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Thermodynamic Consequences of Sodium Spray Fires in Closed Containments

Part 2 — Calculations with PULSAR

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THERMODYNAMIC CONSEQUENCES OF SODIUM SPRAY FIRES IN CLOSED CONTAINMENTS

Part 2 - CALCULATIONS WITH PULSAR

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SUMMARY

To predict the consequences of sodium spray fires in closed containments the computer code PULSAR has been developed by CEA/Cadarache. For verification the calculations of PULSAR had been compared with experiments performed in the FAUNA-facility of KfK.

THERMODYNAMISCHE KONSEQUENZEN VON NATRIUM-SPRAYBRÄNDEN
IN GESCHLOSSENEN BEHÄLTERN
Teil 2 - RECHNUNGEN MIT PULSAR

ZUSAMMENFASSUNG

Um die Auswirkungen von Natrium Spray Bränden in geschlossenen Containments zu berechnen, wurde von CEA/Cadarache der Computer Code PULSAR entwickelt. Zur Verifikation der PULSAR-Rechnungen wurden die Ergebnisse mit Experimenten verglichen, die in der FAUNA-Anlage des KfK durchgeführt worden sind.

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I - INTRODUCTION

Pulsar is a bidimensional code designed to calculate the thermodynamic consequences and the release of aerosols from burning sprayed sodium in confined atmosphere. The aim of the present work is to validate the code for large volume (220 m^3). Four experiments were recalculated from the six performed in FAUNA. Due to the very small amount of ejected sodium and short ejection time, experiment FS1 is not to be taken into account /1/. In an other way experiments FS3 and FS4 having the same initial experimental conditions give consequently the same calculated results.

II - MODELLING OF PULSAR

Pulsar computer code, written in axis-symmetrical geometry, deals with one (or several) stream (s) of liquid sodium droplets in an atmosphere composed of a mixture of gases. To the purely hydrodynamic aspect, the phenomenon of the combustion of the droplets in contact with oxygen is added. The combustion is described using the Spalding theory connected to the d^2 law for computing the variations in the droplet radii. The diameter of these droplets is an average surface diameter. The walls or structures in the containment vessel are considered mechanically undeformable, but their thermal behaviour is taken into account. Pulsar describes the evolution of the gas and wall temperatures, the pressure of the gases, the trajectory of the sodium droplets and their possible impact on the walls, and the convective movement of the aerosols and gases.

III - INPUT DATA

For each experiment, PULSAR has been run in two steps:

1st step: Mesh building, initialization and calculation of the transient during the violent phase up to the decrease of the gas pressure.

2nd step: Initialisation and calculation of the transient during the decreasing phase up to the end of the simulation.

Mesh building: In order to avoid too long calculation time the atmosphere of the vessel has been divided into 20 meshes. The situation of the mesh inside FAUNA is shown in fig. 1 and the connecting mesh used in PULSAR fig.2.

Initialization: The characteristics of the experiments are sumarized on table 1, and the relative input data used for the run on table 2.

Transfer from the violent to the low transient: It automatically occurs when there is no more liquid sodium in the gaseous atmosphere. The specific mass of sodium in a mesh is cancelled when it becomes lower than a specific value depending on the mass ejected. This value is empirically determined and lays in the range 0.14 to0.4 kg m^{-3} .

FS2 = 0.14; FS4 = 0.20; FS5 = 0.30; FS6 = 0.40.

In order to avoid discontinuity problems the test is applied only when the ratio of sodium burnt and deposited to the amount of sodium ejected is higher than 90 % and the violent transient still runs on some more seconds. In the present calculation, this time is 0.2 s.

IV - COMPARISON OF THE RESULTS WITH THE EXPERIMENTS

The comparison deals with the more representative results:

- the pressure transient
- the amount of oxygen consumed.

