COTHAA Programme: An Experimental Approach to Thermomechanical Aspects of the T.I.B. of a Subassembly

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ABSTRACT

In the frame of the work undertaken to study the consequences of a subassembly local fault, CEA-DRP-CADARACHE is performing the experimental COTHAA programme. This programme is intended to investigate the thermomechanical behaviour of a subassembly wrapper tube in case of a Total Instantaneous Blockage of this subassembly. This programme will also allow to validate the numerical basis methods and the failure hexcan mode. The ultimate objective of the work is to realize a simple thermomechanical model in the SURFASS code which describes the whole TIB accident sequence.

1. INTRODUCTION

The central theme of the subassembly work currently underway at CEA-DRP-Cadarache is the demonstration to the safety authorities that a subassembly local fault, with subsequent melting, is not likely to propagate beyond seven subassemblies.

The accident scenario adopted is the Total Instantaneous Blockage (T.I.B.) of a fissile subassembly at nominal power, this case being taken as the boundary case of the possible modes of blockages considered as credible in the Beyond Design Basis Range.

The T.I.B. accident sequence is analized with the SURFASS code /1/, developed at CEA-DRP-Cadarache, through sodium boiling, clad and fuel melting and movement, development of a boiling pool, crust formation, hexcan melting and melt propagation to surrounding subassemblies. It is in the context of this last item (melt propagation) that the COTHAA programme has been instigated. The objective of this programme is to study the thermomechanical behaviour of the hexcan of the accidented subassembly under T.I.B. conditions in order to adequately and simply represent, in the SURFASS code, the deformation, the failure and the propagation modes for the accidented subassembly and its surrounding neighbours.

The COTHAA programme deals with experimental and theoretical studies :

- The experimental approach is based on simple technological experiments consisting of the heating of an hexcan up to its destruction by melting and/or bursting.
- Theoretical interpretations of these experiments are performed with basis thermomechanical tools, jointly with PSI (CH-Würenlingen) and ENEA (I-Bologna) /2/, in order to particularly validate numerical methods and failure criteria. The calculations need material properties characterisation

obtained from uniaxial tensile tests. These tests allow to determine the stress-strain behaviour as a function of cold working, temperature, temperature ramp rate, strain rate, and ultimately irradiation and irradiation temperature.

The global approach pursued with the COTHAA programme is summarized in figure 1.

2. TECHNOLOGICAL EXPERIMENTS

2.1 Experimental set-up (figure 2)

The experimental device allows :

- the heating (by direct Joule effect) of a wrapper tube stub up to melting ($\dot{T} \leq 100°C/s$),
- the internal pressurization of the wrapper tube with an imposed steady pressure ramp rate ($\dot{P} \leq 10$ b/s) up to a maximum pressure of 100 bar.

Temperature and pressure ramps, internal maximum pressure have been determined with SURFASS precalculations.

The heating of the wrapper tube is obtained by means of a 3-phase transformer of 220 KW, cooled by water and giving a secondary current of 20 kA at 11 V (between phase and neutral) over a 5 minutes period. The temperature control is achieved by the use of a control system driven from a temperature sensor fixed to the wrapper tube.

The internal pressurization of the tube is obtained by an argon source at 180 bar. The pressure control is assumed by two fast-acting pneumatic valves placed upstream and downstream of the tube and controlled by a 3-element control system (proportionnal, integral, derivative) using a pressure signal.

For safety reasons (explosion risks), the experimental rig is placed within an enclosure comprising one wall which will blow out under an excessive internal pressure.

2.2 Measurement device

The severe experimental conditions (high temperature, pressure and temperature transients) require a non-traditionnal measurement set-up.

- Temperatures, function of time, are obtained by an optical dynamic system (without contacts) in the range 500°C-1400°C. These optical transducers (max 12) are calibrated upon the 316 stainless steel emissivity. This set-up allows measurement every 100 ms with a ± 5°C incertitude, at different positions along the tested tube.
  In addition, an infrared video camera can be used to obtain the global temperature map.
- The displacement at the hexcan mid-face, function of time, is measured by ceramical displacement gauges.
  The hexcan deformed shape is visualized with an optical system.
  A microcomputer directly provides with the graphic analysis of the whole data acquisition.

