THINY-WALLED 1 : 20 PRESTRESSED CONCRETE PRESSURE VESSEL MODEL FOR THTR REACTOR TYPE

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ABSTRACT

This paper gives preliminary information on tests performed on a 1:20 PCPV model for a reactor HTGR type. The model refers to an advanced design of a PCPV devised by the Author. This pressure vessel has been developed and designed on the basical inputs data of a German pressure vessel THTR type (edition 1966).

The peculiarity of this design consists in the thinning of the walls, reduced to the thickness (cylindrical walls) required for biological shielding. The tests have shown the reliability of the purposed solution that once reconfirmed by further experiments and investigations will lead to a money saving in the order of many million dollars.

1. INTRODUCTION

This paper summarizes the basic data and test results relevant to a 1:20 advanced PCPV model. The model design is based on the experience acquired by the Author during about 8 years in designing and testing small-scale models of PCPV or portions like rings and cap slabs. The reference prototype is the VEW 300 MWe, THTR type, German reactor (edition 1966).

A previous model based on the current phylosophy of designing was tested during 1967 (see fig. 1 showing the cut-out section after the ultimate tests (at 192 ate). The present German pressure vessel and the reference solution (advanced model) can be easily compared in the figs. Nos. 2 and 3. In the fig. 4 is represented the real section of the model whose diameter (~ 16 m) is exactly the same than the German prototype. The height of the model corresponds to the first design of the German pressure vessel (18. 30 m) in order to have a direct comparison between the two small-scale models. We point-out that the present height of the German prototype is 15. 30 m. In the above-mentioned figs. 2 and 3, the model was represented reduced by 3 meters in height, to evidence the considerable reduction in the wall thickness of the design; that is:

	German Prototype (meters)	Advanced Model (meters)
1. Cylindrical Walls	4. 45	2. 50 (^)
2. Cap Slabs	5.10 - 6.60	3. 36 - 4. 50

(^) Minimum per biological shield

2. ASSUMPTIONS

The advanced solution is mainly based on the following assumptions and inputs data:

- the triaxal state of stresses acting on this kind of structures, seems to us to be able to allow a highest value of stress with respect to that conventionally assumed
- the geometry of the structure must take into consideration the experimented collapse asset (inverted dome for the slabs) and easy of construction (uniform outside shaping)
- the thickness of the walls and slabs shall be such as to assure an adequate biological shield
- working pressure P_w = 40 ate
- ΔT across the walls (ultimate conditions) 10°C
- structural collapse safety margin $> 2,5$
- quasi-elastic behavior (1. 5 P_w) up to 60 ate
- fully compressed structure for the operating conditions.

3. MODEL IDENTIFICATION CARD (Figs. 4, 5, 6, 7)

The main data of the model are given in Table I "Model Identification Card".

4. MAIN TEST RESULTS

Because of coincidence of time testing with Conference time, we are now in the position of giving only some basic information.

4.1 Elastic Tests

The Fig. 8 shows the comparison between the deflection on the model and those calculated (finite element method). The calculation does not simulate the penetration effects. The test results shown, represent the average values of a very high number of cycles in the elastic range up to 40 ate. (Deviation from the average is absolutely negligible).

4.2 Ultimate Tests

The Fig. 9 represents the behavior of the structure up to 80 ate as far as the deflections are concerned. In the Fig. 10 are shown the cracks in the cylindrical walls occurred from 70 ate (first visible cracks) to 90 ate. The collapse of the model occurred at 120 ate, because of the breakage of one cable of the hooping cable system at the height of the blower penetrations.

Fig. 11 shows the cut-out model after the ultimate test.

No cracks appeared in both the cup slabs.

5. CONCLUSIONS

We are in a too early stage to give detailed conclusive comments. But, we believe that the few first information given are enough self-evident to demonstrate the validity of the concept. What we can say now is that the safety margin of this structures already is very conservative and that we are able to drive the ultimate of the structure (breakage of the vertical or circumferential cables) with minor changes in the quantity of the prestressing steel of one system with respect to the other.