Pressure transient, experimental and calculated values are plotted on the same graph (fig. 3, 4, 5, 6). The initial value of the pressure for the low transient is calculated from the total energy available in the whole volume. The last value in the violent transient, which is calculated from the energy in every mesh does not fit exactly. Therefore the step in the pressure curve appears, the height of the step depends on the temperature gradient in the volume. For the consequences (e.g. pressure maximum) only the calculation of the violent transient, and not the step, is of importance. The initial and final oxygen content which are the only experiment results available are compared to the calculated ones on table 3.

The maximal absolute deviation for the pressure reaches 0.5 bar (FS4) associated, a relative deviation lower than 17 %. Generally the computer code shows a small overestimation for the oxygen concentration reaches other hand, the maximal deviation for the oxygen concentration reaches 4.8 % O_2. The associated relative deviation is around 25 %. These results shows that the energy release in the gaseous phase is quite well calculated, but the amount of oxygen consumed is underestimated.

Computing the low transient needs to define a flux function driving the thermal exchange between the gaseous atmosphere and the walls. All the results were obtained using a convection law. The comparisons of the computed and the experimental graphs show that the slopes of pressure decrease are always in very good agreement.

V - CONCLUSION

This set of runs allows to predict quite well the pressure inside the vessel. The energy release in the gaseous atmosphere is in agreement with the experiment. However, the burning rate is a little low due to the fact that the mass of sodium burnt associated to the content of oxygen consumed it too small.

Better agreement for the oxygen consumption should be reached when the energy exchange between the reaction zone, the sodium droplet and the gaseous atmosphere will be better known.

REFERENCES

/1/ CHERDRON, W., CHARPENEL, J., Thermodynamic consequences of sodium spray fires in closed containments: Part I experiments, Kfk-3829.

TABLE 1

CHARACTERISTICS OF THE EXPERIMENTS

Experiment	Volume m^3	Flowrate Kg/s	Ejection time s	Molar* Ratio	Absolute Humidity g/m^3	% Na_2O
FAUNA 20 KG FS2	220	56	0,35	0,45	15,65	0
FAUNA 30 KG FS4	220	56	0,53	0,68	2,46	0
FAUNA 40 KG FS5	220	56	0,70	0,90	3,16	10
FAUNA 60 KG FS6	220	56	1,05	1,36	4,51	15

$$\star \text{ Molar Ratio} = \frac{\text{Moles of sodium sprayed}}{\text{Moles of oxygen available}}$$

TABLE 2

INPUT DATA

Experiment	Mesh	Initial. Pressure Pa	Initial temperature K	Nitrogen % volume	Oxygen % volume	Water Vapour % volume	Wall temperature K	Na_2O %	Droplet radii m	Sodium temperature K	Ejection speed m/s	Ejection time s
FS2	20	$1,008x10^5$	297	0.7709	0.2080	0.0211	286	0.	$2x10^{-3}$	773	20	0.357
FS4	20	$0,978x10^5$	273	0.7709	0.2080	0.0211	272	0.	$2x10^{-3}$	773	20	0.529
FS5	20	$0,977x10^5$	279	0.7879	0.2080	0.0041	279	10.	$2x10^{-3}$	773	20	0.706
FS6	20	$0,999x10^5$	287	0.7841	0.2080	0.0079	287	15.	$2x10^{-3}$	773	20	1.000

TABLE 3

COMPARISON OF CALCULATED AND EXPERIMENTAL RESULTS

	MAXIMUM PRESSURE			OXYGEN		
	P (Bar)	Absolute deviation	Relative deviation	% O_2	Absolute deviation	Relative deviation
FS2	EXP 2,20 CALC 2,27	0,17	7,17	18,4 18,8	0,4	2,13
FS4	EXP 2,40 CALC 2,89	0,49	16,96	17,2 18,2	1	5,49
FS5	EXP 2,50 CALC 2,89	0,39	15,6	13,3 18,1	4,8	26,5
FS6	EXP 2,85 CALC 3,00	0,15	5	13,4 17	3,6	21,2

