FR8401733

COMMISSARIAT A L'ENERGIE ATOMIQUE

INSTITUT DE PROTECTION ET DE SURETE NUCLEAIRE

DEPARTEMENT D'ANALYSE DE SURETE

DAS

[redacted]

RAPPORT DAS N° 44e

SOURCE TERMS ASSOCIATED WITH TWO SEVERE ACCIDENT SEQUENCES IN A 900 MWe PWR

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International meeting on light water reactor severe accident evaluation
Cambridge, MA (USA) 28 Aug - 2 Sep 1983
CEA-CONF--7209

Décembre 1983

* DAS/SASR/SAER

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INTRODUCTION

Hypothetical accidents taken into account in PWR risk assessment result in fission product release from the fuel, transfer through the primary circuit, transfer into the reactor containment building (RCB) and finally release to the environment.

The objective of this paper is to define the characteristics of the source term (noble gases, particles and volatile iodine forms) released from the reactor containment building during two dominant core-melt accident sequences : S_2CD and TLB according to the "Reactor Safety Study" terminology [1]. The reactor chosen for this study is a French 900 MWe PWR unit. The reactor building is a prestressed concrete containment with an internal liner (Figure 1).

According to the results obtained, action might be planned for the protection of public health, within the framework of an emergency plan called the "Plan Particulier d'Intervention (PPI)".

Core melting produces aerosols in abundance ; the greater part of fission products will be in particulate form, will be mixed with the inactive aerosols and will be depleted together with these aerosols. The sensitivities of aerosol behavior to the rate of material released from the fuel and to thermodynamics in the reactor containment building (presence of steam) are high. Consequently, aerosol behavior calculations have to be performed by using input data given by thermodynamic codes (in particular, atmosphere moisture).

Iodine, which dominates the short-term radiological consequences, is assumed to be released mainly as CsI aerosols in the reactor containment building. This radioactive material, associated with other fission product species such as cesium hydroxide, will form small droplets in humid atmosphere. The small size of the droplets, around 10 µm, might promote iodine release in the containment atmosphere because volatile iodine species can be generated by β/γ irradiation of the CsI solution. The airborne activity of iodine under gaseous form in the containment might therefore increase until an equilibrium is reached between the iodine concentration in the water at the bottom of the reactor containment building and that in the atmosphere of the reactor containment building.

Besides, containment building pressure loadings have been evaluated (from steam and non-condensible gas releases and from hydrogen burns) in order to predict failure modes, failure time and subsequent radioactive releases to the environment.

SELECTION OF ACCIDENT SEQUENCES

The characteristics of the source term (noble gases, particles and volatile iodine forms) released from the reactor containment building have been determined during two core-melt accident sequences.

The first core-melt accident sequence is a 2" break loss-of-coolant accident on the cold leg, with failure of both the emergency core cooling system and the containment spray system. The second one is a transient initiated by a loss of offsite and onsite power supply and auxiliary feedwater system. These two sequences have been chosen because they are representative of risk dominant scenarios.

For each accident sequence, two cases have been studied :

1/ Nominal containment leak rate (0.1 vol.%/day at 0.175 MPa - 0.3 vol.%/day at 0.5 MPa).

2/ Containment isolation failure (β mode) with leak area of 50 cm^2.

METHODOLOGY

Table 1 shows a flow diagram of the relationships between the different codes.

First, the core fission product inventory at the onset of the accident is calculated by the PEPIN Code. Then, from the core temperature, one estimates the rate of release of the various fission products from the core and the duration of the release (BOILK Code). The thermal-hydraulic conditions in the primary system are determined :
- up to the point of severe fuel damage by the RELAP 4 Mod 6 Code [2],
- during the core melting by the BOILK Code.

The source rates of the various fission products, their relevant chemical and physical properties and the thermal-hydraulic conditions calculated above can be used in a computer model to predict the retention of fission products in the primary system. This code predicts a release from the primary system which, in turn, serves as input to the AEROSOLS/B1 Code which calculates the removal of fission products from the containment atmosphere.

N.B. : In the present work, the retention of fission products in the primary system is not taken into account for temporary lack of adequate computer model. The writing of such computer model (adaptation of AEROSOLS/B1) is now in progress at the CEA.

The JERICHO Code [3] provides the thermal-hydraulic conditions in the reactor containment building from the onset of the accident through the stages of blowdown, core heat-up, boiloff, core meltdown, pressure vessel bottom head failure and interaction of the molten debris with the concrete containment basemat. The energy and mass flowrates of the different gaseous species (H_2O, H_2, CO_2, CO) entering the containment are evaluated :

- by the RELAP 4 Mod 6 Code (blowdown),
- by the BOILX Code (core heat-up, boiloff and core meltdown),
- by the INTER Code [4] and from published data related to fuel debris-concrete interaction [5], [6].

Using AEROSOLS/B1 and ANTARES Code results (aerosol behavior and β/γ dose rates in the containment respectively), the COPAR Code predicts the molecular iodine behavior in the containment. Finally, the ABAC Code estimates the radionuclide release to the environment.

The source term assessment codes are briefly described below.

PEPIN Code (core inventory)

The PEPIN Code computes the evolution of decay heat, gamma and beta radiations emitted by fission products after the scram of the reactor. It solves coupled differential equations binding 635 fission product concentrations during operating and cooling times. These equations describe the following phenomena :

- direct fission product formation,
- production and disappearance by radioactive decay and neutron capture.

