COMPUTING THE EFFECTS OF A
CONTAINED SODIUM SHEET FIRE:
THE "FEUNA" CODE

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ABSTRACT :

FEUNA is a computer code developed to calculate the thermodynamic
effects of a sodium fire in a ventilated or unventilated containment
volume.

Developed jointly by the CEA/DSN and Novatome, the FEUNA code
involves two oxide formation reactions, aerosol generation and
deposits, heat transfer by convection, conduction and radiation,
gas inflow and outflow through the ventilation system and the
relief valves.

The code was validated by comparing calculated values with
the results of an actual sodium fire in a $400m^3$ caisson.

1 - INTRODUCTION

With the development of the French fast neutron reactor program
it soon became vital to design a computer code capable of
predicting the thermodynamic effects of a contained sodium pool
fire.

The FEUNA code was thus developed jointly by the CEA/DSN and
Novatome to cary out safety and project calculations. This
achievement required a thorough prior knowledge of sodium
combustion physics, acquired after a series of pool
fires in a 400 m^3 caisson with various combustion surface
area dimensions (the CASSANDRE program) (1).

This experimental base provided the data necessary for the code
formulation, i.e. development of a combustion model, determination
of the exchange coefficients between the air-aerosol system,
the sodium and the containment walls, and evaluation of the aerosol
deposit constants.

2 - MODEL HYPOTHESES

2.1 - Combustion Hypotheses

- The sodium monoxide and peroxide formation reactions occur
  simultaneously and the proportion of sodium in monoxide form
  remains constant at 60 % throughout the fire.

- The aerosol formation rate is also constant. It is computed
  from the oxide release ratio (ratio of aerosol sodium mass
  to burned sodium mass) which is 40 % ; this implies that all
  the peroxide is pres ent in aerosol form.

- The combustion energy is a function of the amount of heat
  produced by Na_2O formation (104 kcal per mole) and
  Na_2O_2 formation (124 kcal per mole), weighted by their
  respective formation percentages.

- The combustion rate depends on the oxygen concentration
  and temperature of the oxydant gas, and is given by the
  Garellis formula :

$$T(t) = T(o) \frac{nO_2(t)}{nO_2(o)} \sqrt{\frac{Tg(t)}{Tg(o)}}$$

where : $T(t)$: combustion rate at instant t $(kg.h^{-1}.m^{-2})$

$T(o)$: combustion rate at initial instant $(kg.h^{-1}.m^{-2})$

$nO_2(t)$: number of moles of oxygen at instant t

$nO_2(o)$: number of moles of oxygen at initial instant

$Tg(t)$: air temperature at instant $t(^oC)$

$Tg(o)$: air temperature at initial instant (^oC)

- The power released from the fire is given by the relation :

$$W_F = E.T(t).S_F$$

where : W_F : power output (Watt)

E : energy released by combustion of 1 kg of sodium $(J.kg^{-1})$

$T(t)$: combustion rate at instant t $(kg.h^{-1}.m^2)$

S_F : fire surface area (m^2)

2.2 - Heat Exchange Hypotheses

- The liquid sodium pool comprises a number of layers of variable thickness.
- Combustion occurs on the sodium surface (first half-layer).
- The burning sodium releases aerosols which mix with the other gases to form a homogeneous atmosphere assumed to be at the same temperature.
- Heat transfer occurs in the following manner :

a) Downwards

by conduction through the sodium, through the combustion pan (a single layer) and through the caisson floor (also broken down into a number of layers of varying thickness).

b) Upwards

. by convection and radiation from the sodium to the air-aerosol system and then to the internal structures and containment walls.

. by conduction through the walls (broken down into a number of layers of equal thickness).

. by convection from the wall outer face to the surrounding atmosphere.

- No direct radiation occurs from the sodium pool to the vessel walls,
- All the exchanges are processed single-dimensionally.

The power exchanged by convection and radiation take the following form :

$$P = P_{radiation} + P_{convection} = (h_r + h_c) S_c \, \Delta\theta$$

where : P : power exchanged (watts)

S_c : source area (m^2)

$\Delta\theta$: temperature difference between source and exchange medium (^oC).