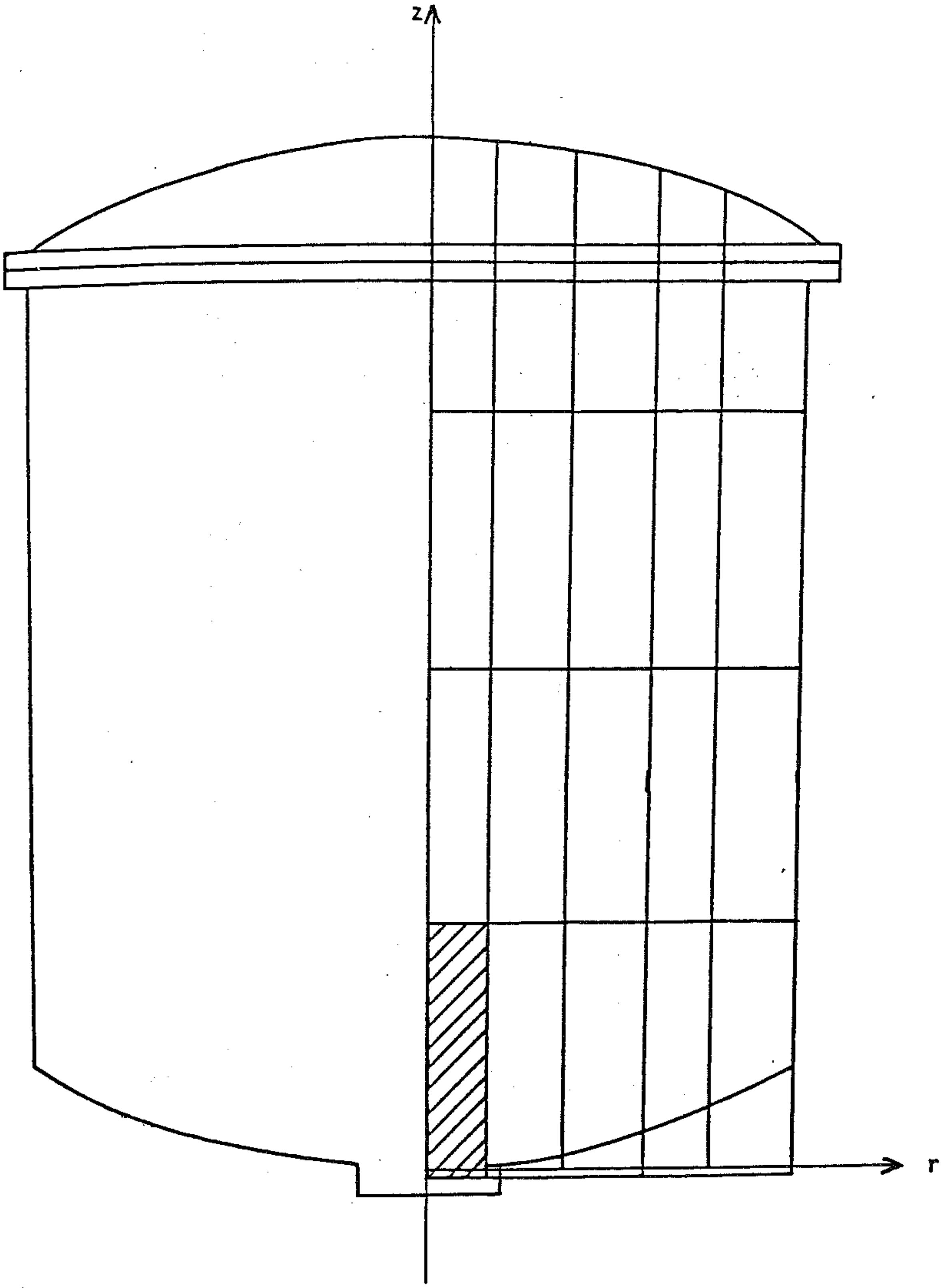

FIG : 1 MESH INSIDE FAUNA

