"THIN WALLED" CONCEPT AND A NEW TOP LID APPLIED TO THE SCANDINAVIAN PCRV FOR A BOILING WATER REACTOR

F.L. SCOTTO

ENEL, Ente Nazionale per l'Energia Elettrica, Centro Progettazione e Costruzione per gli Impianti Nucleari, I-00198 Rome, Italy

SUMMARY

Most of the world's nuclear plants are of the so-called water type. Said plants are ALL equipped with steel pressure vessels so that the operability of ALL the nuclear plants is strictly related to the efficiency of such basic components!

It comes out from the above, in the opinion of the Author, that it is almost "prudent" to try to develop and prepare alternative and possibly more economical and safe solutions.

This is precisely the purpose of the research that is the subject of this paper. This research is carried out in the frame of an agreement between AB ATOMENERGI of Sweden and ENEL (Ente Nazionale per l'Energia Elettrica) of Italy, for an exchange of information in the field of PCPV for BWR, and takes as a reference the Scandinavian solution as far as the thermal insulation system and the geometry are concerned, proposing new solutions for the prestressed concrete structure (namely the Author's concept of thin walls and a new concept of top lid).

The proposed top lid sealing system solution is in line with the one adopted for the conventional steel pressure vessel enclosures; furthermore the prestressed concrete lid is restricted to the prestressed concrete structure to form a continuous concrete structure, in line with the PCPV conventional solutions for gas reactors.

The paper describes in detail the selected design philosophy that is slightly different from the one defined by the Scandinavian project. In fact, as far as the design limits are concerned, it refers mainly to the steel pressure vessel philosophy and, as to the concrete behaviour, to the design philosophy proposed by the author for the PCPV "thin walled" structures for gas-cooled power reactors.

Rheological, mathematical and physical models had been suitably devised in order to check the reliability of the proposed assumption. This paper therefore, will also give a brief description of said tools and the main results acquired at the time of the conference, and technical and economical considerations made to support the interest of the research, showing the relevant cut down of the costs.

The comparative reference steel pressure vessel belongs to Mark III ENEL VI and VIII BW plant to which design and construction the author gives his contribution.

1. INTRODUCTION

Historically speaking, the prestressed concrete pressure vessel (PCPV) concept was born in the fifties in Europe, namely at Marcoule in sweet France, the country of Freyssinet, the father of prestressing. As a matter of fact, the application of the PCPV concept, must be considered as an obligatory step to solve the problems raised by the second generation of the European gas filieres asking for dimensions and pressures leading to the overcoming of the technological limits allowed by the more conventional existing steel pressure vessels (SPV).

For the large units "gas filiere", High and Very High Temperature (HTR) and (VHTR) and Gas Cooled Fast Reactors (GCFR) the PCPV concept is, at the present, the unique solution; at least, it seems that no other concept could be technically feasible.

For the Light Water Filiere, applied to more than the 90% of all the nuclear power station all over the world, the SPV is the absolute protagonist, but it doesn't represent the "unique" solution. Now, commercial reasons (good exploitation, cost for: research, development, design, licensing practice, established codes, facilities for manufacturing, patents and a lot of other reasons) seem to have frozen the SPV solution. An exception to the rule is represented by the important and meritorious efforts (under full development) of the Scandinavians, under AB ATOMENERGI, for the application of the PCPV concept to their 1000 MWe BWR; also very interesting is the original German research on the matter conducted by FRIED KRUPP.

Following informal contacts made during the 2nd SMIRT in Berlin, a cooperation between AB ATOMENERGI of Sweden and ENEL (State Electricity Generating Board of Italy) is now operative for an exchange of information in the field of PCPV for BWR.

2. ENEL RESEARCH

The ENEL Research, object of this report, made reference to the Scandinavian PCPV as far as the basic input data, the geometry and the thermal insulation system are concerned, while, as to the prestressed concrete structure, application is made of the Author's "thin walls" concept and his new type of prestressed concrete lid (PCL).

2.1. Research purposes and safety aspects

ENEL Research is based on the intention of developing and suggesting for the Light Water Reactor Pressure Vessel, an alternative prestressed concrete solution to the SPV one, with the aim of improving, as much as possible, the structural safety, and to cut down the excessive costs of such basic components.