We would like to point out that, in our opinion, the behavior of such structures must be focused more in the so-called elastic range than in the ultimate conditions and particularly up to the "Reversibility limit" as was defined in our previous papers. This limit, that for the reference model is in the order of about 90 ate, gives the real limit of the pressure that can be withstood, even cracked, by the structure. Up to this limit, the prestressing steel of the cable must still behave in the elastic range, that is, we are in the field of small deformations (and small cracks) that do not affect the liner integrity.

The PCPV is, therefore, still able to "reverse" to work in the previous conditions. (Above this pressure, the structure should be rejected).

Coming to economic considerations, this solution allows a reduction in the order of 60% in the materials and relevant loads on foundations. In addition, we have a significant reduction of the diameter of the Reactor Building. This implies a very high reduction of the construction and long-term costs. Special attention must be paid to the seismic problems related to these Class I structures which result facilitated.

Furthermore, we believe that this solution can also be helpful for the people involved in the studies for the application of PCPV concept to water reactors.

In the next future we will continue our experimental work in this field, hoping that our proposal can be taken in consideration by the constructors in order to achieve the purpose that mainly leads our works; to contribute to keep the nuclear plant costs down and to render the nuclear source of electricity more and more competitive.

AKNOWLEDGEMENTS

I would like to express my appreciation to the Direction of the ISMES Institute and especially to Mr. Verdelli who has solved all the intricate problems related to the construction and instrumentation of this model, and to my precious collaborator Mr. Ranieri.

Thiny - walled 1 : 20
P. C. P. V. model for THTR
Reactor type

"IDENTIFICATION CARD"

Model scale	1 : 20	
Dimensions	Total height H=136,5 cm Internal height h= 91,5 cm Cup-slabs thickness - center hc=16,8 cm - shoulders hs=22,5 cm External radius Re=52,5 cm Internal radius Ri=40,0 cm	
Materials	<u>Microconcrete:</u> Granulometric curve cubic type Aggregates: - siliceous sand (Torre del Lago) up to 1 mm - calcareous gravels (Zandobbio) up to 8 mm - Portland cement 425 - 400 Kg per cubic meter - water-cement ratio 0,475 - additive Chebau-Verflussiger 0,2% Ultimate compressive cubic strenght of microconcrete at 28 days on 16x16x16 cm sample K_{rc} 28 = 440 kg/cm^2 $K_{rc\ test}$ = 522 kg/cm^2 Ultimate tensile strenght at 28 days on cylindrical sample ϕ 10 cm h=20 cm (Brasilian test) K_{rt} 28 = 25,5 kg/cm^2 $K_{rt\ prova}$ = 32,7 kg/cm^2 Young modulus on prismatic sample 16x16x32 cm in the range 10 ÷ 70 kg/cm^2 E_c = 400.000 ÷ 360.000 kg/cm^2 Poisson ratio = 0,20	

H 5/6	Model identification card	N. 2 of 3
follows Materials	Cable steel: Supplier - Redaelli S.p.A. - Milano, Italy Proportionallity limit: K_s = 0,1% = 147,7 kg/mm^2 ϕ 6 mm 140,7 kg/mm^2 ϕ 7 mm Apparent elastic limit: K_s = 0,2% = 151,7 kg/mm^2 ϕ 6 mm 145,0 kg/mm^2 ϕ 7 mm U.G.S. K_{rugs} 169,7 kg/mm^2 ϕ 6 mm 165,3 kg/mm^2 ϕ 7 mm Young modulus E_s = 2,1 x 10^6 kg/cm^2	(mean value)
Prestressing	- BBRV - System - Cable efficiency 0,992 K_{rugs} Prestressing system: - vertical system n. 36 x 2 monowire cables ϕ 7 mm -. circumferential system: Slabs: - cable monowire ϕ 7 mm - n. 3 hooping cables per layer. Total 12 - layers per slab n. 12 x 3 x 2 = 72 anchor-heads on 12 buttress 30° - cylinder: 6 mm monowire cable as per slabs Total n. 26 layers Cable pattern - Ing. Scotto Patent - London - Conference 1967 Initial prestress: - Vertical cables ϕ 7 - 79% (UGS) - slab circ. cables ϕ 7- 83% (UGS) - cyl. " " ϕ 6- close to the slab 81% close to the center 67% friction coeff. f = 0,15 Cable geometrical data: Rc1 = 48,1 cm Rc2 = 49,3 cm Rc3 = 50,5 cm	5208 kg per cable 5541 " " 4071 " " 3409 " " internal cable radius medium " " external " "

