EXTINCTION OF SODIUM FIRES

J.C. MALET* (CEA)
F. SPAGNA** (ENEA/CAD)

ABSTRACT

This paper presents how, starting from a knowledge of sodium ignition and burning, principles for extinction (smothering catch trays, leak recuperation systems, powders) can be developed. These techniques applied in Superphenix 1 and PEC reactors have been tested in the ESMERALDA experimental program which is a joint French/Italian project.

1. INTRODUCTION

The use of sodium in fast reactors requires that the safety risks produced by sodium fires are considered and guarded against.

The research and development programs undertaken in France and Italy had the objectives of minimising these risks by defining solutions and then designing tools and equipment for their implementation. In particular the type of fire and the layout of the premises must be taken into account. Some of these type of considerations lead to design requirements for buildings, which require the support of calculations in order to forecast the thermodynamic consequences, others lead to studies of extinction methods.

This paper presents how, starting from a knowledge of sodium ignition and burning, principles for extinction (smothering tanks, leak recuperation systems, powders) can be developed. These techniques applied in Superphenix 1 and PEC reactors have been tested in the ESMERALDA experimental program which is a joint French/Italian project with 15 objectives, some of these are directly concerned with the extinction of fires.

2. IGNITION AND COMBUSTION OF SODIUM

2.1. Sodium ignition

The basic studies conducted into the ignition of sodium show that it is primed by nodules created at the surface of the metal by local high temperature phenomena caused by oxidation.

Table I shows that it is difficult to establish a limiting temperature under which sodium does not ignite. It does appear, however, that with under 3 % oxygen sodium does not ignite (Table II).

From this it follows that in order to extinguish a sodium fire it is not useful to attempt to cool the metal to below its ignition temperature, this not being well defined. On the contrary it is possible to make the atmosphere of the cell inert by the injection of nitrogen.3

2.2 Combustion of sodium

The study of the combustion of sodium permits the mechanisms of the reaction to be understood.

TABLE I

SODIUM IGNITION TEMPERATURE (° C)

Reference	droplets	agitated pool	calm pool	heated pool
COWEN - VICKERS	133 - 138		280	440 - 470
(experiment)	120			
TOUZAIN			150	280
RICHARD	200			280
GRACIE - DROHER	120	204	288	
NEWMAN		150	320	
LONGTON			280	
GROSSE - CONWAY			118	
LEMARCHANDS - JACOB			208	
MALET (experiment)			215	
MALET (theory)			208 - 201 - 224	
REYNOLDS (theory)			218	
SESTR Cadarache		140	205	

TABLE II

SODIUM IGNITION TEMPERATURE AS A FONCTION OF AIR OXYGEN CONTENT

Oxygen fraction	0.050	0.075	0.100	0.150	0.21
Ignition temperature (°C)	344	252	228	220	205

The phenomena which determine the kinectics of combustion are on one hand the diffusion of oxygen traversing the flame region to react with the liquid sodium, forming a crust, and on the other hand the transfer by diffusion and evaporation of sodium vapour towards the flame region. There is therefore a double mechanism for combustion (see figure I) : the importance of one process in relation to the other depends on the sodium pool temperature. This is different from hydrocarbons where the combustion takes place by a succession of chain reactions, the phenomena leading to the formation of combustion products in the flame region is a process of nucleation and germination, the products of combustion being aerosols.

Two conclusions can therefore be drawn :

1. It is useless to introduce an inhibitor of combustion into the flame region, as can be done in the case of hydrocarbon fires.

2. First of all the isolation of combustible from the oxygen must be attempted. The following methods are available :

   - the creation of an inert atmosphere in the cell;
   - the recuperation of sodium with its removal to reservoirs filled with a neutral atmosphere ;
   - the use of static smothering devices placed in the lower part of the plant ;
   - the use of dynamic extinction methods such as the spreading of a powder able to form an isolating crust.

The research and development studies in the domain of sodium fire extinction in France and Italy have been directed towards developing the above methods.