At the present stage of development of the research, it was decided to hold up the safety problem, in the sense that, both the PV concepts being intrinsically very safe, it was deemed advisable to postpone this intricate analysis to a more advanced phase of the work.

An assessment, from the bibliograpy of the present position on the relative safety merits of steel and concrete PV leads to a sort of "stalemate" position. Mr. I. CAVE in his masterly paper "the future prospects for the PCRPV" concludes his summary on "safety re view" as follows "... Thus a comparison on the safety of the two types of vessel must be based largely on a comparison of the effectivness of the inservice inspection of each type.....".

Agreeing in principle with this line in fact (the steel and the concrete solutions are so different conceptually that a direct comparison is probably meaningless and certainly is different from case to case), attempt was made to improve the safety of the reference solution by easing in each design choice the possibility for the inservice inspections.

Namely the prestressing system of the so called "post tensioning" - not grouted was selected as well as: a BBR type anchorage system, that is no wedge anchorages; the tendons consist of an assembly of single wires, for easy application of a suitable anticorrosive protection; prestressing steel of the stabilized type; cable ducts (gas type) acting like a mild steel reinforcement to improve the ultimate limits of the structure.

For the circumferential prestressing, the "post tensioning" system was preferred to the "wire winding" method, because besides other considerations, (related to the layout of the Reactor Building and scheduling problems), in the opinion of the Author the choice of the "wire winding" system asks for severe provisions to prevent a possible "tendon whip effect" self generated (per corrosion or other reasons) or generated by missiles or steams jets in the dry-well. (This effect can be interactive).

The pattern of the circumferential tendons (post tensioning type), invented by the Author, besides of improving the structural safety, allows the visual inspection ot the outer surface of the PCPV in operation.

Italian interpretation of PCPV differs from the Scandinavian and German ones not only for the solution adopted for the circumferential prestressing system (post tensioning instead of wire winding) but also for the type of removable lid. The solution proposed for the lid tries to remain in the field of accepted solutions and philosophies. (Fig. 1).

Namely, the prestressed concrete lid PCL is fixed to the prestressed concrete "glass" by means of suitable high potency tendons (36 x 1300 t) with the aim to restore an overall structural continuity. This follows the exsisting practice acquired for the gas reactor continuous PV and improves the safety, reducing in addition the displacements of the top of the glass (cfr. H 2/7). The high potency tendon belts replace the function of the SPV anchoring bolts; the head sealing system is the same adopted for the SPV, Metal (Inconel 718) 0 Rings installed in the Lid.

The proposed solution gives, in the opinion of the Author, the advantage to mantain also for the PCPV the established practice and up to a certain extent the rules. In particular, from the safety point of view, both the solutions can experience (theoretically) the same conditions of "lid floating", that is, incorporate a sort of structural self-safety valve.

3. COST CONSIDERATIONS

All roads lead to Rome, it is said in our country, now than is the PCPV way the cheap est one?

From a very rough first approach on a limited number of fundamental items, the answer seems to be largely positive:

		ITEMS	Steel P.V.	Concrete P. V.	COST
			million dollars		
1		Steel P. V. BWR/6	9. -		
2	2. 1	PCPV prestressed steel + concrete		2. -	
	2. 2	Penetrations, cooling system, internals		4. -	
		1 - 2 delta cost			3
		Reactor Building emboding S. P. V.			
3	3. 1	Mark 3 70, 000 mc	6. 4		
	3. 2	Steel primary containement	6. 6		
		Reactor Building emboding PCPV			
4	4. 1	Building 35, 000 mc		3. 2	
	4. 2	Prestressed concrete primary containement steel lined		3. 8	
		3 - 4 delta cost			6
			22. -	13. -	9
		SPV - PCPV	- 13. -		
			9		

It must be clearly said that the figures listed in table 1 should be considered very rough; just as a preliminary basis for judging about the economical interest of developing the research.

The problem of emboding a PCPV in a BW station, has not yet been studied by our team. The schetch of fig. 2 is to be considered therefore as a tentative approach; the seismic effects, for instance, will probably lead to flatten the shape.

