FR 8800996

COMMISSARIAT A L'ENERGIE ATOMIQUE

**INSTITUT DE PROTECTION ET DE SURETE NUCLEAIRE**

# DEPARTEMENT D'ANALYSE DE SURETE

CEA-DAS--399

RAPPORT DAS N° 399e

RISK ASSESSMENT FOR LONG-TERM
POST-ACCIDENT SEQUENCES.

F. DUCAMP*, A. ELLIA-HERVY**

Probabilistic safety assessment
and risk management.
ANS/ENS "PSA 87"
(Zurich, 31 août-4 septembre 1987)

CEA-DAS--399

**RAPPORT DAS N° 399e**

RISK ASSESSMENT FOR LONG-TERM
POST-ACCIDENT SEQUENCES.

F. DUCAMP*, A. ELLIA-HERVY**

Probabilistic safety assessment
and risk management.
ANS/ENS - "PSA 87"
(Zurich, 31 août-4 septembre 1987)

* CEA/IPSN
** FRAMATOME

RISK ASSESSMENT FOR LONG-TERM POST-ACCIDENT SEQUENCES

F. DUCAMP
CEA/IPSN/DAS (FRANCE)
A. ELLIA-HERVY
Framatome (France)

## INTRODUCTION

Probabilistic risk analysis, currently conducted by the CEA (French Atomic Energy Commission) for the French replicate series of 900 MWe power plants, has identified accident sequences requiring long-term operation of some systems after the initiating event. They have been named long-term sequences.

Quantification of probabilities of such sequences cannot rely exclusively on equipment failure-on-demand data : it must also take into account operating failures, the probability of which increase with time.

Specific studies have therefore been conducted for a number of plant systems actuated during these long-term sequences. This has required :

- Definition of the most realistic equipment utilization strategies based on existing emergency procedures for 900 MWe French plants.
- Evaluation of the potential to repair failed equipment, given accessibility, repair time, and specific radiation conditions for the given sequence.
- Definition of the event bringing the long-term sequence to an end.
- Establishment of an appropriate quantification method, capable of taking into account the evolution of assumptions concerning equipment utilization strategies or repair conditions over time.

## 2 - EQUIPMENT UTILIZATION STRATEGIES

System components actuated during the long-term sequences have to satisfy two requirements :

- Maintain a minimum system configuration in order to mitigate the consequences of the accident (minimum flow rate, heat exchanger outlet temperature, etc). This minimum configuration depends on system design.
- Follow an utilization policy which minimizes the failure probability of the function assigned to the system.

The emergency operating procedures give the actions to be taken in the first few hours after the initiating event.

They mention the number of trains operating (redundant systems) and, for instance, system configuration in the direct injection phase.

Later during the accident, the major concern is to minimize challenges to individual components (although this is not always integrated into emergency operating procedures). This way impose shutting down redundant components and minimizing challenges to other components.

For instance, the low head safety injection system is automatically put into service (two pumps are started) after a loss of coolant accident.

Operation of the two actively redundant train of this system over a long period of time may not be the best policy. One train can therefore be stopped after a certain time and the system will then operate in passive redundancy.

## 3 - POST-ACCIDENT ACCESSIBILITY OF EQUIPEMENT

Those systems, required to operate for extended periods after occurence of an initiating event, are primarily those essential to core flooding and removal of residual heat. They are :

- the safety injection system (RIS),
- the containment spray system (EAS),
- the residual heat removal system (RRA).

All three systems convey recirculated reactor coolant, which may be contaminated.

Area accessibility to repair RIS or EAS systems will depend solely on the coolant activity (the source term). Two parameters control the activity of coolant recovered in the containment sumps :

- the first is initial coolant activity during operation which is limited by plant technical specifications and depends on plant operating conditions,
- the second is accident-specific and depends on damage experienced e.g. cladding failures, or core overheating. Damage may result either from the initiating event or from the ensuing accident sequence.

Seven levels of source term have been selected, ranging from no contamination to maximum contamination due to release of fission products by core overheating Accessibility and repair conditions over time have been predicted for each, on the basis of the decrease in activity.