BOILX Code (core heat-up, boiloff and core meltdown)

The BOILX Code is a modified version of the BOIL Code [7] including best-estimate fission product emission rates described in the NUREG 0772 report [8]. Besides, the ANS decay heat has been replaced by decay heat tables calculated by means of the PEPIN Code (fission products divided into several classes according to their chemical and physical properties).

JERICHO Code [3] (thermal-hydraulic conditions in the reactor containment building)

JERICHO Code provides the thermal-hydraulics in the containment ; in particular, gas pressure, gas and wall temperatures, atmosphere moisture, atmosphere composition and leak rate.

The containment volume is modelized in one compartment with two phases : gaseous atmosphere and sump water. Both phases are assumed to be homogeneous, in pressure equilibrium, but in thermal non-equilibrium. In case of diphasic flow at the primary circuit break, several options can be used to divide it up over gaseous and liquid phases. Heat and mass exchanges between both phases are precisely described : convection, condensation, evaporation and eventually ebullition. In case of supersaturation, condensation in the bulk gaseous phase can occur.

Containment walls and internal structures are modelized as one-dimensional slab geometry heat sink (up to 12 slabs). In order to calculate the temperature surfaces of heat slabs, the code uses an original method : the heat transfer equations have been converted into a set of ordinary differential equations [9].

Energy and mass transfer (between atmosphere and structures) laws corresponding to convection and condensation have been introduced.

Containment atmosphere can be composed of air, steam, hydrogen, carbon dioxide and carbon monoxide. Volumetric concentrations are compared to flammability limits, expressed in a (H_2+CO, H_2O+CO_2, air) ternary diagram.

Hydrogen and carbon monoxide burning is modelized in different ways :

- continuous burning as soon as flammability limits are reached,
- storage and instantaneous burning (deflagration) at input specified time.

Containment related safety engineering features (containment spray system) are modelized. Spray water comes first from the refueling water storage tank, then it is recirculated from the containment sump water.

In order to respect long-term energy balance, decay heat associated with fission products released into the containment can be accounted for. Likewise, energy radiated by the corium during the corium-concrete interaction phase can be included in the energy balance.

Finally, possible leakage through the containment building is modelized in order to take into account the natural leakage rate of the containment or failure in the tightness system. Venting devices, under consideration to avoid containment failure due to overpressurization, can also be represented.

The numerical treatment consists in the integration of linear differential equations by the ADAMS-PECE method.

AEROSOLS/B1 Code (Aerosol behavior in the reactor containment building)

AEROSOLS/B1 computes the physical behavior of aerosols in a containment or in a multi-compartment containment. This code uses the linear finite element method for the discretization of the particle spectrum. The range of volume is divided into N-1 intervals regularly spaced according to a logarithmic scale. A set of N equations is then obtained by writing the integro-differential equation describing the physical behavior of aerosols for the nodes of the mesh. This set of equations is solved by using the ADAMS-PECE algorithm.

The phenomena taken into account are the following :

- floor deposition by gravitational sedimentation,
- wall deposition by brownian diffusion and thermophoresis,
- coagulation (brownian, gravitational and turbulent),
- leakage.

The implementation of steam condensation/evaporation on the particles and diffusiophoresis is now in progress.

ANTARES Code (β/γ dose rates)

. The ANTARES Code computes the evolution of gamma dose rate and integrated dose at several points inside the reactor containment building during an accident. The radiation source is evaluated using PEPIN Code results and some assumptions on fission product release and transport in the containment building Gamma transport is evaluated by using a three dimensional geometry model (with containment internal structures) and Monte-Carlo method.

. Concerning beta dose rate inside the reactor containment building, the radiation source is also evaluated using PEPIN Code results. The beta transport is evaluated by using a spherical geometry model (infinite environment) and by assuming that beta radiation propagation occurs in a straight line.

COPAR Code (Iodine behavior in the reactor containment building)

Concerning iodine behavior in the reactor containment building, several mechanisms have been taken into account [10] :

- molecular iodine formation through β/γ irradiation as a function of dose (calculated by the ANTARES Code), pH and iodide concentrations in the droplets (aerosols),
- iodine retention by chemical reactions in the aqueous phase (partition coefficient between water and the atmosphere above it).

ARAC Code (Fission product releases from the reactor containment building)

By taking into account the fission product behavior in the containment building (AEROSOLS/B1 calculations), the containment leak rate (JERICHO calculations) and the fission product radioactive ~~decay~~, the ARAC Code provides source term (noble gases, particles and volatile iodine forms) emitted into the environment : released fraction of core inventory as function of time.