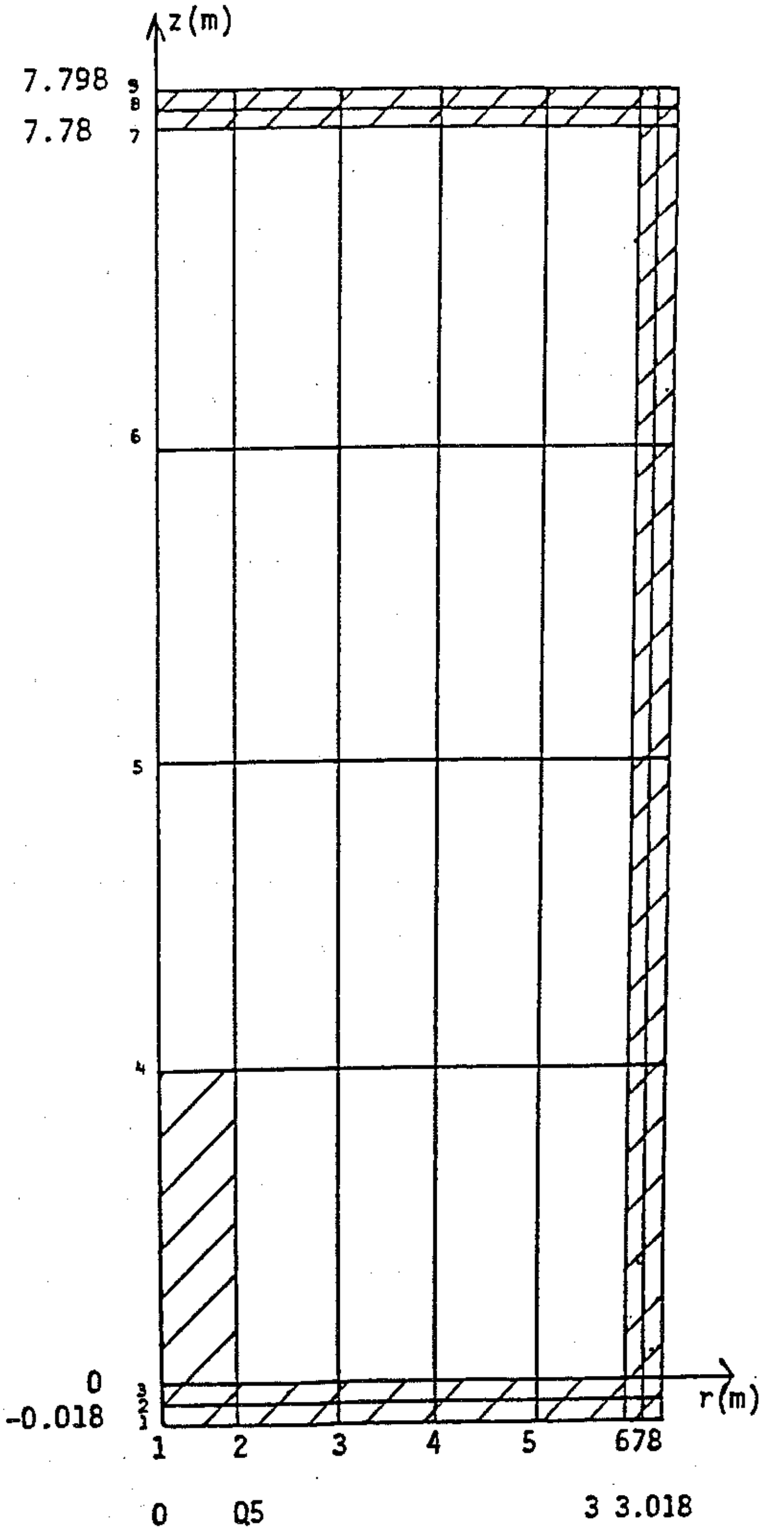

FIG : 2 PULSAR SIMULATION : MESH OF FAUNA

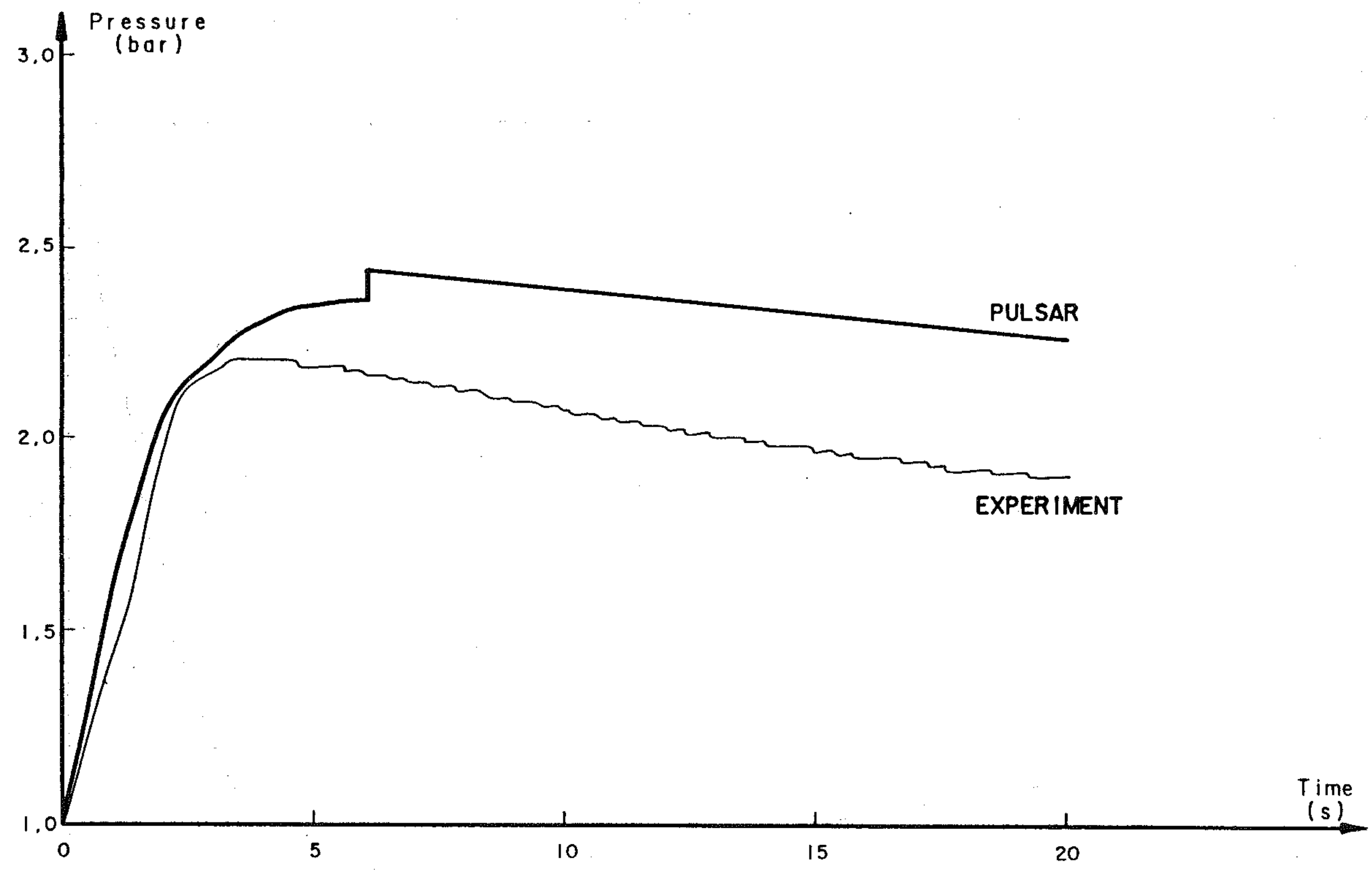

