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ANALYSIS OF SEVERE ACCIDENTS ON FAST REACTOR TEST LOOP

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SUMMARY

The Pec reactor is a sodium cooled fast reactor which is being designed for the primary purpose of accomodating closed sodium cooled test loops for the developmental and proof testing of fast reactor fuel assemblies. The test loops are located in the central test region of reactor. The basic function for which the loop is designed is burn-up to failure testing of fuel under advanced performance conditions. It is therefore necessary to design the loop for failure conditions.

Basically two types of accidents can occur within the loops: rupture of gas plenum in the fuel pins and coolant starvation. Somewhat similar consequences can be expected from these two accidents: a large amount of the heat that was built up in the fuel could be transfered to the coolant very rapidly. The design of the loop should take into account the amount of dynamic work that would be done in the relief of the high temperature and pressure consequent to this accident. Explosive tests on Pec loop, whose first set is described in this report, are devoted to investigate the effects of an accidental energy release on loop containment.

The loop model reproduces in the test section the prototype dimensions in radial scale 1:1. Using a wire explosive charge of 300 mm, the height of test section is sufficient for determining the containment capability of the loop that has a nearly constant deformation in a length of 3−4 time the diameter. The inertial effects of the coolant column are reproduced by two tubes at the extremities of test section, closed with top plugs. Some tests has been performed by wrapping around the test section four layers of steel wire ($\phi=0,4$ mm, $\sigma_u=2100$ N/mm^2) in order to evaluate the influence on the containment of tungsten wire that is foreseen in prototype loop. The influence of the coolant around the loop was evaluated by inserting the model in water. Dummy sub-assemblies was used and the explosive substitutes the central rods. Explosives with different detonation rates were used: Plastit, detonation rate 7000 m/sec and E.1, detonation rate 2500 m/sec. Some tests are being performed with "gas producer" consisting of steel container with vent holes in wall delivering gases by cordite combustion. Piezoelectric pressure transducers were mounted on the three plugs and radial deformation was measured directly at different height.

From experiments performed it resulted the importance of harmonic wires and of the inertial reaction of external water on loop containment; maximum containable energy is about 50 Cal with E.1 explosive.

1.- Introduction

The PEC reactor is a sodium cooled fast reactor which is being designed for the primary purpose of accomodating closed sodium cooled test loops for the developmental and proof testing of fast reactor fuel assemblies. The test loops are located in the central test region of reactor.

The basic function for which the loop is to be designed is burn-up-to failure testing of fuel under advanced performance conditions. It is therefore necessary to design the loops for failure conditions.

In order to establish failure design criteria it is necessary to consider:

- accident mechanism with the qualitative descriptions of the sequence and the consequences;
- the available evidence for making quantitative estimates of the consequences.

Basically two types of accidents can occur within the loops:

- rupture of gas plenum in the fuel pins;
- coolant starvation.

Somewhat similar consequences can be expected from these two accidents: a large amount of the heat that was built up in the fuel could be transfered to the coolant very rapidly and this can produce a vapor explosion with high temperatures and pressures being produced in the coolant.

The design of the loop should take into account the amount of dynamic work that would be done in the relief of the high temperature and pressures consequent to a vapor explosion. There are certain analytical and experimental bases for making quantitative estimates of the conditions that can be expected after the accident. Coolant-fuel interaction consequences are difficult to estimate with accuracy: works are still in progress in many laboratories. Hicks-Menzies calculations are now considered over conservatives.

Explosive tests on PEC loop, whose first set is described in this report, are devoted to investigate the effects of an accidental energy release on loop containement.

2.- Model

The loop model (fig. 1) reproduces in the test section the prototype dimensions in radial scale 1:1. The test section (fig. 2) has height h = 700 mm (while the prototype U-loop has a lenght of 16.000 mm). Wall thickness is t = 5 mm and is equal to the sum of the thickness of the two concentric pipes in the prototype.

Using a wire explosive charge of 300 mm, the height of test section is sufficient for determining the radial containement capability of the loop that has a nearly constant deformation in a lenght of 3-4 time the diameter as shown by preliminary tests and confirmed by other laboratories.

The inertial effects of the coolant column (sodium being simulated by water at room temperature) are reproduced by two tubes at the extremities of test section, closed with top plugs. Axial effects arising from accidental energy liberation can not be evaluated by this model that is intended only for axial containement analysis.

Some tests has been performed by wrapping around the test section four layers of steel wire (diameter Φ= 0.4 mm, ultimate stress σ_u= 2100 N/mm^2) in order to evaluate the influence on the containement of tungsten wire that is foreseen in prototype loop (tungsten being used because of its high melting point).