-INPUT DATA

Calculations have been performed for a French 900 MWe PWR (Figure 1) with the following data :

. Reactor containment building and primary coolant system

The main characteristics of this containment type and the primary coolant system are summarized below :

Reactor containment building	
Volume	49,900 m^3
Design pressure	0.5 MPa
Failure pressure estimate (through-crack)	0.8-0.9 MPa
Leak rate	0.1 Vol %/day at 0.173 MPa 0.3 Vol %/day at 0.5 MPa

Primary coolant system		
Mass of water		181,000 kg
Accumulator tank:	Mass of water	83,150 kg
	Initial pressure	4,2 MPa
Mass of UO_2 in core		79,600 kg
Mass of Zr in core		17,400 kg
Mass of steel in core		3,000 kg
Mass of Ag,In,Cd, in core (control rods)		2,000 kg

. Concrete chemical and physical properties

The following data have been used for INTER calculations (corium-limestone concrete interaction) :

Concrete composition		
Ca CO_3	0.580	weight fraction
$Ca(OH)_2$	0.013	
SiO_2	0.263	
Free H_2O	0.038	
Al_2O_3, Fe_2O_3,...	0.106	
Steam and gas releases		
Free water	91 kg/m^3 concrete	
Bound water	55 kg/m^3 concrete	
Carbon dioxide	588 kg/m^3 concrete	
Concrete physical properties		
Thermal conductivity	2 W/m.°C at 80°C 1 W/m.°C at 400°C	
Specific heat	836 J/kg.°C	
Density	2,400 kg/m^3	

. Decay heat

Concerning the decay heat associated with the fission products released in the reactor containment building, γ and β radiation energy dissipations are treated in the following way :

For γ radiation	10 % in the gas atmosphere 90 % in the walls
For β radiation	50 % in the gas atmosphere 50 % in the walls

. Aerosol behavior in the RCB

The aerosol release from the fuel has been determined from calculations by BOILK. A total of 629 kg of airborne aerosol mass is released, including inactive and active fission products :

Volatile fission products (100 % of core inventory)	CsOH	137 kg
	CsI	22 kg
	Te	20 kg
Non-volatile fission products (Sr,Ba,Zr,Nb,Ru,...)		100 kg
Fuel clads (Zr,Sn) Control rods (Ag,In,Cd) Structure material (Fe,Ni,Cr)		350 kg
	TOTAL :	629 kg

Aerosol source during the corium-concrete interaction is not taken into account firstly due to the lack of accurate data on the emission rate and emission duration, secondly due to the probably high retention of these aerosols in the reactor cavity. This approach is conservative because these aerosols (which the greater part consists of inactive aerosols) would emphasize, by coagulation, aerosol depletion in the containment.

The following input data have been used for the AEROSOLS/B1 Code :

Aerosol source	
Aerosol mass released	529 kg
Source duration	45 minutes
Mass median radius	0.5 µm
Standard deviation	2
Aerosol material density	6,000 kg/m³
- Sedimentation area	330 m²
- Total surface	28,426 m²
- Collision efficiency	0.1
- Turbulent energy dissipation rate	0.1 m²/s³
- Thermal boundary layer thickness	0.002 m
- Gas pressure	JERICHO output
- Gas and wall temperatures	
- Leak rate	

RESULTS OBTAINED - DISCUSSION

Tables 2 and 3 give the timing of predicted events for the two core-melt accident sequences S_2CD and TLB.

Note that :

For S_2CD,
- the fission product release starts at 150 minutes,
- the core slump occurs at 195 minutes,
- and the corium-concrete interaction begins at 262 minutes.

For TLB,
- the fission product release starts at 65 minutes,
- the primary system depressurization and accumulator discharge occurs at 138.5 minutes,
- and the corium-concrete interaction begins at 139 minutes.

For both sequences, the containment floor melt-through occurs at five days (thickness of the concrete containment basemat = 4.2 m) ; this is in agreement with the concrete penetration rates given in Table 4.

Containment Atmosphere Pressure

Figure 2 shows the containment building internal pressure as a function of time for S_2CD, S_2CD β, TLB and TLB β. These curves indicate the effects of the events described in Tables 2 and 3, in particular :

- For S_2CD, the peak at 195 minutes corresponds to the core slump.
- For TLB, the peak at 138.5 minutes corresponds to the primary system depressurization and accumulator discharge.

For S_2CD, the containment design pressure of 0.5 MPa is reached after about three days ; at five days, when the containment floor melt-through is supposed to occur, the gas pressure is 0.46 MPa for TLB and 0.6 MPa for S_2CD. For S_2CD, the pressure increase rate is 2.10^3 Pa per hour ; and, for TLB, $1.4\ 10^3$ Pa per hour.

For the β cases, the containment pressure is near 0.1 MPa after one and a half day.

N.B. : Additional calculations have been performed assuming continuous burning of hydrogen and carbon monoxide. The results obtained are very similar to the previous ones without burning.

Containment Atmosphere Temperature

Figure 3 gives the evolution of the containment atmosphere temperature for S_2CD, S_2CD β, TLB and TLBβ. As previously, these curves show the effects of the events described in Tables 2 and 3.

For each accident sequence, the gas temperatures differ very little whether or not containment isolation failure takes place.

For S_2CD, the containment atmosphere temperature is about 160°C when the containment design pressure of 0.5 MPa is reached. At five days, the gas temperature is about 200°C for S_2CD and 120°C for TLB. These high values of temperature for S_2CD can be explained by the inclusion of energy radiated by the corium during the corium-concrete interaction phase. In the present calculations, the radiation energy is directly transmitted to the gas phase while, in the actual case, a part of this energy will be used to heat the structures located in the reactor cavity.

The gas temperature increase rate is 0.7°C per hour for S_2CD and 0.17°C per hour for TLB.