2.3 Experiments

In order to make theoretical interpretations easier, temperature and pressure ramps are not imposed together in the same test. Several sets of tests are performed on subassembly wrapper tubes in RAPSODIE reactor geometry (50 mm accross the flats, 370 mm long, 1 mm thick) :

- At first a constant temperature is maintained and the internal pressure steadily increases.
- In a second step, internal pressure is kept constant (P ≤ 30 bar) and a steady temperature ramp (T ≤ 100°C/s) is applied.
- Under reactor conditions, at least at the start of the T.I.B. transient, there will be enhanced cooling at the corners of the faulted subassembly, due to the volume of sodium flow in the intersubassembly gap. This effect is considered in a third step, by introducing forced cooling (air cooling) at the corners of the tested hexcan, inducing a peripheral external temperature gradient.
- In a fourth step, a displacement stop is fitted outside the hexcan flat to simulate a possible contact between the faulted subassembly and its neighbours in reactor situation.
- Finally, a scaling up of the preceding tests will be undertaken in PHENIX geometry (124 mm accross the flats) or/and in SUPERPHENIX geometry (173 mm accross the flats, 4.6 thick) in order to notice the influence, on the failure mode under internal pressurization, of the hexcan thickness and of the cold working at corners enhanced in a larger geometry.

All tests are carried on, up to destruction of the wrapper tube (with probably slower temperature ramps in SPX1 geometry).

The following table 1 summarizes the different sets of tests and the expected results (T = Temperature, P = Pressure).

TABLE 1

SET	CHARACTERISTICS	RESULTS
1	P = constant 5,10,20,30 bar T = 1, 10, 100°C/s	P at failure = f (T)
2	T = constant 600°C → 1000°C P = 1 bar/s	Time at failure = f (T)
3	T = constant+peripheral thermal gradient - 100,-200°C at corners P = 1 bar/s	Time at failure = f (T)
4	T = constant P = 1 bar/s + Mechanical stop	Time at failure = f (T)

3. MATERIAL PROPERTIES CHARACTERISATION

Basis precalculations of the thermomechanical behaviour of an hexcan under TIB conditions have predicted slow (quasi static) strain rates (~ 10^{-3} s^{-1}). These results have been confirmed by tensile tests performed under a constant loading and applying a temperature ramp.

Samples are cut off from PHENIX wrapper tubes (316 Ti cold working stainless steel), in the perpendicular direction to the hexcan axis.

The different tensile tests are described in the following table 2.

TABLE 2

Temperature ramp rate	1°C/s		100°C/s
Temperature	600	→	1250°C
Strain rate	10^{-4} s^{-1}		10^{-2} s^{-1}

4. HEXCAN THERMOMECHANICAL BEHAVIOUR MODELISATION IN THE SURFASS CODE

Simple thermomechanical modelisations will be introduced in the SURFASS code to take into account :

- the radial expansion of the wrapper tube under heat loading and/or internal pressure (cylinder model or be`m model with fixity at each end in hexagonal geometry),
- the bending of the subassembly rows under temperature gradient between opposite faces (beam model with a fixed end),
- the mechanical failure considering two extreme criteria to define the time limitations of a possible failure formation.

These models and the assumptions describing the material failure conditions will result from the COTHAA experimental programme and the related interpretation with basis thermomechanical computer codes.

5. CONCLUSIONS

The whole COTHAA programme as well as experimental, as theoretical is intended to investigate and to modelise thoroughly the thermomechanical behaviour of the hexcan which governs the initiating conditions of the propagation process calculated with the SURFASS code.

REFERENCES

/1/ P. Anzieu et al
"A computer code describing the consequences of TIB of a subassembly on the RNR 1500" - Science and Technology of Fast Reactor Safety - BNES - London 1986

/2/ R.O. Attinger et al
"Thermal and mechanical behaviour of a subassembly hexcan under total Instantaneous blockage conditions ; a code comparison".
SMIRT 10th - Division E - Anaheim 1989