The influence of the coolant around the loop was evaluated by inserting the model in water. Dummy sub-assemblies were used consisting of exagonal box of mild steel (thickness s= 2.5 mm) with 61 copper rods (diameter Φ= 8 mm, interaxis d= 10 mm) inserted in Al-grids (fig. 3). Copper was chosed owing of the fact that its density (8900 kg/m^3) is similar to average density of pins (uranium oxide plus stainless steel).

The explosive substitutes the central seven copper rods and has cylindrical form (diameter Φ= 26-30 mm, height h= 300 mm). Explosive wire is not extended to entire test section lenght; 200 mm at both extremities are occupied by copper rods. This arrengement allows an easy and accurate insertion of explosive charge.

3.- Instrumentation

Main measurement performed were:

- pressure-time histories at different position in the model;
- test section radial deformation;
- plug bolts deformation.

Moreover visual examinations were done on the consequences of explosions on test section and exagonal boxes.

Three piezoelectric pressure transducers were mounted in positions A,B,C (fig. 1) and connected to oscilloscopes with polaroid photocameras and transient records. Test section radial deformations were deduced by direct measurement of pipe circumference elongation. Alternative measurements (that show local deformation) were performed by tracing circumference on the pipe surface at different heights and measuring their deformations after the explosions.

No. 6 bolts of the upper plug were mounted as shown in fig. 4 by using hollow cylinders that become compressed in elastic field during the explosion and are instrumented with strain-gages.

4.- Explosives

Explosives with different detonation rates were used:

- Plastit, detonation rate 7000 m/sec;
- E.1 (Sprengstoff N. 117 Dynamit Nobel), detonation rate 2500 m/sec. Most part of tests were performed with this explosive because of its lower detonation rate in respect with plastit.

Some tests are being performed with "gas producer" consisting of steel container with vent holes in wall delivering gases by cordite combustion and producing a desired pressure vs. time behaviour in order to better simulate the accidental energy release.

5.- Results

Tab. 1 and fig. 5 summaryse experimental results obtained up to now with different loop conditions.

Test No. 1

Charge was 100 g plastit (120 Cal). The loop was wrapped around with four layers of harmonic wire (diameter Φ= 0.4 mm). No experimental results are available because of the rupture of the central part of test section (fig. 6 and fig. 7).

Test No. 2

Charge was 50 g E.1 (50 Cal). The loop was wrapped around with four layers of harmonic wire (diameter Φ= 0.4 mm) and immersed in water.

The harmonic wire was broken. Radial deformation (fig. 5) ranges from 2% to 5.3% along the charge wire. Bolts deformation resulted of 5% in position B and 16.3% in position A. In this test as in subsequent tests difference in bolts deformation as in pressure peak in position A and B is probably due to the secondary pipe connected at the bottom of test section.

Fig. 8 shows exagonal box and test section after the explosion; exagonal box presents a longitudinal rupture.

Test No. 3

Conditions are similar to test No. 2 without water around the test section.

The harmonic wire was broken. Radial deformation (fig. 5) ranges from 2% to 8.2% along the explosive wire. Bolts deformation resulted of 3.4% in position B and 13.4% in position A.

By comparison with test No. 2 one can deduce that inertial effect of water around the loop reduce its radial deformation while increases the energy impacting the plugs at loop estremities.

Test No. 4

Charge was 50 g E.1 (50 Cal) and the bare loop was immersed in water. Radial deformation (fig. 5) ranges from 2% to 7.7% along explosive wire and shows a flat shape for 200 mm in the central region. Bolts deformation resulted of 2.6% in position B and 11% in position A. By comparing with test No. 2 it is possible to see that the harmonic wire causes a reduction and a different shape in radial deformation; consequentely it generates an higher dynamic load on the plugs.

Test No. 5

Charge was 70 g E.1 (70 Cal). The loop was wrapped around with four layers of harmonic wire (diameter Φ= 0.4 mm) impregnated with araldite and immersed in water. Measurements are not available because of the rupture of test section (fig. 9).

Test No. 6

Charge was 50 g E.1 (50 Cal). The loop was wrapped around with four layers of harmonic wire (diameter Φ= 0.4 mm) and two layers of tin wire (diameter Φ= 1.6 mm). Radial deformation (fig. 5) ranges from 2% to 8.5%. Bolts deformation is 3.9% in position B, 7.4% in position A. No appreciable differences are found in comparison with test No. 2 a part a discrepancy in bolts elongation in position A.