FIG .3 FS.2 20 Kg Na

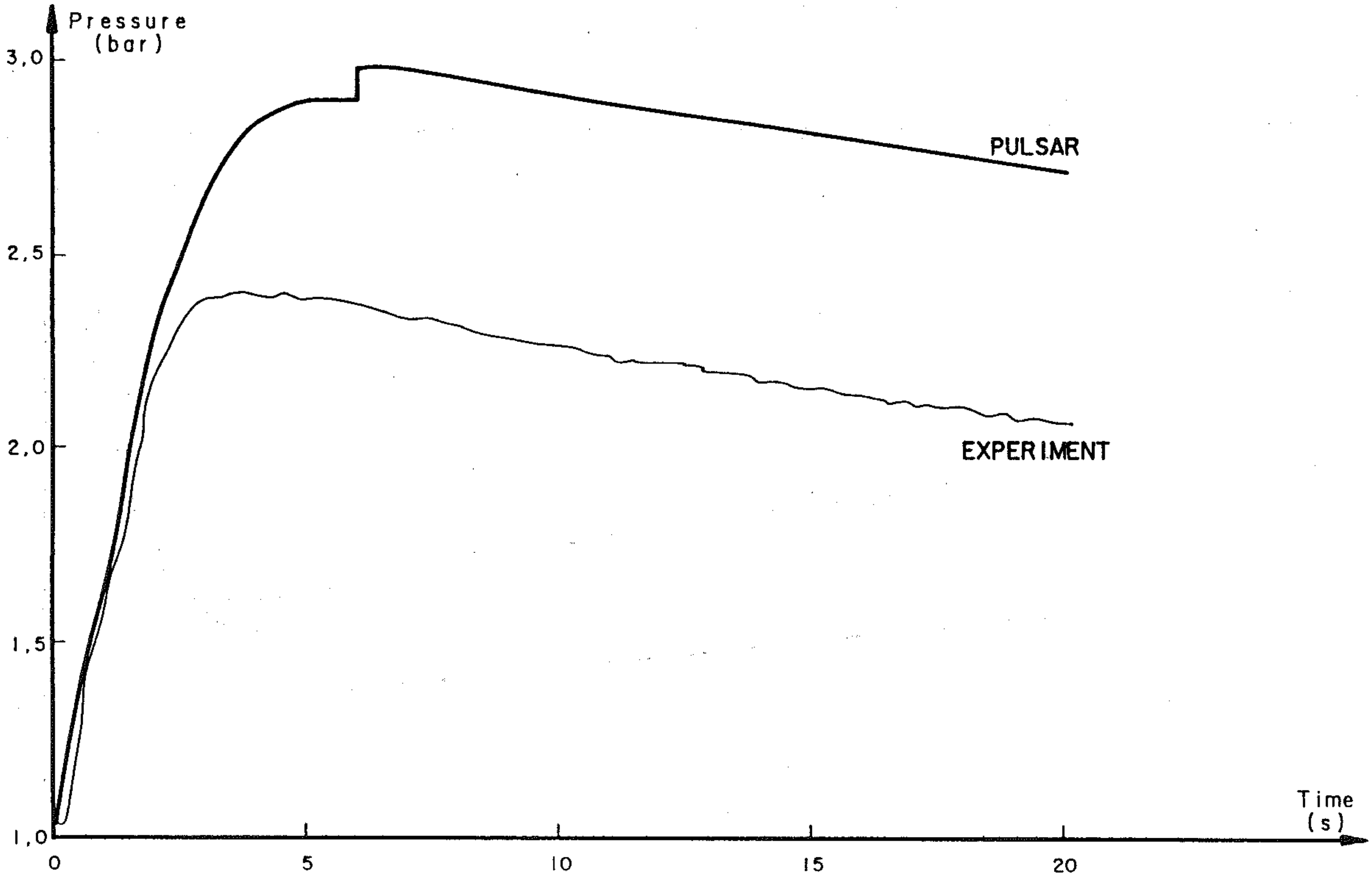

FIG .4 FS.4 30 Kg Na