4. DESIGNING TOOLS

The true problem for the designer of a PCPV is to define the limits of acceptability of the stress of state of the structure, once satisfactorily defined; these limits, in their turn, will affect the cost.

The stress values, as accepted in the existing codes and standards, impose the construction of oversized structures, as evidenced by the built prototypes and as experienced in our models. In order to elapse from these limitations and better utilize the material resources, it is therefore necessary to dispose of adequate designing tools able to fill the gap existing in the field of the information on the behaviour of the materials adopted for PCPV in the triaxial stress state.

The first problem consists in selecting and defining reliable tools to be used easily, rapidly and economically.

Our designing tools are the physical and the mathematical models of the structure, and the rheological model of materials. More detailed information on these tools and on the basic data coming from the first phase of our research is provided in the reports H 2/7 and H 3/5 which are to be considered an extension of this report and which are also been presented at the Conference.

From the complex recycling of the information provided by each of these tools, it is possible to obtain the calibration of each of them and, consequently, the check on the reliability of the design.

Both the mathematical and the physical models become essential and complementary design means: the first to cover the structural design phase (geometries) and the linear behaviours; the second, with the help of the first one (supplying a global information of the elastic phase) to cover the ultimate states, that is, all the non-linear (short time) behaviours up to the collapse.

5. DESIGN PHILOSOPHY

Our design philosophy is based on the data coming from the SPV BWR/6 specification and design, and on the Author "thin walls" design philosophy concept developed for the HTR reactors (gas filiere).

One of the significant aspects of ENEL research lies in the application to the PCPV for Light Water Reactors of the "thin walls" concept leading to halve the structural dead load with respect to the Scandinavian and German solutions, with all the consequent self-evident constructional and economical benefits (with special care for the sites excited by high motions).

From the examination of the SPV documents we draw the following SPV characteristic limits:

- the safety relief valve upper pressure limit is 88, 87 atm (in some limited areas we can reach highest values of pressure)
- the specified tightness upper limit of the sealing system is 88 atm
- at the pressure level corresponding to the hidraulic test 88 x 1, 25 = 110 atm the pressure vessel head is yet in "floating conditions" and the leak tightness is kept by the 0 ring system by overpulling the anchoring bolts.

Moreover, from elementary calculations, we found that the steel vessel barrel reaches its yield limits at a pressure of about 170 atm while, the anchor bolts, are able to whitstand pressures, well over 200 atm.

From the above, it comes that, from the SPV design accepted performances (philosophy), we can assume that:

- because of the presence of the safety relief valve system, the maximum pressure level that can be experienced in a PV for BWR is assumed to be 88 atm;
- in the SPV the "floating of the head" condition is experienced for pressures of the order of 100 atm;
- the weaker main SPV component is probably the barrel

On this basis and taking into account the geometrical and technological limits resulting from the thinning of the structure, our design has been based on the general assumption summarized in fig. 3.

From the fig. 3 clearly appears the basic choice of our design philosophy establishing to have a "fully compressed concrete structure" at the pressure limit of opening of the safety relief valve system, that is at 85 atm.

Because of this choice, we expect, on the basis of our experience, a "quasi elastic behaviour" of the structure of the "glass" for a range, 0 to 140 atm, largely covering all the possible incidental conditions including the self-safety valve limit that we have fixed at 114 atm by sizing the specially devised system of springs located in the lid (fig. 4).

The "quasi elastic behaviour" of the "glass" will therefore include also the incredible condition of "floating head and tightness loosing" (114 atm) at which the structure will act like a self-safety-valve.

From our experience we can expect that the "glass" will be in the condition to reach pressure of the order of 180 atm still being able to safely "reverse" elastically in the operating range 0 to 70 atm.

The failure of the "glass", because of the collapse of the weaken circumferential cable system, is envisaged for pressure well over the 200 atm ($\sim$ 240 atm), that is, at about 3 times the operating pressure. This limit is well over the corresponding SPV yield barrel limit.

The prestressing system is sized to support a triangular diagram of pressure across the concrete walls 0 to 85 atm to withstand the incidental condition of liner leakages, taking into account also the contribution given by the mild steel cable ducts. (Under this respect the "thin" solution is obviously advantaged).