H 5/6	Model identification card	N. 3 of 3
follow prestressing	Curved portion angles: $C1 = 282^{\circ}\ 44'$ $C2 = 229^{\circ}\ 48'$ $C3 = 178^{\circ}\ 18'$	
Instrumentation	N. 19 - thermocouples N. 80 - inductive displacement transducer - W 20 type N. 43 - load cells on cable heads N. 98 - strain-gauges 20 mm on concrete	 Hottinger ISMES
Basical test results	$P_{ic} =\sim 60$ ate $P_{vch} =\sim 70$ ate (^) $P_{vcv} =\sim 80$ ate (^) $P_{r} = \sim 90$ ate (^) $P_{c} = 120$ ate (^) on cylindrical external surface. No crack up to 120 ate in slabs.	first instrumental cracking first visible crack-horizontal idem vertical reversibility limit collapse
Basic contructional and testing data	- Pooring of the model Maj 17th, 1971 - Prestressing - July 20th, 1971 - Elastic tests - August-Sept. 1971 - Ultimate tests: first crack: Dec. 15th 1971 collapse: Jan. 13th 1972	

The cost of the model (construction and testing) is of the order of 100.000 $.

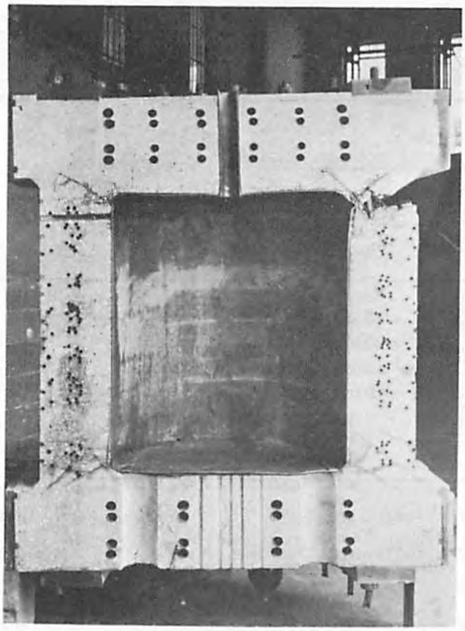

Fig. 1 - Cut-out Section of 1 : 20 PCPV Model, THTR Type Reactor (Ed. 1966)