Containment atmosphere moisture

Figure 4 gives the containment atmosphere moisture versus time for S_2CD, S_2CD β, TLB and TLB β. These curves show that the containment atmosphere moisture is far from saturation, except at the beginning of the accident, during the fission product release. Consequently, the aerosol behavior calculations (AEROSOLS/B1 Code) have been performed without taking into account steam condensation/evaporation on the particles ; this corresponds to a conservative approach.

Containment Atmosphere Composition

Figure 5 gives the atmosphere composition (O_2, N_2, H_2O, H_2, CO_2 and CO) as a function of time for S_2CD. These curves show the importance of carbon dioxide : 50 % of the total mass at five days.

Hydrogen Combustion

The inventories of hydrogen sources are given in Table 5.

For S_2CD, S_2CD β, TLB and TLB β, the hydrogen concentrations always exceed the flammability limits : hydrogen volume fraction more than 4 % and steam volume fraction less than 60 %. Nevertheless, the detonation limit is not reached : hydrogen volume fraction is less than 15 % by assuming homogeneous mixing of hydrogen in the containment atmosphere.

Fission Product Release from the Core

Figure 6 gives the fission product release versus time for S_2CD and TLB (BOILK calculations). These curves show that the fission products are released during a period of time of about one hour. The end of the fission product release period corresponds to the dry-up of the reactor vessel.

Besides, these curves show that almost 100 % of noble gases and volatile fission products are released for S_2CD and TLB.

Aerosol Behavior in the RCB

Figure 7 shows the airborne aerosol concentration for S_2CD and S_2CD β (AEROSOLS/B1 calculations). The maximum aerosol mass concentration is about 10 $g.m^{-3}$ and this maximum occurs at the end of the emission time.

After five days, the aerosol mass concentration has decreased by four orders of magnitude for S_2CD, and more than five orders of magnitude for S_2CD β.

For S_2CD, the aerosol mass concentration is about 6.10^{-3} $g.m^{-3}$ (this corresponds to 300 g of airborne material) when the gas pressure is equal to the containment design pressure.

For S_2CD, S_2CD β , TLB and TLB β at the same time, more than 95 % of the total released aerosol mass has settled on the floor of the containment building.

Figure 8 gives the evolution of the aerodynamic mass median diameter (AMMD) of the suspended particles versus time for S_2CD and S_2CD β. The maximum value is about 10 µm at the end of the emission time. When the gas pressure reaches the containment design pressure, at three days, the AMMD is about 4 µm for S_2CD.

Source term (noble gases, particles and volatile iodine forms released from the reactor containment building).

In order to characterize the source term for S_2CD, S_2CD β, TLB and TLB β, the following isotopes have been selected :

. ^{133}Xe (noble gases)	for exposure resulting from the passage of radioactive cloud,
. ^{131}I (iodine)	for inhalation (thyroid dose) and for short-term exposure from ground contamination,
. ^{137}Cs (cesium)	for long-term exposure from ground contamination,

Source term calculations (ARAC Code) have been performed using :
. containment leak rate (JERICHO output),
. aerosol mass leakage (AEROSOLS/B1 output),
and taking into account fission product radioactive decay.

Besides, when the containment floor melt-through occurs, we have assumed that the fission product inventory in the containment is instantaneously emitted to the environment with the following ground decontamination factors :
. 1 for noble gases and organic iodide,
. 10^3 for particles and molecular iodine.

Noble Gases

Figure 9 shows the ^{133}Xe integrated release as a fraction of initial core inventory, versus time for S_2CD, S_2CD β, TLB and TLB β. For S_2CD β and TLB β, 84 % and 81 % of the initial core inventory are released from the containment. For S_2CD and TLB :
. about 1 % is released at five days, before the containment floor melt-through occurs,
. about 45 % are released after the containment floor melt-through occurs ; this large amount is explained by the ground decontamination factor taken equal to 1 for noble gases, and by the ^{133}Xe radioactive decay.

Cesium

Figure 10 shows the ^{137}Cs integrated release fraction of initial core inventory versus time for S_2CD, S_2CD β, TLB and TLB β. For S_2CD β and TLB β, about 2 % of the core inventory is released from the containment ; for S_2CD and TLB, 0.006 % and 0.007 % are released, respectively.

Iodine

. Figure 11 shows the particulate ^{131}I integrated release fraction of initial core inventory versus time for S_2CD, S_2CD β, TLB and TLB β. For S_2CD β and TLB β, about 2 % of the core inventory is released from the containment ; for S_2CD and TLB, about 0,006% is released.

. Concerning the molecular iodine, calculations have been performed by taking into account molecular iodine release through β/γ radiolysis of CsI/CsOH droplets : about 0.5 % of the initial amount of iodide in CsI droplets is released per MRad [10]. From the residence time of the droplets (Figure 7) and the β/γ dose rates (about 10 MRad per hour) in the containment building, molecular iodine releases have been evaluated : 3 % of initial iodine core inventory for S_2CD and 3.5 % for TLB. Besides, due to the presence of CO_2 in the gas atmosphere and in order to be conservative the pH of the sump water is supposed to be acid ; consequently, the iodine partition coefficient is very low (~ 100) ; and as the ratio gas volume/liquid volume is about 250, the greater part of the molecular iodine remains in the gas phase (it is not trapped in the sump water).