3. EXTINCTION OF SODIUM FIRES

The techniques of sodium fire extinction presented below have been applied on the Superphenix and PEC reactors and were tested in the framework of the ESMERALDA program.

3.1 Passive means of extinction

3.1.1. The smothering catch trays

Figure 2 shows the basic element of a smothering catch tray as developed by experiments performed in a 400 m^3 and in a 3600 m^3 cells. It is constructed of a recuperation catch tray in conjunction with a set of plates forming a lid. This lid is fitted with moving flaps allowing the leaking sodium to flow into the catch tray. At the end of the leak the moning flaps lose again to restrict the diffusion of oxygen toward the sodium pool.

With such a device it was shown that when one ton of sodium is spilt only 32 kgs burn, and the amount of aerosols (sodium) produced is limited to 7 kgs.

These devices were tested in experiments ESM V.1 and ESM V.2 of the ESMERALDA program, the main objective being to verify the thermal behaviour of the smothering tanks as installed in the Superphenix reactor secondary circuit galeries.

3.1.2. Sloping floors

These devices were installed in the Superphenix 1 steam generator building.

These types of devices were tested in a 400 m^3 and in a 3600 m^3 cells to study the efficiency of the system and expecially the behaviour of floors, recuperation ducts and tanks, to thermal shock. These devices, allowing the drainage of sodium through pipeworks to the recuperation tanks, have got an advantage over smothering catch trays, in fact they avoid long term thermal stresses on concrete, however it is necessary to be sure that pipework can stand the inflicted thermal shock. Indeed during sodium transport stresses are induced due to :

- the change in temperature of the pipework, initially being at room temperature.
- the flow not filling the entire pipe.

During the experiments, in the ESMERALDA plant, the resistance to thermal shock of units similar in design to those installed at Superphenix (experiments ESM II) was tested.

3.1.3 PEC reactor catch trays

The catch trays installed in the secondary circuit galeries of the PEC reactor were tested in the ESMERALDA plant, the objectives being to study mechanical behaviour and smothering efficiency.

From the results of the experiment (ESM IX.1), in which 555 kgs of sodium at 550° C were spilt from a low height, we can concisely tell that the catch trays are successfully fireproof.

3.2 Extinction by powders

The choice of the extinguisher is particularly difficult because it must be chemically inert to sodium and assure a covering as complete as possible.

Among the available powders on the market that were tested, the most efficient was found to be TOTALIT M2. This powder has the drawback of being based on alkaline chlorides which can cause serious corrosion. Moreover it contains organic products, necessary for its fluidisation, which react with sodium to give cyanides.

The CEA has undertaken the development of a powder (MARCALINA) based on sodium and lithium carbonates in proportions close to those of an eutectic : at high temperature it forms an uniform and continuous doughy coating on the metal surface. Thus creating an air tight barrier restricting the passage of liquid or sodium vapour and likewise the diffusion of oxygen towards the sodium surface. However, as its thermal expansion is not the same as sodium, fractures of the crust can be formed during cooling giving rise to local re-ignition of the sodium. It is therefore necessary to maintain a surveillance until the surface has completely cooled ; fractures must simply be covered by additional powder either from an extinguisher or by hand.

To apply this powder different types of extinguishers were developed, with capacities between 10 and 320 l. For fixed installations and for lorry installations, capacities of 1 000 l or more were developed.

Two specific experiments on MARCALINA powder were executed in a 3600 m^3 cell of the ESMERALDA plant. The objectives of these experiments are to verify the efficiency of the powder and the application of the spilling system. One (ESM. III.1) concerns the application of powder around the Superphenix subassembly storage tank overflow reservoir. The second one (ESM III.2) concerns its application around the storage reservoir.