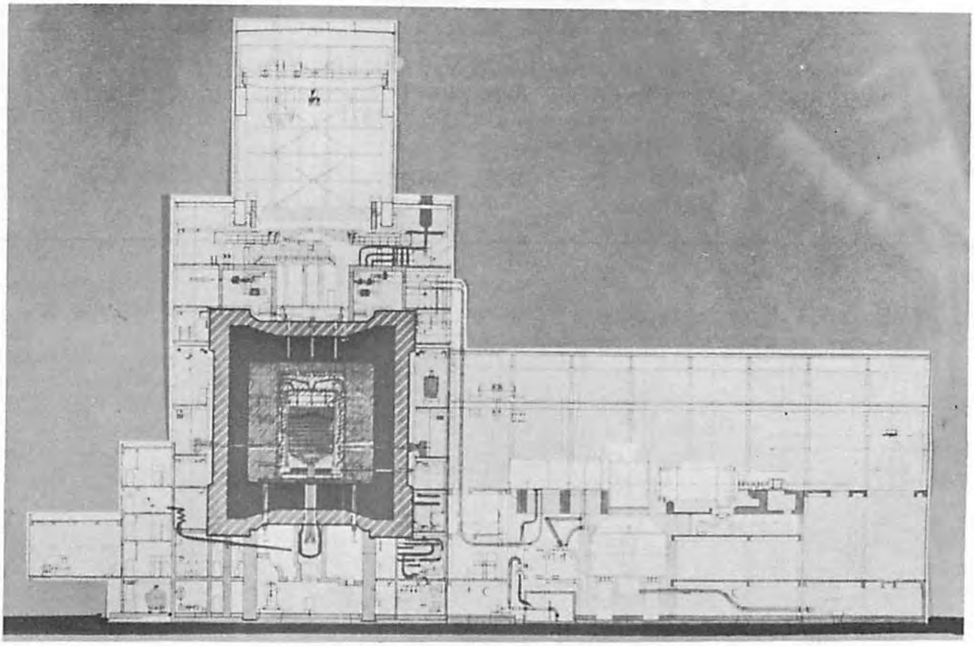

Fig. 2 - Longitudinal Section of THTR German Reactor (Ed. 1971).

Comparison between the thiny PCPV solution (black) and the actual PCPV (black + dashed)

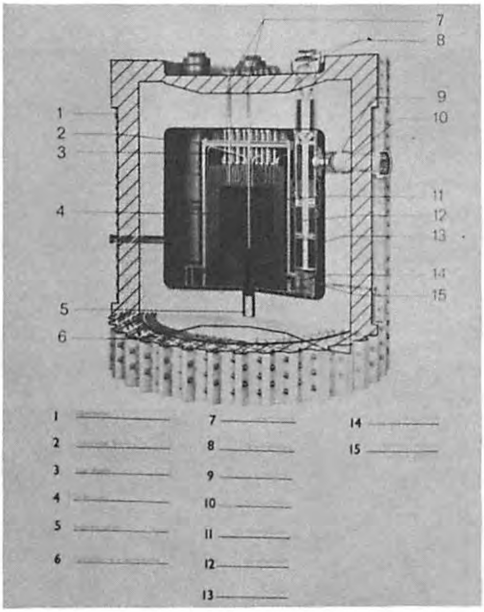

Fig. 3 - Section of THTR German Reactor (Ed. 1971)

Comparison between the thiny solution (white) and the actual PCPV (white + dashed).

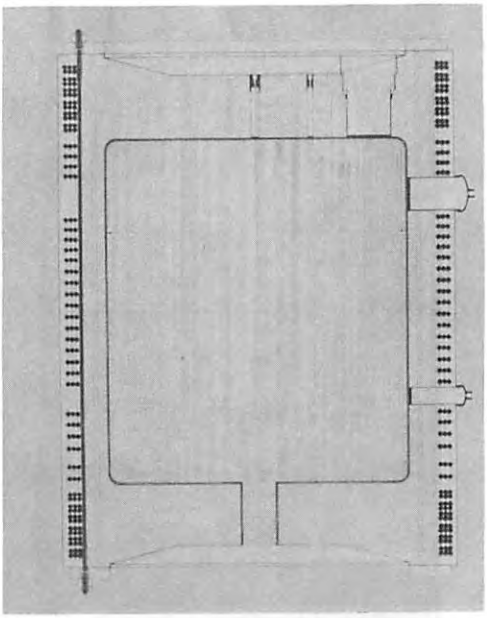

Fig. 4 - Vertical Section of the 1 : 20 PCPV Model

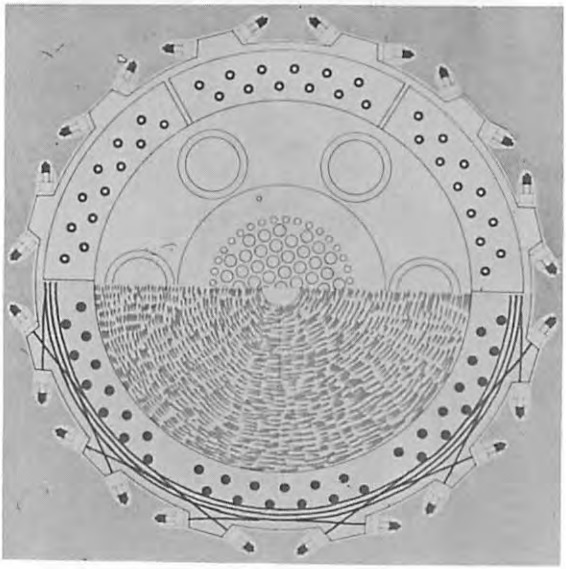

Fig. 5 - Horizontal Section of the 1 : 20 PCPV Model and plan view.

