sand bed filters. But both filters have limited load capacities; up to now results suggest that large quantities of sodium fire aerosols can be filtered with high efficiency only by a combination of different devices. These filter systems are not yet established but several countries are working on this problem.

Computer codes for predicting aerosol behaviour in closed containments have been developed in different countries and are in relatively good agreement with experimental data. Nevertheless there is a lack of quantitative information on the aerosol source term.

There are still large uncertainties in data on aerosol parameters for example size, shape, density and chemical composition in different atmospheres. These data are very important for modeling aerosol behaviour and are included in the so called "shape factor" of the codes. Although many experiments on aerosol behaviour have been done in various countries and in different containments (2 to 850 m^3) additional tests at high aerosol concentration and with mixed sources (e.g. sodium fire aerosol, fuel, steel) are necessary.

CONCLUSIONS - RECOMMENDATIONS -

1. Testing of commercially available devices which have not yet been tested, such as Venturi scrubbers and electrostatic precipitators should be carried out.

2. For filter testing, the complete characterization of the aerosols encountered in the various test conditions is necessary.

3. It should be taken into account that the retention efficiency may not be the decontamination factor in a mixed aerosol system.

4. Increased development is required to optimise different filtration systems for high efficiency and high load under various conditions.

5. Research is needed on aerosol source term, (active sodium fires containing fission products, fuel, etc. and non-active fires) to quantify conservatisms in currently assumed values.

6. Current research on physical and chemical properties of aerosols should be extended, mixed aerosols should be included.

7. The assumption of continuous coaglomeration of different aerosols should be experimentally verified.

8. Computer codes for predicting aerosols behaviour have been developed in several countries. More comparison of these codes against the same experiments should be made.

9. Further information is required on the accuracy of the experimental data and calculation codes.

3. General Recommendations

1. "Sodium concrete" interaction and protective clothing were not discussed specifically at this meeting. It was generally agreed that these topics should be included in the programme of a next meeting on sodium fires, which was recommended to be held in four years time.

2. The chemical evolution of sodium aerosols has not been discussed at this meeting, but it is considered necessary to undertake further studies on the chemical behaviour of aerosols and on their harmful effects.

THE INFLUENCE OF SODIUM FIRES ON LMFBR's SAFETY ANALYSIS

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PLAN

1. Safety analysis methodology
2. Primary sodium fires
3. Secondary sodium fires
4. Auxiliary sodium fires
5. Related experimental research programmes

FOREWORD :

In a sodium cooled reactor, sodium fires are accidental conditions to be taken into account in safety analysis. For the various sodium categories, fire conditions, associated risks, safety analysis objectives and detailed corresponding issues are indicated. An experimental research programme can be deduced from these considerations.

1. Safety analysis methodology

The protection of the public against the consequences of an accidental release of dangerous products contained in a nuclear reator relies on the interposition in series of leaktight "barriers". Therefore , the safety analysis consists first in checking the validity of each barrier during normal and accidental conditions ; this analysis includes three steps : prevention, monitoring and safety action. Secondly, it is necessary to study the course of typical accidents in order to synthetize the examination of barriers as well as to know their independence level.

The dynamic behaviour of dangerous products during their transfer can then be estimated and order of magnitude for radiological consequences of these conditions can be given.

In this respect, sodium fires are examined from several point of views :

- they are an indication of a leak on sodium containers and so concern prevention and monitoring
- they let an extension to barriers or associated systems to be feared
- they can be a vehicle for dangerous products, by themselves for activated sodium or indirectly for sodium polluted by fission or activation products.

In order to give a positive support to the following developments we shall consider only LMFBR's power plants of the type built in France, with a sodium primary circuit integrated in one single vessel (POOL concept), and we shall describe successively the three main systems containing sodium.

2. Primary sodium fires

2.1 - Fire conditions

The primary sodium, huge quantities of which are contained in the main vessel, or in the safety vessel in the case of a main vessel crack, is kept under inert atmosphere.

Only an accident releasing mechanical energy inside the vessel can lead to a leak in the roof and inject sodium in the air atmosphere inside the dome. The sodium amount would be limited to nearly 200 kg, but a 1000 kg mass has been considered for containment strength calculation.