4. CONCLUSIONS

If the premises are sealed, furnished with passive extinction devices and provided with a powder application system, it is possible to affirm that an efficient means of fighting sodium fires has been provided. Each of these methods presents advantages and disadvantages. These techniques developed in experimental cells are in practice used for fires on a different scale. It is therefore necessary to verify the solutions adopted in the design on a real reactor scale. This is why CEA (France) and ENEA (Italy) have made an agreement to carry out the ESMERALDA program whose objectives are :

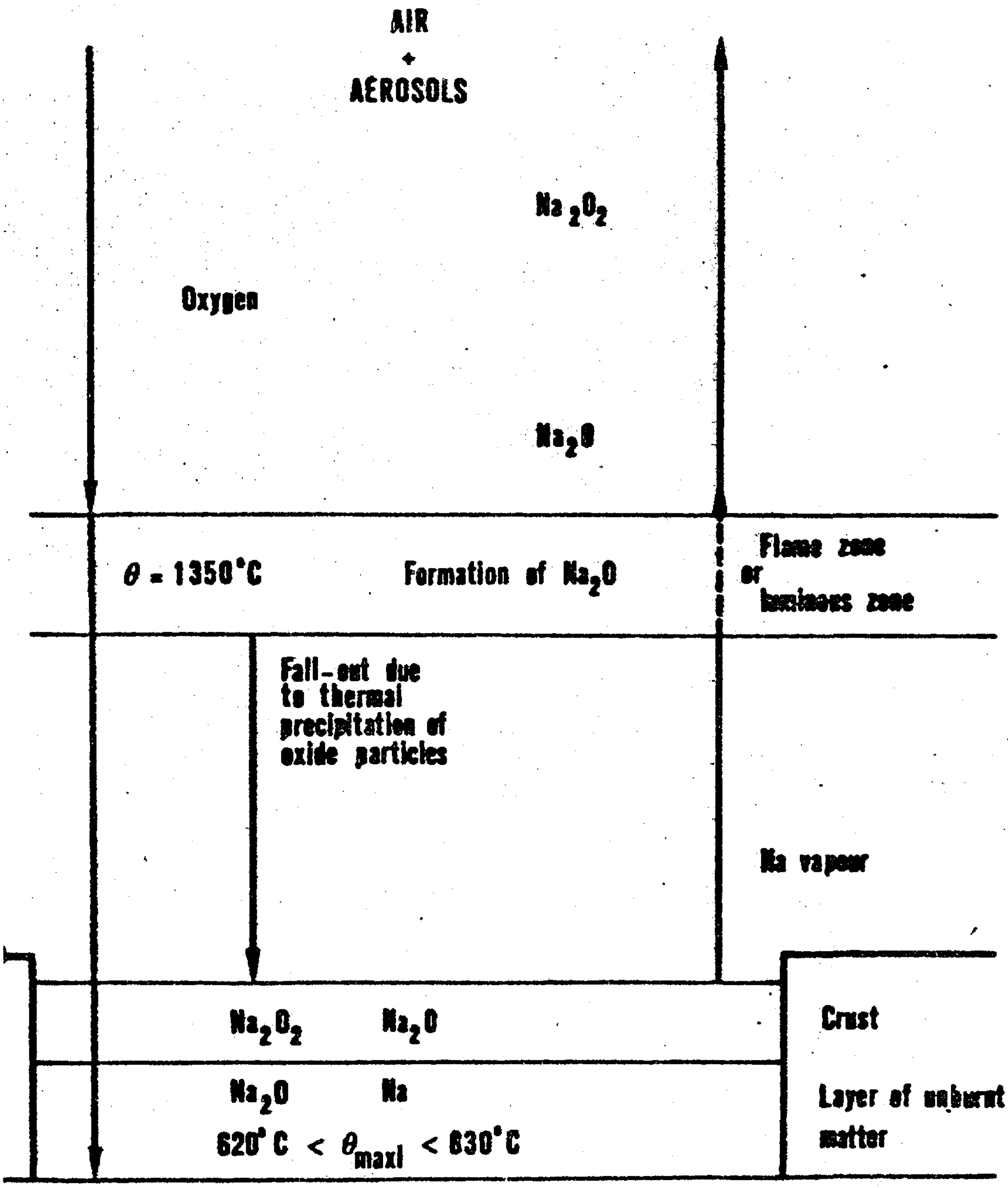
- research : the development of an understanding of the phenomena of sodium fires and their effects ;
- design : the verification of design solutions relative to certain fast reactor power station components from the point of view of their behaviour in consequence of sodium fires ;
- exploitation : the upgrading of instrumentation and intervention techniques during and after a sodium fire in an installation, and the training of the operating staff.