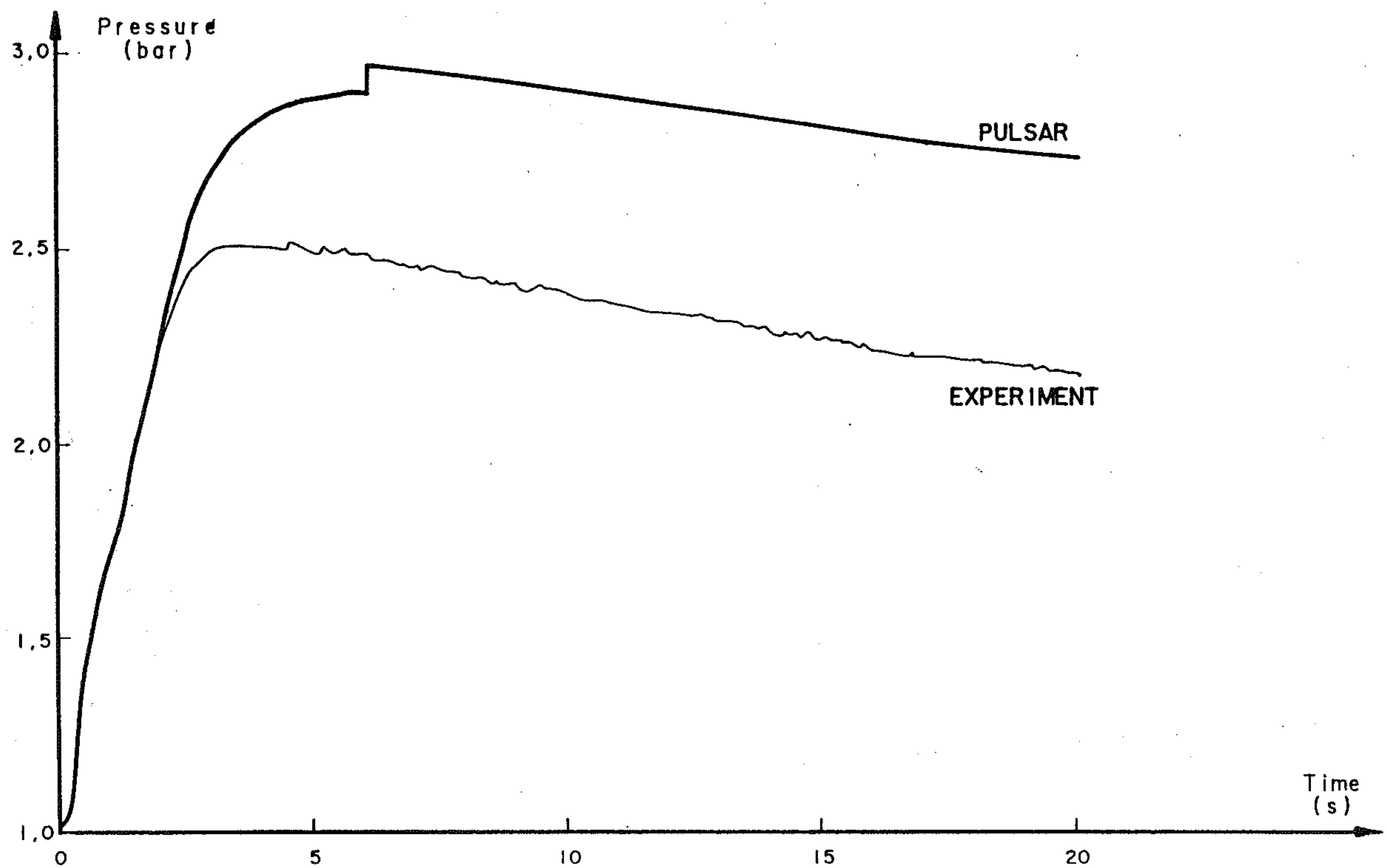

FIG .5 FS.5 40 Kg Na