As shown in fig. 3, the cable system ultimate resistance is duly scaled (the weakest is the circumferential system).

The PC Lid is designed to be the safest element of the PCPV assembly.

6. CONCLUSIONS

Our research work is just in its initial phase, nevertheless the data coming from the mathematical and physical model and reported in the paper H 2/7 and H 3/5 pretty confirm our expectations.

Evidence to this confirmation is given in fig. 5 in which is plotted the deformative behaviour of the "continuous physical BWR model" that practically superimposes the pattern experienced for the thin solution of the gas reactor models, giving thus additional credit to the concept.

It is worth mentioning that for the near future plants, for which very high values of specific power are envisaged, and for the plants to be sited in regions presenting insoluble problems of transportation of the SPV parts, the PCPV is the unique solution.

ACKNOWLEDGMENTS

I owe warm thanks to the Prof. Ing. G. Oberti for his precious advice during the research, I am also indebted to ENEL CPN Manager Ing. R. Lepore, ENEL CRIS Manager Prof. Ing. A. Marazio, ISMES Director Prof. E. Fumagalli and BBR representatives of Italy PREBETON Ing. Marioni and Sonzogno for the assistance given us and to all the valid contributors of the research team.

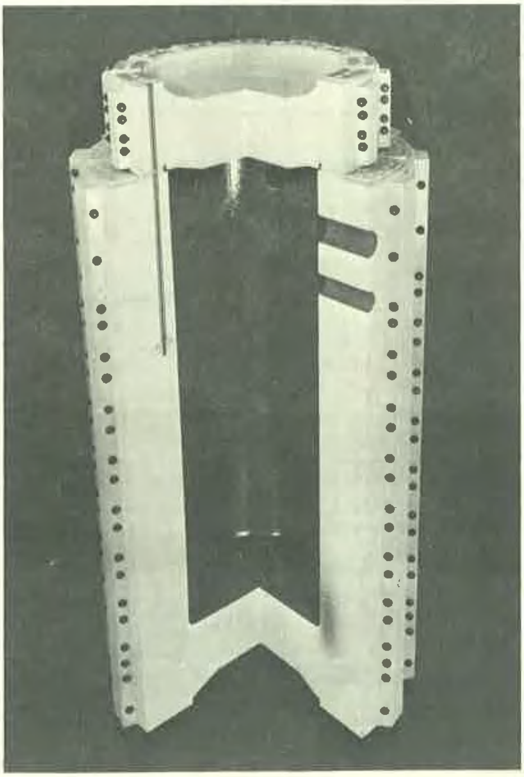

Fig. 1: PCPV for 1000 MW e BWR Power station - ENEL solution.

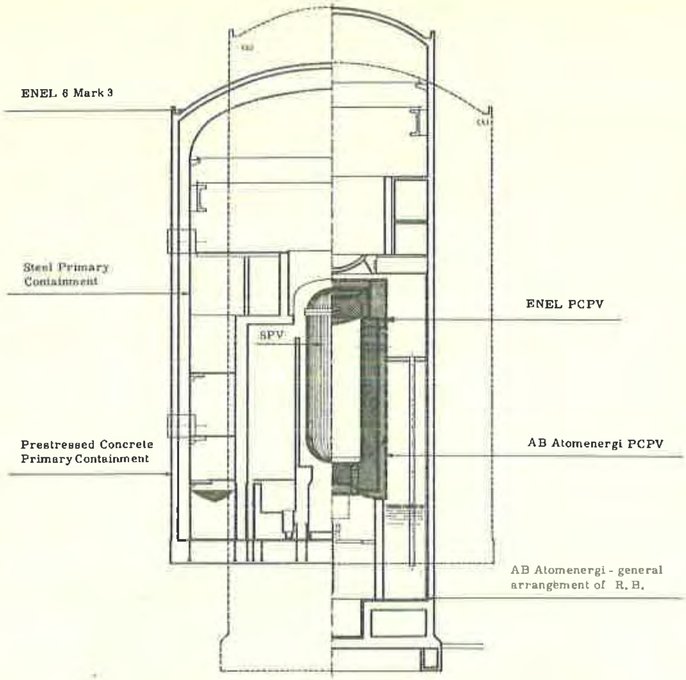

Fig. 2: Reactor Building for BWR - PCPV and SPV solution - Layout comparison.