$h_c + h_r$: heat exchange coefficient by natural convection and radiation $(W.m^{-2}. {}^oC^{-1})$

These coefficients involve a number of absorption and emission factors which were adjusted on the basis of the CASSANDRE experiments :

$\varepsilon_a = \alpha_a = 0.3$ (gas-aerosol system radiant emission and absorption factor),

$\varepsilon_p = 0.3$ (containment wall radiant emission factor),

$\varepsilon_{Na} = \alpha_{Na} = 1$ (sodium radiant emission and absorption factor).

Heat transfers by conduction were calculated using
Dusimberre's method (2) which gives the interface temperatures
of the various layers through which the conduction occurs.
The variation in time of the temperature T_i at a surface
separating two layers is given by the thermal equilibrium
in a zone extending to either side of the interface and
assumed to be at temperature T_i :

$$\rho \, Ce \, \frac{dT_i}{dt} = \frac{\lambda_i}{e} \, (T_{i-1} - T_i) - \frac{\lambda_i}{e} \, (T_i - T_{i+1})$$
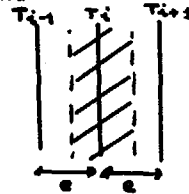
where : ρ : density of material (kg.m^{-3})

λ_i : thermal conductivity of material (W.m^{-1}.K^{-1})

Ce : specific heat of material (J.kg^{-1}.K^{-1})

e : layer thickness (m).

2.3 - Gas Hypotheses

- The gas inlet and outlet flow rates are obtained by
  assuming that the pressure difference between the
  containment and the exterior is proportional to the
  dynamic pressure :

$$\Delta P = K \, \frac{\rho V^2}{2g}$$

where : ΔP : pressure differential (mm H$_2$O)

ρ : gas density (kg.m^{-3})

V : gas velocity (m.s^{-1})

g : gravitational acceleration ($\simeq$ 10m.s^{-1})

K : pressure drop coefficient

- The containment volume is provided with pressure relief
  valves and pressurizing valves of specified surface areas,
  pressure drop coefficients and opening pressures.

- The gas temperature evolution is determined by assuming
  that the internal system energy variation per unit
  time is equal to the power exchanged among the sodium,
  gases, internal structures and walls together with the
  enthalpy variation of the air per unit time.
- The gas pressure evolution is obtained by differentiating
  the gas status equation.

3 - DESCRIPTION OF THE FEUNA CODE

The FEUNA code, written in FORTRAN, is based on the
resolution of a set of first-order differential equations.
For each time step it computes the following independent
physical quantities :

- burned sodium mass
- oxygen mass in the containment volume
- nitrogen mass in the containment volume
- aerosol concentration in the containment volume
- air temperature
- air pressure
- sodium layer temperatures
- sodium/container and container/floor interface
  temperatures
- internal structure temperature
- containment wall temperatures

Euler's tangent method is used for the integration.

The remaining physical values are then computed from the
values of the independent variables at instant t.

After every m consecutive integrations (m is defined
as a code input) the following results are printed out
in tabular form.

- Elapsed time of sodium fire
- Gas temperature (°C)
- Gas pressure (mb)
- Combustion rate ($kg.h^{-1}.m^{-2}$)
- Burned sodium mass (kg)
- Gas density ($kg.m^{-3}$)
- Gas inflow rate ($m^3.H^{-1}$)
- Gas outflow rate ($m^3.h^{-1}$)
- Oxygen molar fraction
- Aerosol mass in suspension (kg)
- Aerosol mass extracted (kg)
- Sodium surface temperature (°C)
- Container/floor interface temperature (°C)
- Wall inner face temperature (°C)
- Internal structure temperature (°C)
- Aerosol extraction rate ($mg.s^{-1}$)
- Extracted gas mass (kg).

The code is capable of handling 70 equations, and 29 are used at the present time. The number of layers discriminated is limited to 30 in the sodium and containment floor, and to 70 in the walls. The code flowchart is shown in Figure 1.

4 - <u>PRACTICAL EXAMPLE - COMPARISON WITH EXPERIMENTAL RESULTS</u>

A typical code run may be illustrated by one of the CASSANDRE experiments.

Basic experimental data :
- Liquid sodium mass   235 kg
- Containment volume   400 m^3
- Combustion surface area   1m^2
- Wall area   336 m^2
- Steel combustion pan thickness 0.003 m
- Concrete wall thickness   0.26 m
- Initial combustion rate   30$kg.h^{-1}.m^{-2}$

- Integration step   0.25
- Max.computing time   10800 s
- Printout interval   300 integrations.