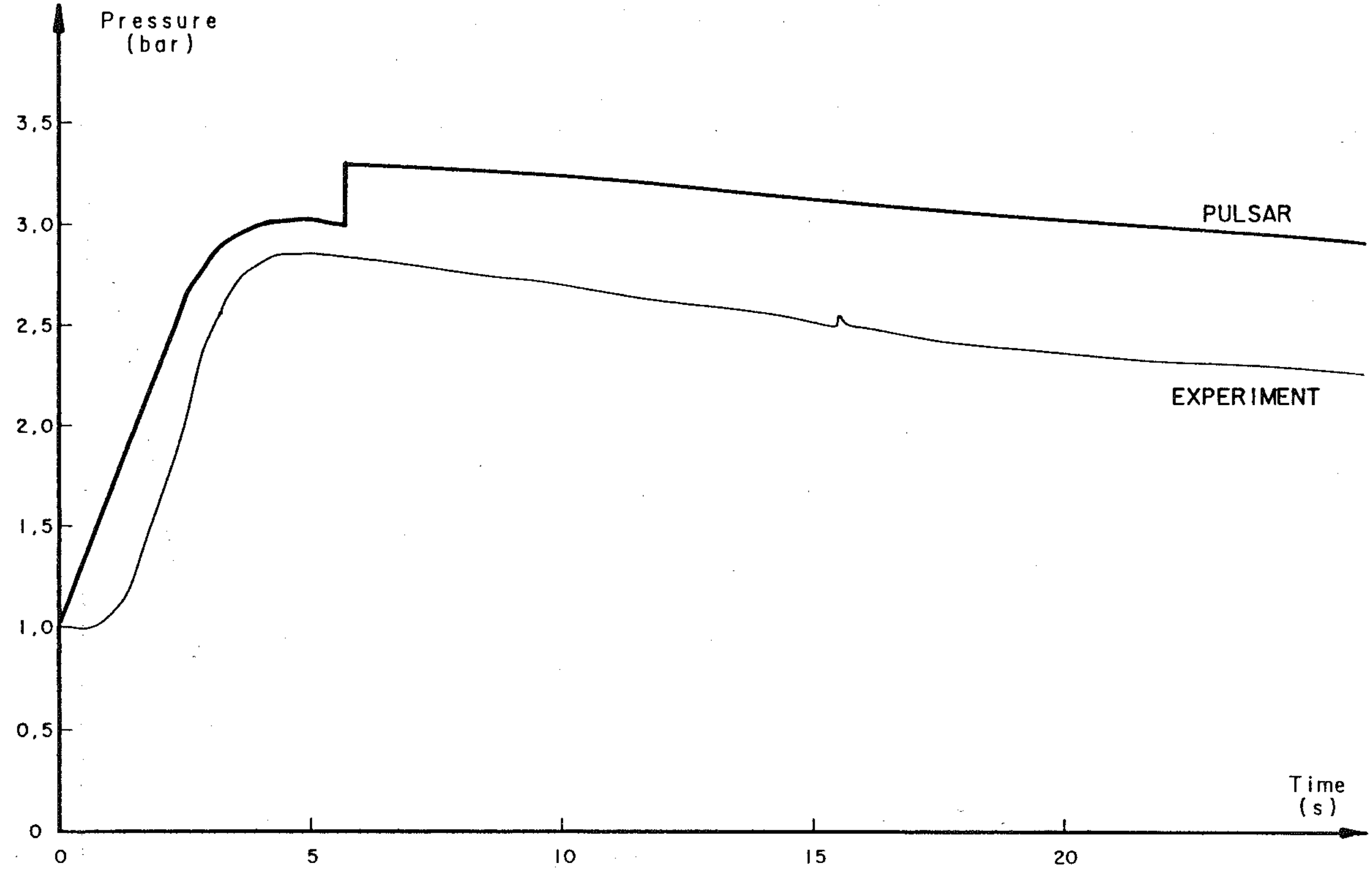

FIG .6 FS.6 60 Kg Na