Such an accident implies such damage that further operation is not considered as possible.

SUPER-PHENIX diagram shows that there is a double containment. The pressure of the intermediate volume (between dome and building) is lower than the atmospheric pressure.

2.2 - Associated risks

Primary sodium is activated(mainly by Na 24) and can be polluted by activated corrosion products, fission products and plutonium released by fuel sub-assemblies during an accident for which mechanical energy is generated by molten fuel-sodium interaction.

Sodium flowing under pressure through thin leaks of the roof could be sprayed and could burn almost instantaneously.

Therefore, risks are linked to :

- the thermal effect of burning
- the pressure effect associated to the thermal effect
- the radiological effects of sodium and associated products.

2.3 - Safety analysis objectives

The main safety analysis objectives will then be :

A/ Insurance that accident conditions do not lead to leaks higher than specified values in the dome, which is the containment barrier.

B/ Possibility to evaluate radiological effects of dangerous products that could leak outside the building.

2.4 - Detailed questions

Type A and B issues can be sub-divided into several more precise questions :

A.1 - Dome wall temperature, atmosphere temperature and pressure inside the dome during a sodium spray fire

B.1 - Fission products and plutonium association with aerosols after a spray fire

B.2 - Aerosol concentration inside the dome as a function of time (sedimentation, deposition...) in the atmosphere and on the surfaces, after a spray fire

B.3 - Aerosol proportion in leaks through the dome (warping into spaces)

B.4 - Contamination transfer, particularly for aerosols, up to the cleaning system, after a spray fire ; deposition inside retention rooms

B.5 - Cleaning system efficiency, particularly for plutonium which may be associated with sodium aerosols

B.6 - Safety of cleaning system against warping

B.7 - Toxicity of fission products and plutonium associated with sodium aerosols

3. Secondary sodium fires

3.1 - Fire conditions

Opposed to primary sodium for which a direct and important aggression on containment barrier can hardly be imagined, except for whole core accidents releasing mechanical energy, secondary sodium is essentially contained in long loops which are protected as well as possible against external mechanical aggressions, but which are always submitted to mechanical and thermal stresses.

Independantly of preventive measures, not developed here, we shall examine here after safety analysis objectives when leaks appear on the secondary sodium containment.

Leaking sodium quantities could range from kilogrammes, according to PHENIX operating experience, to tens of tons if a guillotine type rupture on a loop is imagined. For very important leaks, the main objective is the protection of public.

The secondary sodium pressure inside circuits is moderated, five bars at most, and would rapidly decrease in case of an important leak. At the beginning, a leak with a jet more or less divided by obstacles leads to a "mixed" fire, in the sense that spraying is only roughly archieved. When sodium is spread, a less active pool fire is formed.

3.2 - Associated risks

Owing to neutron shielding and leaktightness with regard to primary sodium, secondary sodium activation and pollution should be low, and even negligible as compared to chemical risks.

Risks will be then :

- thermal effects on structures in contact with hot sodium
- thermal effects associated to burning sodium (hot gases and aerosols)
- associated pressure effects
- chemical effects of different aerosol forms on man
- longterm chemical effects of sodium, aerosols and extinguishing powders on structures.

3.3 - Safety analysis objectives

Direct consequences of a secondary sodium fire are not radiological, but we need insurance that it cannot propagate so that dangerous product containement is jeopardizing directly or indirectly. To this end we need :

C. Insurance of the efficiency of some safety related components, for considered fire conditions, such as shut down rod mechanisms, primary pumps, roof, dome, circuits for decay heat removal.

D. Limitation of damage propagation due to leak, fire and extinction of sodium fires, for protecting safety related components and insuring good safety conditions for future operation.

E. To know the toxicity of sodium aerosol releases into atmosphere for man, flora and fauna.

3.4 - Detailed questions

The preceding objectives (C, D, E) lead us to ask some detailed questions :

C.1 - Sodium leak detection

C.2 - Sodium fire detection

C.3 - Strength of structures in contact with sodium

C.4 - Secondary circuits protection against fire

C.5 - Temperature and pressure associated to mixed fires

C.6 - Protection of water circuits during a fire

Questions C.1, C.3, C.4, C.6 can result in preventior measures aiming at decreasing fire extension or minimize its consequences

D.1 - Temperature and pressure associated to a mixed fire into rooms containing sodium circuits, this point being related to C.5.