Thickness of sodium layers (m) ;

0.007 0.010 0.05   0.05 0.05 0.05 0.01 0.007 0.003

Thickness of support layers (m) ;
0.003 0.007   0.01   0.01 0.01 0.02 0.02 0.02

Figure 2 compares the FEUNA computed results with the measured experimental values. The following computed and experimental curves are plotted versus time :

- oxygen molar fraction
- relative gas pressure
- sodium temperature
- gas temperature
- wall inner face temperature.

The figure shows the close agreement obtained between the two curves.

The FEUNA computer code has been applied to project design and safety analysis in the scope of the Super-Phénix program.

REFERENCES

(1) COLOME J. - GUERIN Ph. - JACQUES J. - MALET J.C. -

Confinement et filtration d'aérosols produits par un feu de sodium sur un réacteur à neutrons rapides.
VII Congrès International de la Société Française de Radioproctection.
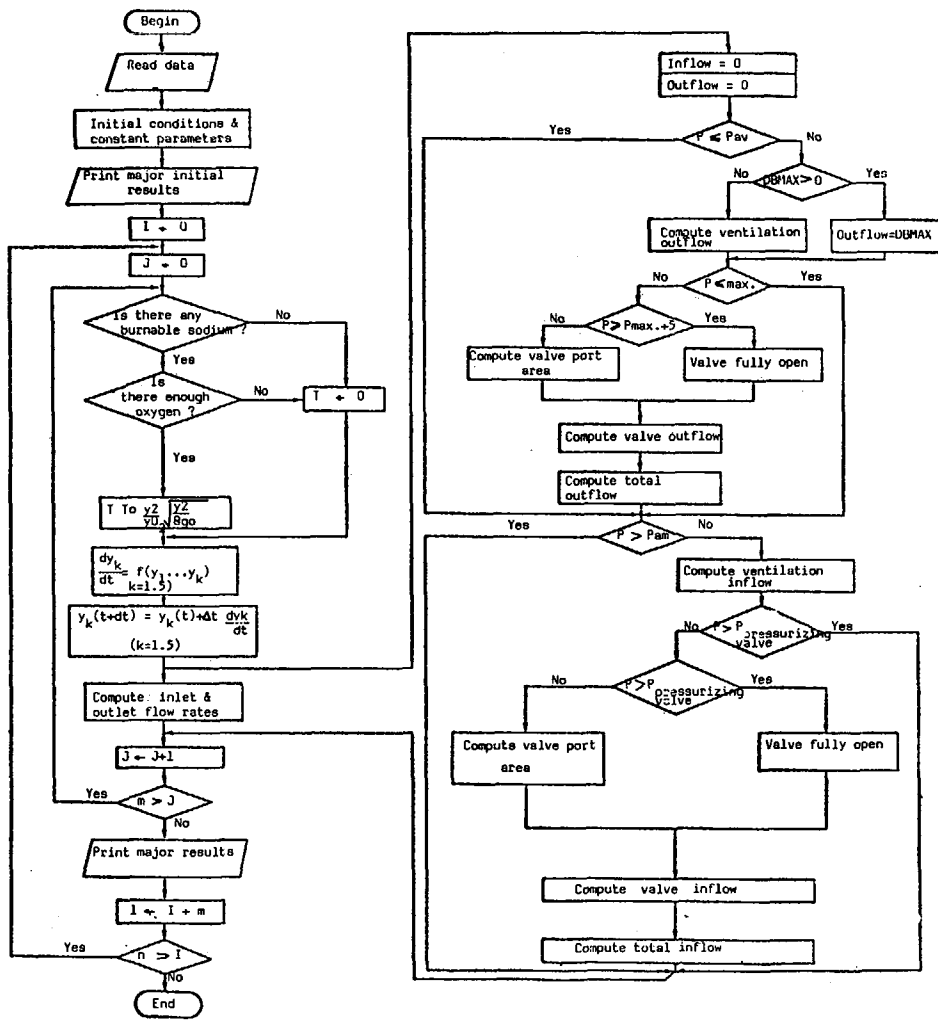Versailles 28-31 mai 1974.

(2) MAC ADAMS N.H.

Transmission de la chaleur DUNOD Paris 1964

FIG 1 : FEUNA CODE FLOWCHART

CASSANDRE 6

COMPUTED RESULTS
VERSUS
EXPERIEMNTAL MEASUREMENTS

Figure 2