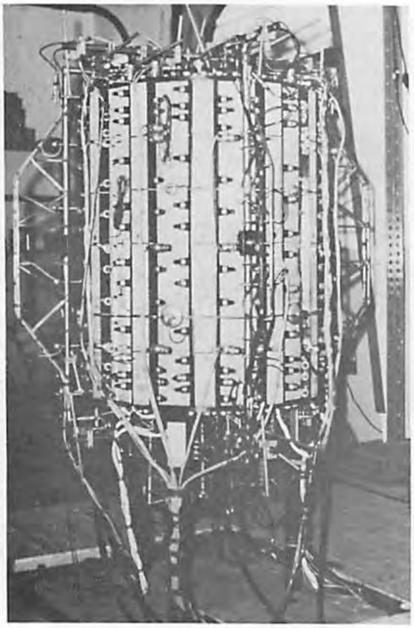

Fig. 6 - 1 : 20 PCPV Model

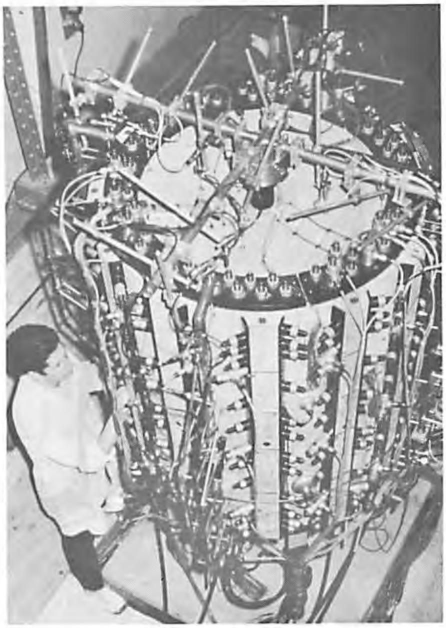

Fig. 7 - 1 : 20 PCPV Model

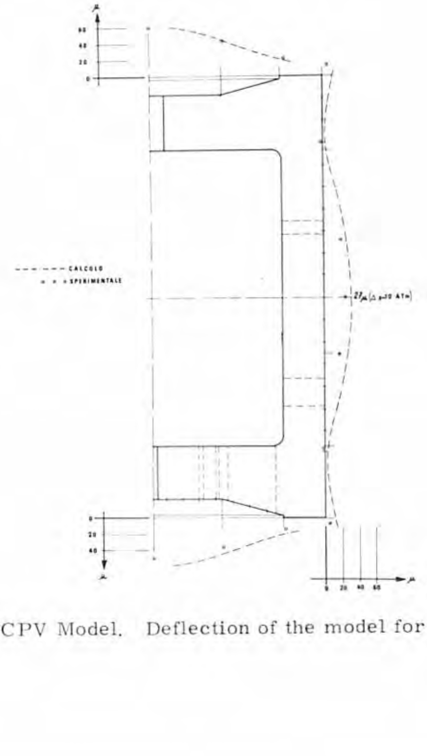

Fig. 8 - 1 : 20 PCPV Model. Deflection of the model for Δ T = 10 ATE