6.- Conclusions

From experiments performed it resulted the importance of harmonic wire and of the inertial reaction of external water on loop containement. Maximum containable energy is some more then 50 Cal with E.1 explosive when the test loop is wrapped around with harmonic wire and immersed in water.

TABLE 1

TEST N°	Explosive energy (Cal.)	E max (%)	Pressure peaks (bar)			E bolts (%)		
			Pos. A	Pos. B	Pos. C	Pos.A	Pos.B	
1 - Air - Harmonic wire	100 gr. plastit 120 Cal.	Rupture	-	-	-	-	-	Destruction of test section
2 - Water - Harmonic wire	50 g.E.1 50 Cal.	5,3	2500	1500	700	16,3	5,0	Rupture of harmonic wire
3 - Air - Harmonic wire	50 g.E.1 50 Cal.	8,2	1700	1000	900	13,4	3,4	Rupture of harmonic wire
4 - Water - Bare loop	50 g.E.1 50 Cal.	7,7	1500	700	600	11	1,6	
5 - Water - Harmonic wire with araldite	70 g.E.1 70 Cal.	-	-	-	-	-	-	Destruction of test section
6 - Air - Harmonic wire + two layers of tin(Ø=1,6 mm)	50 g.E.1 50 Cal.	8,5	-	-	-	7,4	3,9	Rupture of harmonic wire; malfunctioning of pressure transducers