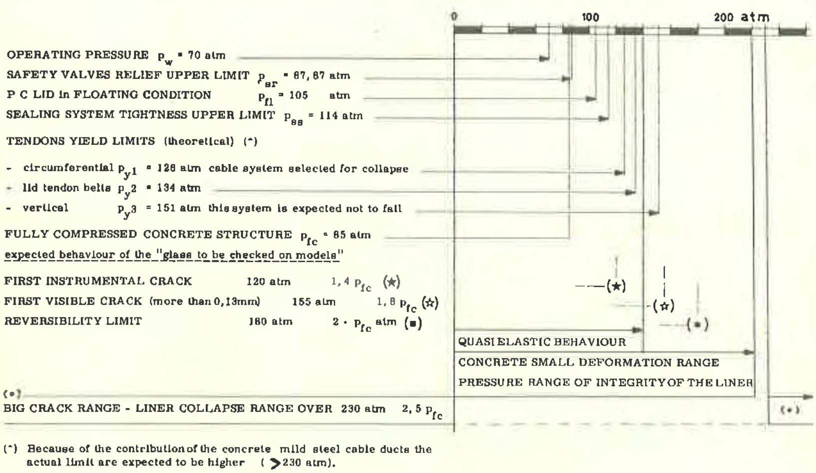

Fig. 3: ENEL - PCPV - Design philosophy.

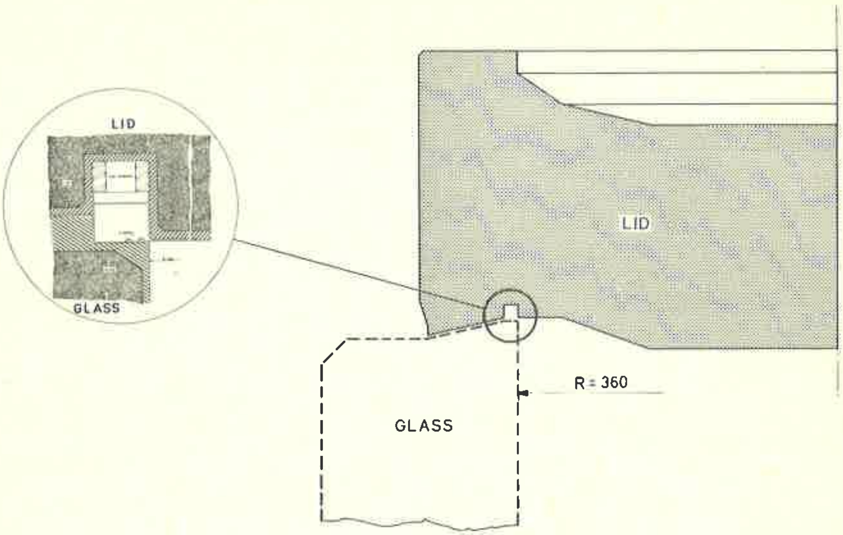

Fig. 4: ENEL - PC LID

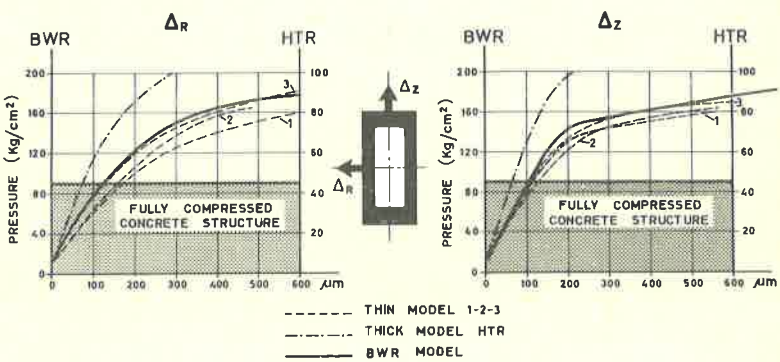

Fig. 5: Comparison between gas and light water model behaviour.