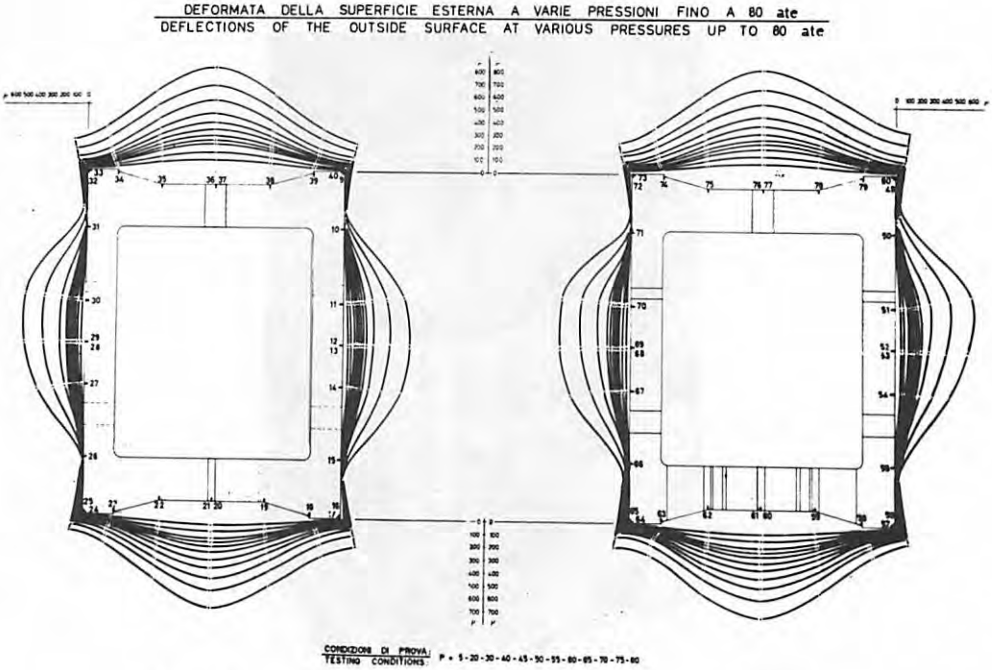

Fig. 9 - 1st phase ultimate tests up to 80 ate - deflections.

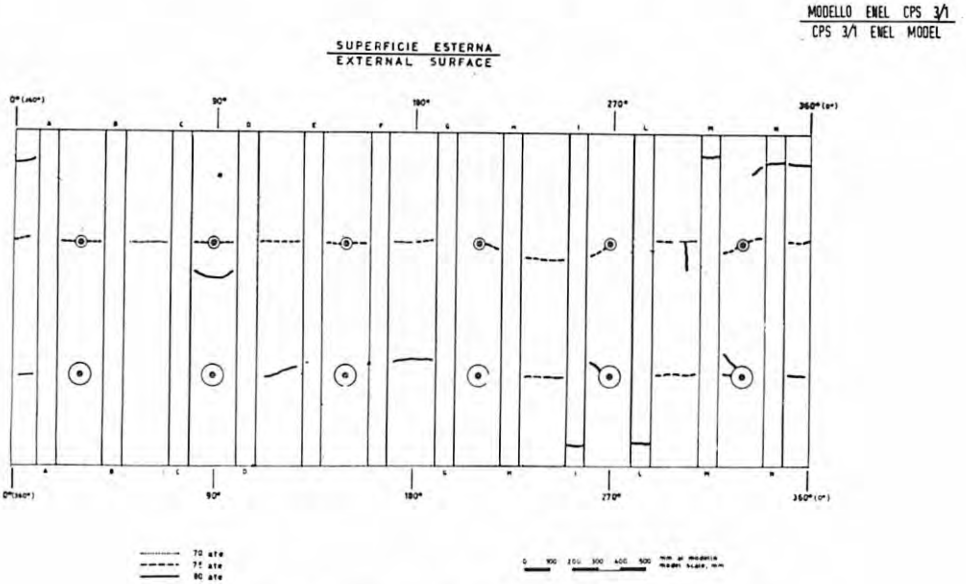

Fig. 10 - Crack pattern at 70; 75; 80 ate on the outer cylindrical surface.