We have further assumed that the molecular iodine (released through β/γ radiolysis of CsI droplets) does not interact with the sump water and containment surfaces.

Figure 12 shows the ^{131}I (molecular iodine) integrated release fraction of the initial core inventory versus time for S_2CD, S_2CD β, TLB and TLB β. For S_2CD β and TLB β, about 3 % of the initial core inventory is released from the containment building ; for S_2CD and TLB, about 0.03 % is released.

- Concerning the organic iodide, calculations have been performed using the formation rate given by R.J. BAWDEN et al [11] : 0.01 % of containment iodine inventory per day. For S_2CD, S_2CD β, TLB and TLB β, about 0.05 % of initial iodine core inventory is released from the contaiment as organic iodide.

Table 6 summarizes the radioactivity released from the containment for S_2CD,S_2CD β, TLB and TLB β.

Note, for the sequences considered, that :

- the source terms for the β cases are high,
- the molecular iodine source term is higher than that of particle iodine,
- for S_2CD and TLB, the organic iodide source term is of the same order of magnitude as that of the molecular iodine,
- the greater part of the release from the containment occurs during the first day (Figures 8 to 12), except for the noble gases (S_2CD and TLB).

CONCLUSION

Source terms associated with hypothetical core-melt accidents S_2CD and TLB in a French PWR -900 MWe- have been performed using French computer codes (in particular, JERICHO Code for containment response analysis and AEROSOLS/B1 for aerosol behavior in the containment) which have given the following results :

- Source term for S_2CD and TLB (% of initial core inventory),

^{133}Xe, Noble gases ~ 45
^{137}Cs, Cesium ~ 0.01
^{131}I , Iodine ~ 0.1 → { 0.01 as particles
0.045 as molecular iodine
0.045 as organic iodine.

- Source term for S_2CD β and TLB β (% of initial core inventory),

^{133}Xe, Noble gases ~ 85
^{137}Cs, Cesium ~ 2
^{131}I , Iodine ~ 5 → { 2 as particles
3 as molecular iodine
0.05 as organic iodine.

The previous source terms are relatively high, in case of the β containment failure mode, but substantially lower than those obtained in the WASH-1400 Reactor Safety Study. In addition, note that the probability of such accidents (mainly β cases) is very low. These source terms are pessimistic envelopes for the following reasons :

- the fission product retention in the primary system is not taken into account,
- the molecular iodine trapping in the containment has not been taken into account for lack of data on :
  - interaction between molecular iodine and other constituents of the aerosols (in particular, silver from control rods),
  - interaction between molecular iodine and surfaces.
- the steam condensation/evaporation on the particles has been neglected,
- and, for the β cases, the fission product will not be released directly to the atmosphere, but through auxiliary building where substantial trapping of the fission products is possible.

Nevertheless, some uncertainties can cause the calculated source terms to be underestimated :

- consequences of hydrogen deflagration and steam spike on the fission product behavior,
- adequacy of the input data (in particular, for the JERICHO Code, those concerning the corium-concrete interaction),
- partial lack of experimental validation of the computer models.

Besides, these calculations have shown that :

- the containment atmosphere is dry during the accident (except during the fission product release),
- carbon dioxide is the main component of the gas phase in the long-term (with limestone concrete)
- the gas pressure and temperature increase rates in the containment are not very high (less than 2.10^3 Pa per hour and less than 0.7°C per hour),
- the aerosol mass concentration decreases sharply after the end of the emission time (reduction factor of 100 after half a day),
- for S_2CD, when the gas pressure reaches the containment design pressure, the suspended aerosol mass is about 300 g and the AMMD of the suspended particles is about 4 µm.

FUTURE WORK

In the near future, we intend to perform similar calculations (S_2C and S_2CH accident sequences) with large amount of water (more than 2 000 kg of water with the refueling water storage tank in service). In these scenarios, significant steam condensation will occur on the particles. Other calculations will be performed in order to test the emergency procedures (in particular, in the case of a vented-filtered containment).

In order to reduce the conservatism of the present calculations, R & D work will be emphasized on the following items : fission product retention in the primary system (in connection with the MARVIKEN V program), aerosol and iodine behavior in the containment (PITEAS program).

ACKNOWLEDGEMENTS

In the present work, the authors would like to thank :

C. DEVILLERS, A. L'HOMME, D. MANESSE (CEA/IPSN), for their fruitful discussion,
P. PEPIN, A. ABBAS, G. CARVALLO, (CEA/IRDI) for their help in performing this work.

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TABLE 1 - Flow diagram of relationships among source term assessment codes

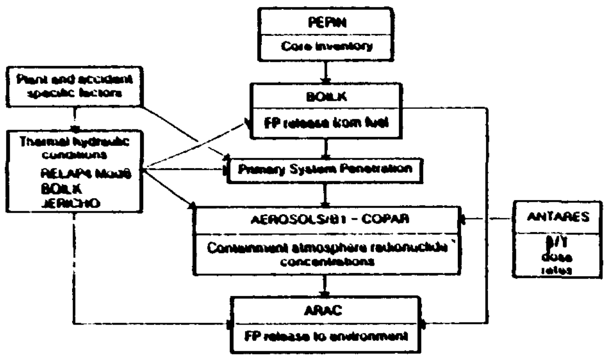

TABLE 2 - Timing of predicted events for S,CD (French PWR - 900 MWe).