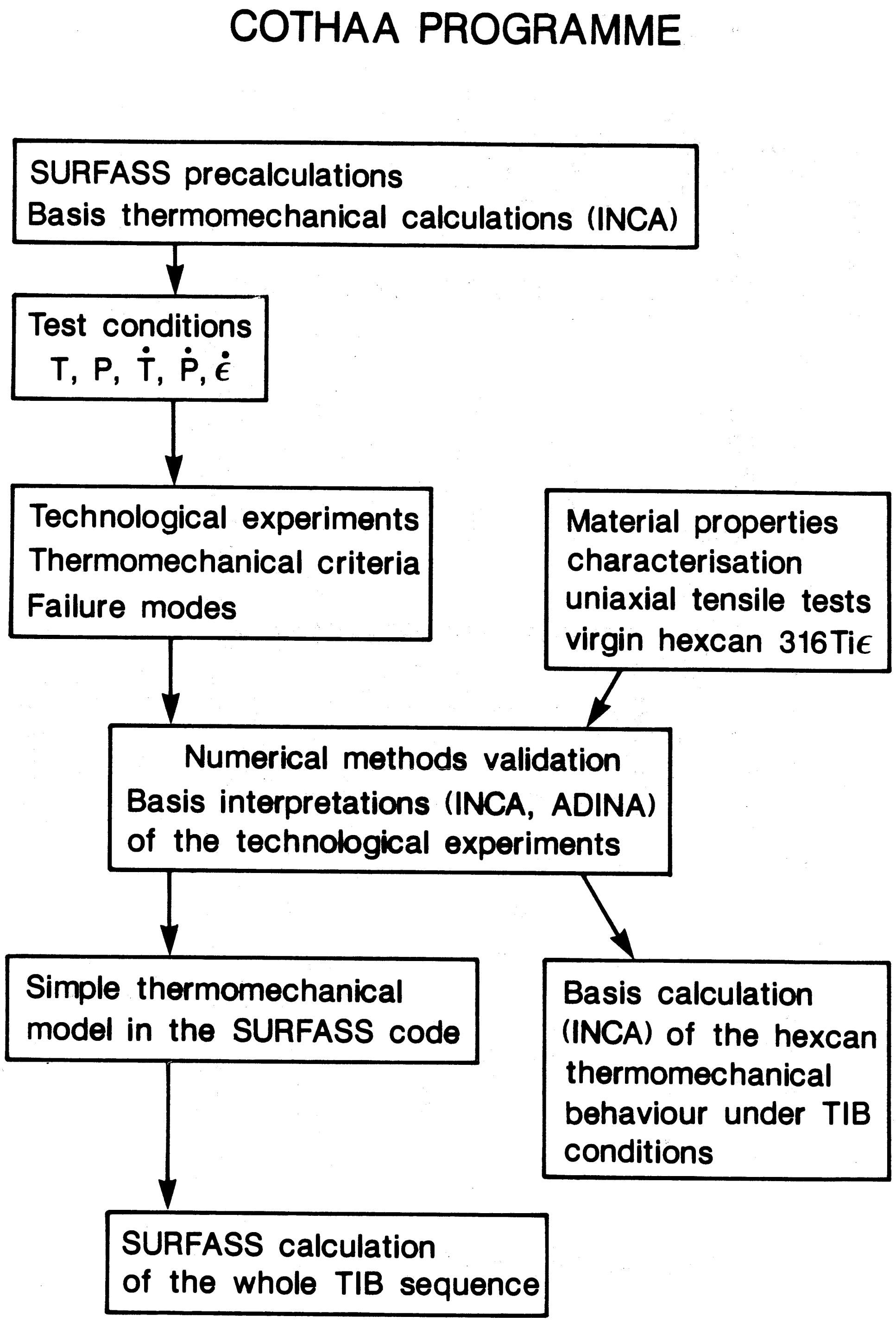
COTHAA PROGRAMME
SURFASS precalculations
Basis thermomechanical calculations (INCA)
Test conditions
$T, P, \dot{T}, \dot{P}, \dot{\epsilon}$
Technological experiments
Thermomechanical criteria
Failure modes
Material properties
characterisation
uniaxial tensile tests
virgin hexcan 316Tiϵ
Numerical methods validation
Basis interpretations (INCA, ADINA)
of the technological experiments
Simple thermomechanical
model in the SURFASS code
Basis calculation
(INCA) of the hexcan
thermomechanical
behaviour under TIB
conditions
SURFASS calculation
of the whole TIB sequence