The objectives fixed for this program are presented in table III.

TABLE III OBJECTIVES OF ESMERALDA PROGRAM

I	Pool fires
II	Recovery of leaks
III	Extinction by powder
IV	Sodium-water-air reactions
V	Smothering catch trays
VI	Atmospheric discharges
VII	Combined fires
VIII	Sodium-concrete reactions
IX	Passive means of extinction, PEC catch trays
X	Filtration
XI	Spray fires
XII	Aerosol behaviour
XIII	Intervention and re-instatement to service
XIV	Residue treatement
XV	Behaviour of materials and components : Sodium-air heat exchangers

The double process
COMBUSTION OF SODIUM POOLS
(vapour – phase and liquid phase)



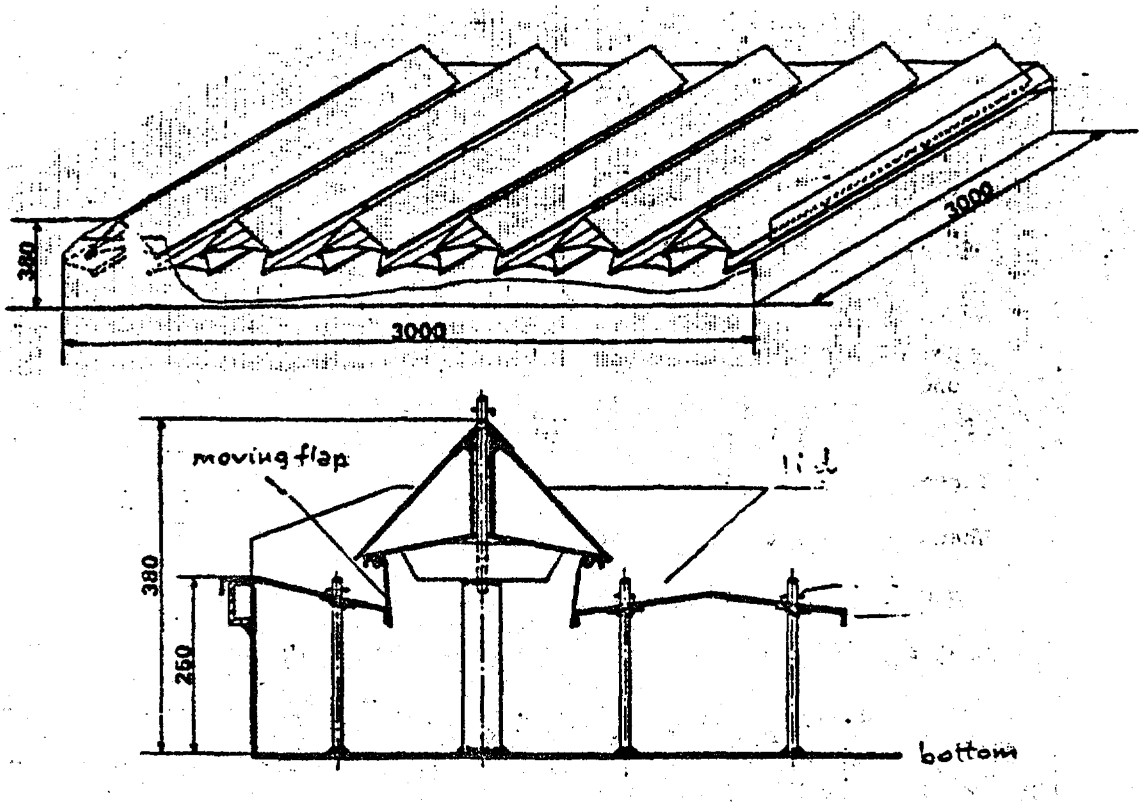


FIGURE 2 : BASIC ELEMENT OF A SUFFOCATION CATCH TRAY