Time (minutes)	Events
0	Start of Blowdown
0.8	Reactor scram (primary pressure less than 12.9 MPa) Secondary circuit : feedwater and steam outlet shut-off
1.8	Auxiliary feedwater pumps start
4	Primary pumps stop (cavitation)
31	Core uncovery begins
47	Accumulator discharge
150	Fission product release starts
155	Core melting begins
195	Core slump
200	Reactor vessel dry
262	Bottom head fails Corium-concrete interaction begins
622	Corium solidification
7200	Containment melt-through

TABLE 3 - Timing of predicted events for TLB (French PWR - 900 MWe)

Time (minutes)	Events
0	Loss of offsite and onsite power supply Loss of auxiliary feedwater system Small break on the cold leg (0.5")
0.33	Reactor scram
17.6	Steam generator dryout
35.4	Primary pumps stop (cavitation)
47.5	Core uncovery begins
65	Fission product release starts
75	Core melting begins
134	Core slump
136.5	Reactor vessel dry
138.5	Bottom head fails Primary system depressurization Accumulator discharge
139	Corium-concrete interaction begins
570	Corium solidification
7200	Containment floor melt-throught

TABLE 4 - Data concerning corium-concrete interaction

	Before corium solidification	After corium solidification
Concrete penetration rate	During the first hour 30 cm/h After the first hour 18cm/h From CORCON-Mod1calculations (Figure 10 in [5])	3 cm/h (page 3.26 in [6]) Based on SANDIA experimental data
Gas generation rate	From CORCON-Mod1calculations (Figure 11 in [5])	From SANDIA model (Table 3.5 in [6])
Upward heat flux (Radiation from the molten pool to the reactor cavity)	INTER output	From SANDIA model (Table 3.5 in [6])

TABLE 5 - Hydrogen sources (in kg) for S,CD and TLB

Hydrogen sources	S,CD	TLB
Zirconium cladding oxidation (zirconium cladding oxidized, in %)	378 (48)	225 (29)
Core slump (corium-water interaction in the reactor vessel)	339	583
Corium-concrete interaction	337	547
Sump water radiolysis (after five days)	40	40
Total	1094	1415

TABLE 6 - Radioactivity released (in Ci) from the reactor containment building for S,CD, S,CD β, TLB and TLB β

	Core inventory	S,CD	S,CD β	TLB	TLB β
Noble gases	$3\ 10^{[illegible]}$	$1.35\ 10^{[illegible]}$	$2.52\ 10^{[illegible]}$	$1.28\ 10^{[illegible]}$	$2.43\ 10^{[illegible]}$
Cesium	$8\ 10^{[illegible]}$	$4.80\ 10^{[illegible]}$	$1.66\ 10^{[illegible]}$	$5.60\ 10^{[illegible]}$	$1.28\ 10^{[illegible]}$
Iodine :					
Particle	$6\ 10^{[illegible]}$	$0.55\ 10^{[illegible]}$	$9.80\ 10^{[illegible]}$	$0.39\ 10^{[illegible]}$	$12.0\ 10^{[illegible]}$
Molecular		$1.98\ 10^{[illegible]}$	$16.6\ 10^{[illegible]}$	$2.28\ 10^{[illegible]}$	$18.0\ 10^{[illegible]}$
Organic		$1.82\ 10^{[illegible]}$	$0.23\ 10^{[illegible]}$	$2.10\ 10^{[illegible]}$	$0.24\ 10^{[illegible]}$

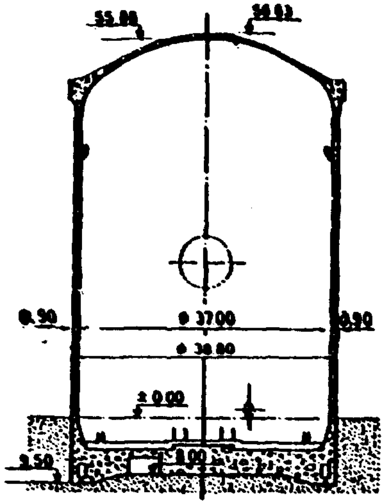

Fig. 1 - REACTOR CONTAINMENT BUILDING
(FRENCH PWR - LARGE DRY - 900 MWe)

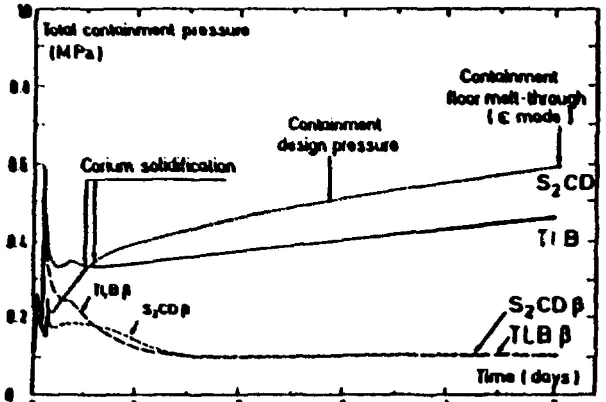

Fig. 2 _ CONTAINMENT BUILDING INTERNAL PRESSURE VERSUS TIME (FRENCH PWR-900 MWe) for S_2CD, $S_2CD\beta$, TLB and TLB β CASES
- JERICHO CALCULATIONS -