FIGURE 1

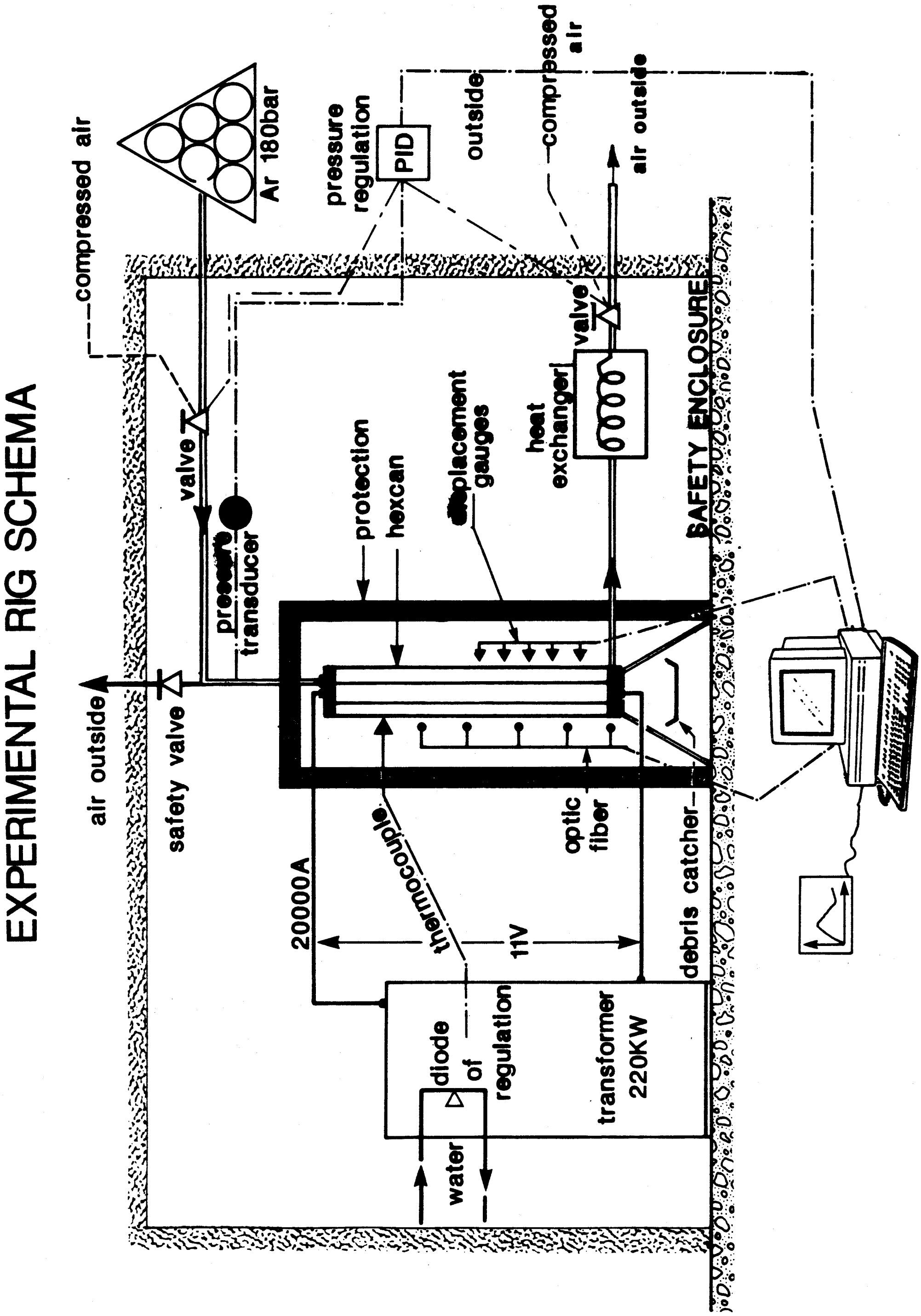
EXPERIMENTAL RIG SCHEMA
air outside
safety valve
compressed air
valve
Ar 180bar
pressure regulation
PID
outside
compressed air
air outside
pressure transducer
protection
hexcan
displacement gauges
heat exchanger
valve
SAFETY ENCLOSURE
20000A
thermocouple
11V
optic fiber
debris catcher
diode of regulation
transformer 220KW
water

FIGURE 2

Authors' Index