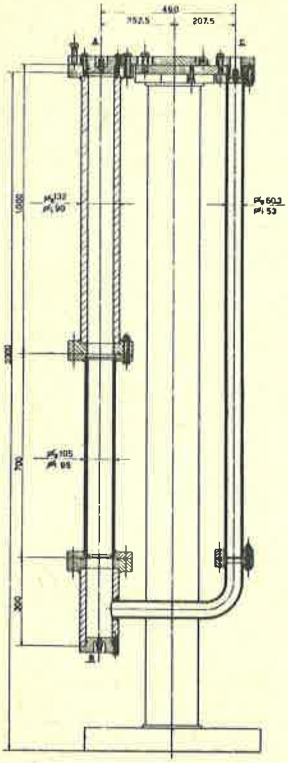

Fig. 1 - Loop model

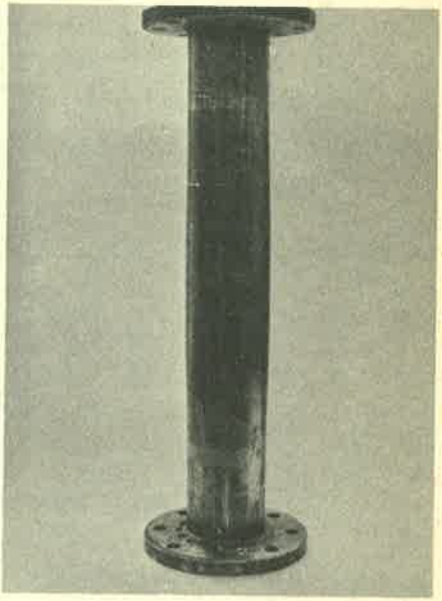

Fig. 2 - Test section

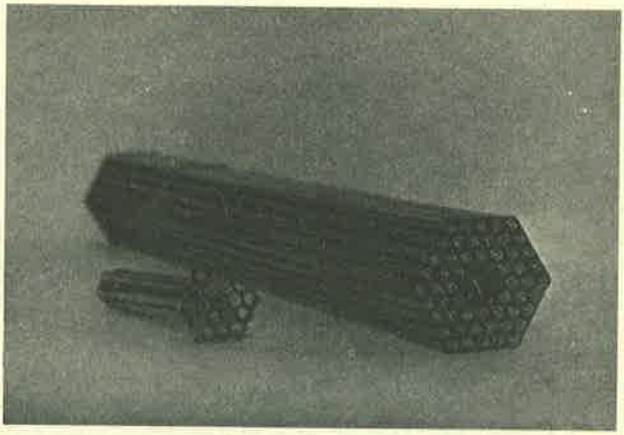

Fig. 3 - Sub-assembly

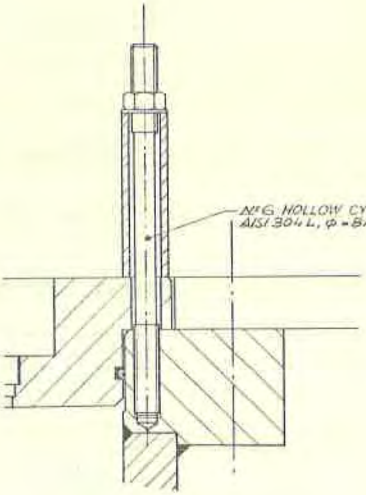

Fig. 4 - Upper plug bolt with hollow cylinder

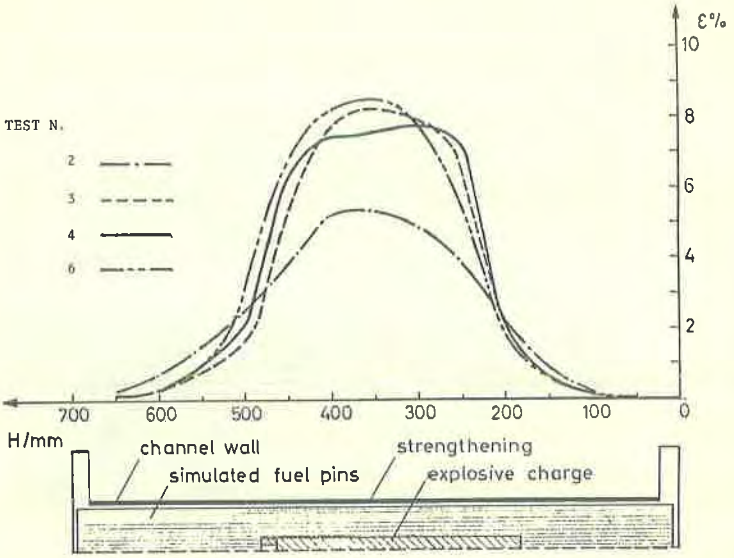

Fig. 5 - Radial deformation of loop along the height

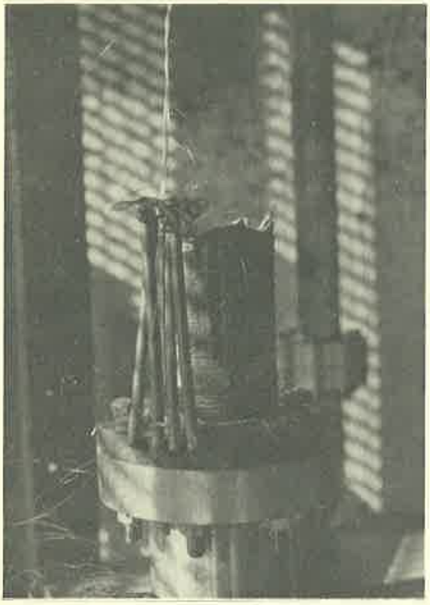

Fig. 6 - Test No. 1 - Loop rupture after the explosion

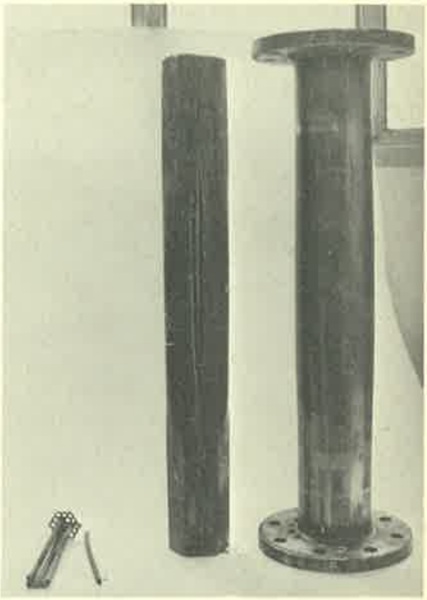

Fig. 8 - Test No. 2 - Exagonal box and test section after the explosion

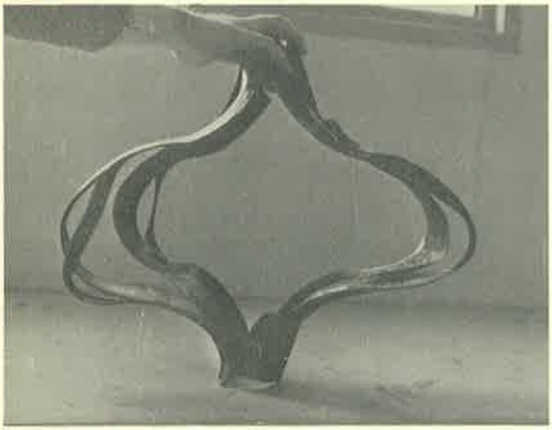

Fig. 7 - Test No. 1 - Exagonal box after the explosion

Fig. 9 - Test No. 5 - Rupture of exagonal box and test section after the explosion