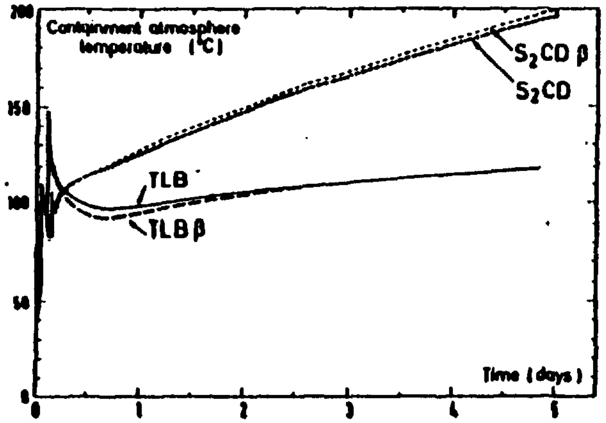

Fig. 3 _ CONTAINMENT BUILDING ATMOSPHERE TEMPERATURE VERSUS TIME (FRENCH PWR - 900 MWe) for S_2CD, S_2CD , TLB and TLB β CASES
- JERICHO CALCULATIONS -

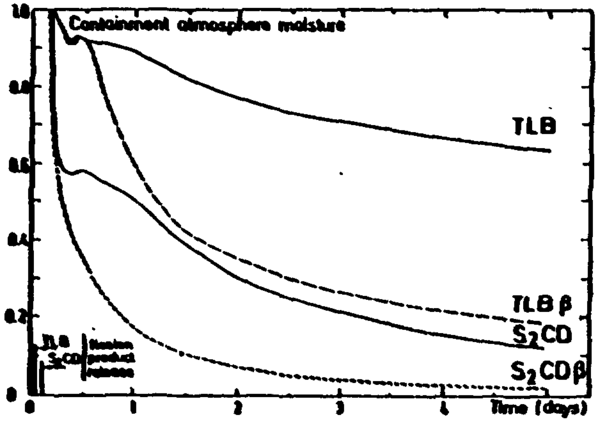

Fig. 4 _ CONTAINMENT BUILDING ATMOSPHERE MOISTURE VERSUS TIME (FRENCH PWR - 900 MWe) for S_2CD, $S_2CD\beta$, TLB and TLB β CASES
- JERICHO CALCULATIONS -

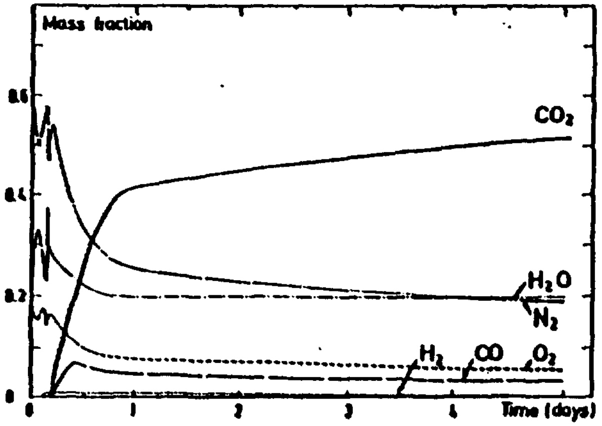

Fig. 5. ATMOSPHERE COMPOSITION VERSUS TIME (FRENCH PWR - 900 MWe) for S_2CD
- JERICHO CALCULATIONS -

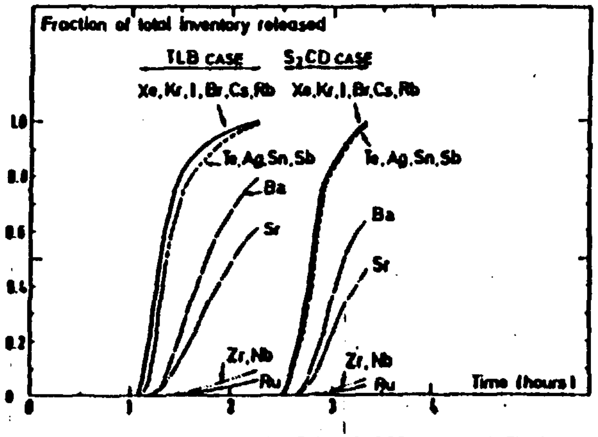

Fig. 6 . FISSION PRODUCT RELEASES VERSUS TIME (FRENCH PWR - 900 MWe) for S_2CD and TLB
- BOILK CALCULATIONS -

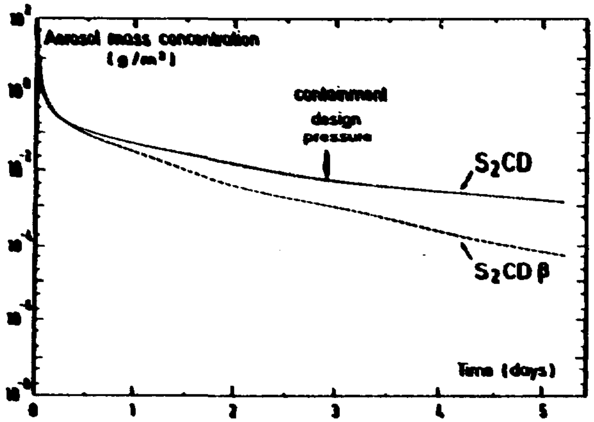

Fig. 7 _ AIRBORNE AEROSOL CONCENTRATION VERSUS TIME (FRENCH PWR - 900 MWe) for S_2CD and $S_2CD\beta$
- AEROSOLS / BI CALCULATIONS -