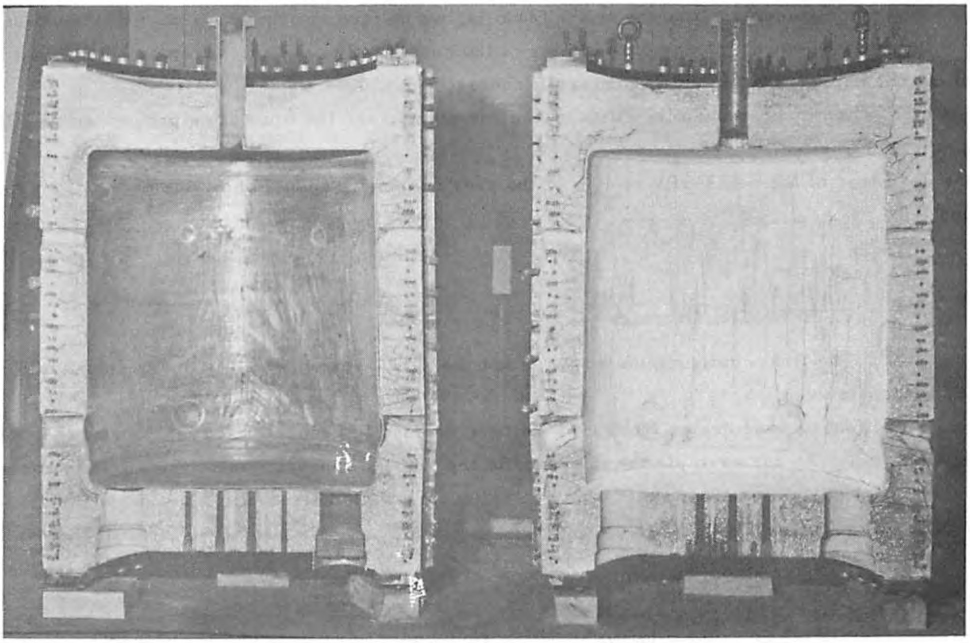

Fig. 11 - Cut out model after the collapse.

DISCUSSION

Q P. LAUNAY, France

We understand that you have reduced the dimensions of the former PCPV in:

1. Taking in account a triaxial effect,
2. Increasing the permissible stresses.

Do you have some more reasons or motivations ?

A F. SCOTTO, Italy

You have correctly understood. We intend to reduce the safety margin of the structure, that for the former PCPV was about 5 times the working pressure (model result), to the commonly accepted margin of 2.5. That is, we believe, on the basis of our model test practice, that the present way of designing is too conservative and that it is possible to better utilize the characteristics of the material (concrete).

Our motivation is: to reduce the costs of nuclear plants, and the foundation problems (specific load; seismic effects, etc.).

The dead load of the new PCPV is 40% of the previous one (a reduction by the order of 20,000 tons !).

Q F. BREMER, Germany

The first configuration shown is not the THTR vessel which is under design and will be constructed.

As a result out of your design from 1966 we have decided to reduce the dimensions of the vessel extremely. As for example the thickness of the slab by approximately 1.50 m. It seems that the seal design is already that what you call a thin-walled structure. So what is the sense of your investigation ?

A F. SCOTTO, Italy

Our model is referred to the first design jointly prepared in 1966. With respect to your present design, the situation is the following:

	German Design(Meters)	Italian Model(Meters)
- Diameter	15.95	15.95
- Internal Height	15.30	18.30
- Cylindrical Wall Thickness	4.45	2.50
- Slabs	5.10 - 6.60	3.36 - 4.50

The internal dimensions of our model refer to the previous design in order to compare the new situation (thin-walled) to the previous one (with special regard to the ultimate conditions). On the basis of our experience acquired on small-scale models, we intend to demonstrate that it is possible to reduce the dimensions of the walls (and, therefore, loads, costs, diameter of the Reactor Building, etc.) and the relevant safety margins of the structure, to the

acceptable limits ($P_u > 2.6\, P_w$), where P_u = ultimate pressure and P_w = working pressure.
The ultimate tests on our model (January 1972) have shown a safety margin of 3.
$P_u = 120$ atm and $P_w = 40$ atm.
The sense of our investigation is to achieve a cost reduction. From our analysis, we have estimated that our solution can lead to a reduction of 4 to 5 million dollars.
The thickness of cylindrical walls is to be considered coincident with that required for biological shielding. This represents the true thin-design limit.