D.2 - Pressure limitation during a fire into rooms containing sodium circuits

D.3 - Limitation of the mass of the sodium burning in rooms containing sodium circuits

D.4 - Limitation of the mass of sodium burning in a generator building

D.5 - During spilling of sodium on walls, concrete protection and hydrogen release

D.6 - Water circuits protection against a sodium fire in a steam generator building

D.7 - Extinction of sodium pool fires : qualification and use of powders, clothes to use

D.8 - After a sodium fire, secondary fires of cables, paints, etc... due to aerosols.

D.9 - Strength and possible use of some components

D.10- Cleaning after a leak, or a fire and its/ /extinctior

Here too, questions D.5, D.6, D.8, D.9 can lead to prevention measures in order to mitigate fire consequences.

E.1 - Know aerosol releases during a fire in rooms containing sodium circuits

E.2 - Know aerosol releases during a fire in a steam generator building

E.3 - Chemical changes of sodium aerosols released in the atmosphere

E.4 - Toxicity of different sodium aerosol releases for man.

E.5 - Toxicity of sodium aerosols for flora and fauna, study of food chains

4. Auxiliary sodium fires

4.1 - Fire conditions

Auxiliary sodium circuits comprise mainly :

- the fuel storage vessel and its auxiliary circuits such as level adjustment and cleaning circuits
- the cooling circuits of the fuel storage
- the sodium storage, located in a remote building
- the cooling circuits of fuel storage are extending to two steam generator buildings, and can therefore cause fires. Other associated circuits are inside of the reactor building.

These fires concern generally moderate sodium amounts (low diameter of pipes, limited volumes), and should not impede further operation.

4.2 - Associated risks

In the present conditions, the radioactive pollution of sodium in fuel storage vessels or their auxiliary circuits is less important than the chemical toxicity of sodium oxyde.

Risks are therefore of the some nature as those associated to a secondary sodium fire, except for the scale. Radiological effects though slight need some examination.

4.3 - Safety analysis objectives

As for secondary sodium one finds :

D. Limitation of damage propagation due to leakage, fire and extinction of sodium fire, in order to protect safety related components and to insure good safety conditions for further operation.

F. Limitation of radiological consequences, by maintaining efficiency of filters by the use of pre-filters

4.4 - Detailed questions

In addition to the normal adaptation of D questions of chapter 3.4, detailed questions are the following :

D.11 - Sodium burning inside a controlled atmosphere room, as far asthe sodium temperature, and the hygrometry are concerned

D.12 - Limitation of the mass of burning sodium in a room

D.13 - Insulation behaviour during a sodium leak

D.14 - Temperature and pressure associated to a mixed fire in a room

F.1 - Aerosol composition from a contaminated sodium pool

F.2 - Aerosol transfer after a fire in a room

F.3 - Prefilter system

F.4 - Cleaning system strength for thermal stresses after a fire

5. Associated experimental programmes

A detailed experimental research programme can be deduced from all these precise questions. In fact, this type of analysis led us to complement on-going programmes with the ESMERALDA project, described in other papers.

IGNITION OF A LIQUID SODIUM POOL

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ABSTRACT :

The ignition temperatures of liquid sodium are poorly defined : the values mentioned in the literature range from 120°C to 470°C. This study determined the liquid sodium ignition limits in terms of temperature and oxygen molar fraction. A sodium ignition mechanism model is presented.

Sodium Ignition

It is essential for sodium users (nuclear power plant operators or experimental research technicians) to know the critical conditions under which sodium ignites in air. It is also desirable to specify the physical phenomena which control sodium ignition in order to define possible preventive means.

1 - GENERAL

The sodium ignition temperatures in air cited in the literature range from 120°C to 470°C (Table 1). This disparity reveals the importance of a number of ignition parameters, such as the sample size (droplet or liquid layer), the static or turbulent state of the metal