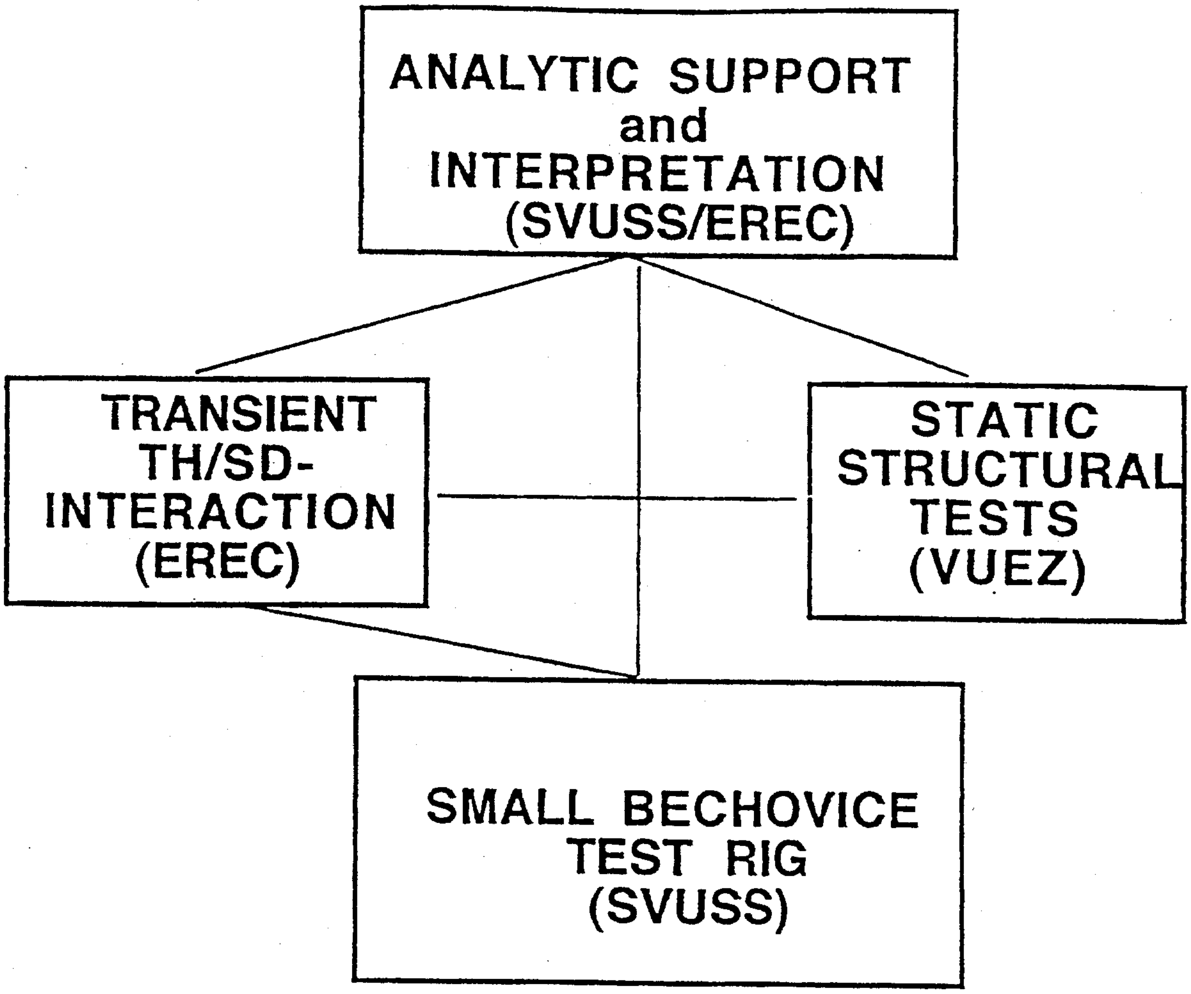
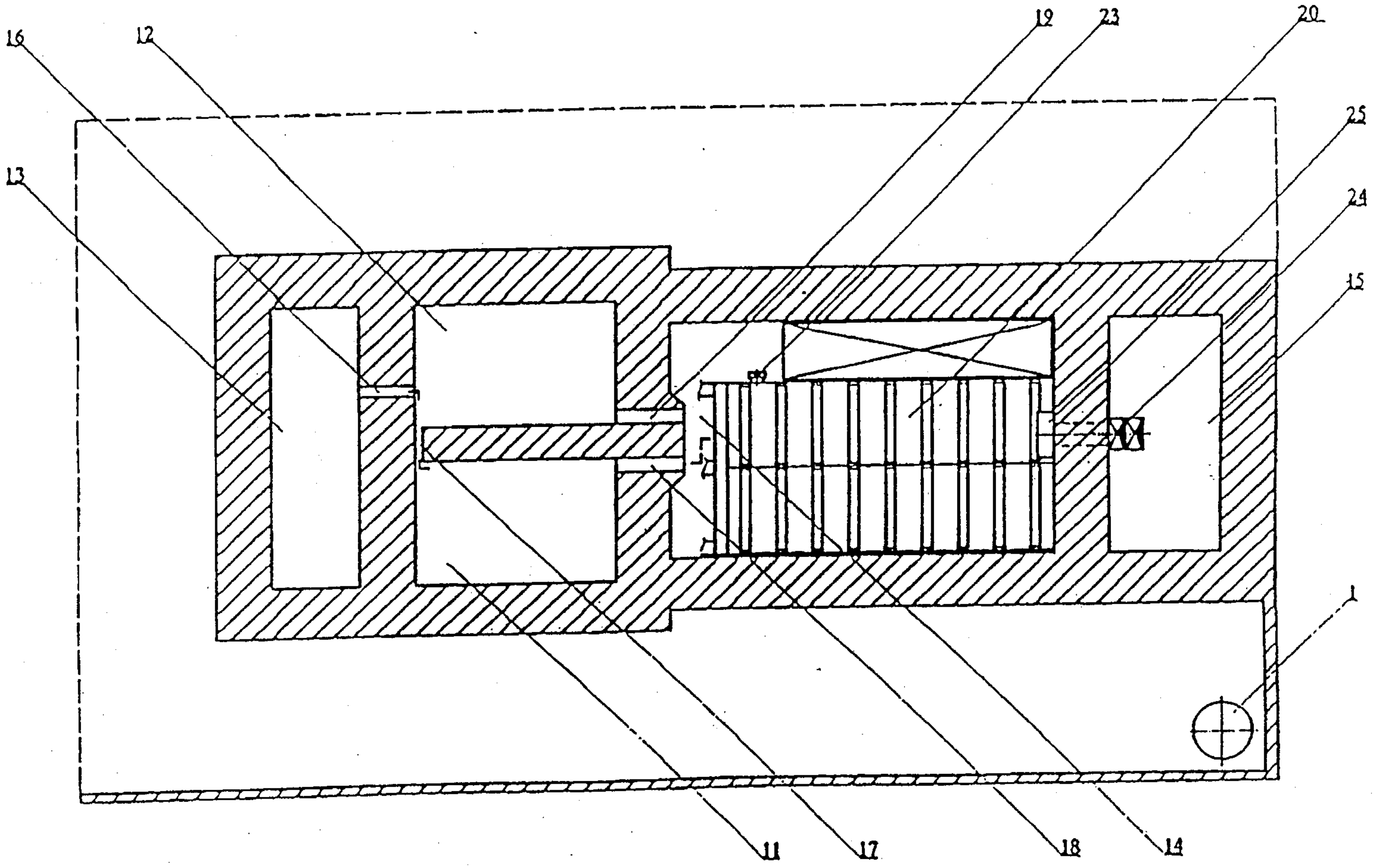


FIGURE 9: STRUCTURE OF THE PHARE-TACIS BUBBLER CONDENSER RESEARCH PROJECT



LEGEND:

1	ENERGY RESERVOIR
11	COMPARTMENT 1
12	COMPARTMENT 2
13	DEAD END-COMPARTMENT
14	SHAFT VOLUME
15	AIR TRAP
16	FLOW PATH
17	JUNCTION
18	CORRIDOR SIMULATOR
19	CORRIDOR SIMULATOR
20	BUBBLER CONDENSER
23	CAP
24	CHECK VALVES
25	DEFLECTOR PLATE

FIGURE 10: HORIZONTAL CUT THROUGH THE THERMALHYDRAULIC / STRUCTURE DYNAMIC TEST CONCEPT OF THE PHARE/TACIS PROJECT