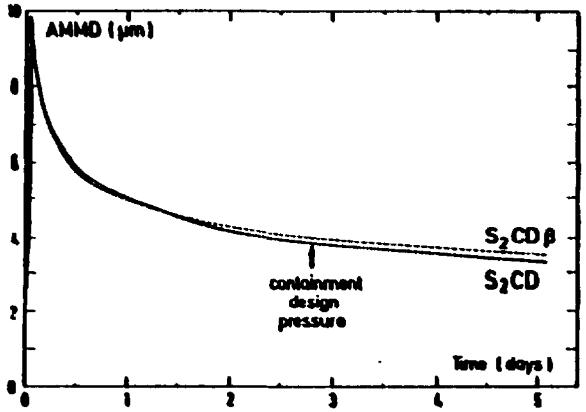

Fig 8 _ AERODYNAMIC MASS MEDIAN DIAMETER of THE SUSPENDED PARTICLES VERSUS TIME
(FRENCH PWR - 900 MWe) for S_2CD and $S_2CD\beta$
- AEROSOLS / BI CALCULATIONS -

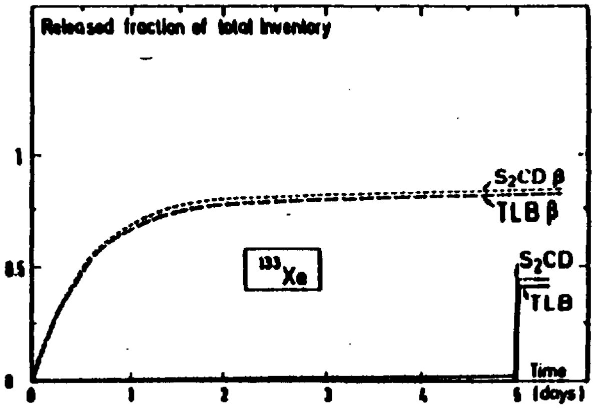

Fig. 9 _ ^{133}Xe INTEGRATED RELEASE FRACTION VERSUS TIME
(FRENCH PWR - 900 MWe) for S_2CD , $S_2CD\beta$, TLB and TLBβ

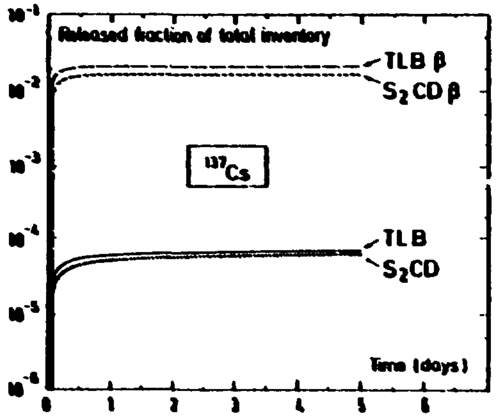

Fig 10. ^{137}Cs INTEGRATED RELEASE FRACTION VERSUS TIME
(FRENCH PWR - 900 MWe) for S_2CD, $S_2CD\beta$. TLB and TLBβ

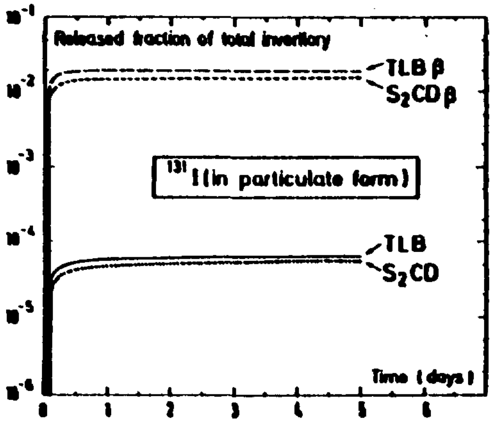

Fig. 11 . ^{131}I (in particulate form) INTEGRATED RELEASE FRACTION VERSUS TIME
(FRENCH PWR - 900 MWe) for S_2CD, $S_2CD\beta$. TLB and TLBβ

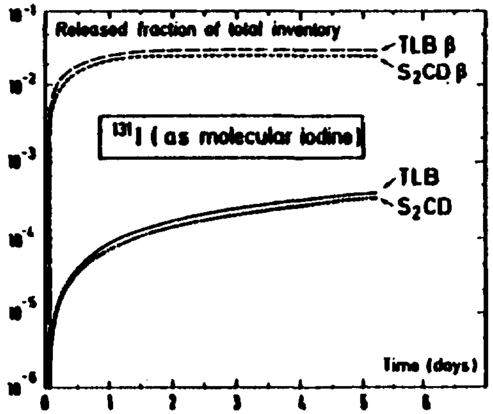

Fig. 12 . ^{131}I (as molecular iodine) INTEGRATED RELEASE FRACTION VERSUS TIME
(FRENCH PWR - 900 MWe) for S_2CD , $S_2CD\beta$, TLB and TLBβ

Janvier 1984

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