### 3.1 - Systems outside the containment

Two types of system equipment conveying reactor coolant have been distinguished :

- equipment in direct contact with reactor coolant (piping, valve bodies, pump casings, etc.) which may be contaminated,
- equipment not in direct contact with reactor coolant (valve motors, pump motors, power supplies, etc.) which is not contaminated.

The repair time for non-contamined equipment is always short. Potentially contaminated equipment may not, at first, be reparable, but may then require a long repair time (due to the use of protective clothing) and may finally require only a short repair time (since the use of protective clothing is no longer necessary).

The time between these various repair stages for potentially contaminated equipment depends on the source term.

### 3.2 - Systems inside the containment

Failed components located in the containment can be accessed and repaired only if ambiant conditions (acceptable dose rates, pressure and temperature conditions) permit access to the containment.

The time at which the containment can be accessed depends on the source term.

## 4 - END OF THE LONG TERM SEQUENCE

Each scenario requires the definition of the event bringing the long-term sequence to an end, that is the definition of the end of the accident.

This event may be :

- closure of the break,

- fuel unloading,

- recovery of almost normal operating conditions.

If none of these events (depending on the source term) occurs before one year is up, then the sequence probability is assessed over thus one year period.

## 5 - MODELS

### 5.1 - Method

Each scenario to be analyzed can be broken down into several consecutive phases. Each is characterized by :

- duration,

- constraints due to the source term (reliability data, etc),

- a resource utilization strategy.

Each of these phases is described by a Markov graph which predicts the response of engineered safeguards and supporting systems. The rate of state transition is computed from fault trees using a description in macrocomponent form.

The occurrence probability of the sequence is then calculated by chaining the Markov graphs, that is by defining relationships between the probabilities of the different states on the Markov graphs describing successive phases.

### 5.2 - Example

The following accident sequence is used to illustrate the method :

- the initiating event is a large LOCA occuring at reactor full power,

- the safety injection operates during the direct injection phase but fails during the recirculation phase.

The source term corresponds to the maximum coolant activity allowed by the plant technical specifications during normal operation.

Purification systems cannot be used after the accident. Consequently, potentially contaminated components of the safeguard systems located outside the containment are assumed to require a long repair time for the first three months following the accident.

After this period of time, they are assumed to require a shorter repair time.

The end of the long term is assumed to be one year.

The successive system configurations taken into account are :

- direct injection of borated water from the RWST tank to the cold legs during the first hour,
- after one hour, switchover to the recirculation mode with water taken from the containment sumps,
- after 18 hours, injection to the hot legs,
- after 15 days, shutdown of one injection train (the system then operates in passive redundant mode and no more in the active redundant mode).

Four time phases are therefore defined which provide the following five successive phases :

- phase n°1 : t = 0 to t = 1 hour,
- phase n°2 : t = 1 hour to t = 18 hours,
- phase n°3 : t = 18 hours to t = 15 days,
- phase n°4 : t = 15 days to t = 3 months,
- phase n°5 : t = 3 months to t = 1 year.

Analysis of these results shows that the probability of the sequence is about 200 times higher after a period of one year than after ten hours, and 10 times higher after a period of one year compared with one month.

If a source term corresponding to 100 % clad ruptures is assumed, these ratios are about 230 and 9 respectively.

## 6 - CONCLUSION

This accident sequence quantification method based on realistic scenarios has been used in the risk assessment of the initiating event "loss of reactor coolant accident" occuring at power and at shutdown.

Compared with the results obtained from conventional methods, this method redistributes the relative weight of accident sequences and also demonstrates that the long term can be a significant contribution to the probability of core melt.

These considerations confirm EDF's decision to provide two specific long-term emergency operating procedures ($H_4$ and $U_3$).

Probabilistic analysis will be used to assess the benefit of these procedures.

Novembre 1987

## DESTINATAIRES

**DIFFUSION CEA**

M. le Haut Commissaire
DSE
DDS
IPSN
IPSN : M. SCHMITT
IPSN : M. CANDES
DRSN : M. BUSSAC
DRSN : M. PELCE
DAS/DIR
DERS Cadarache
SES Cadarache
SERE Cadarache
SIES Cadarache
SESRU Cadarache
SRSC Valduc
SEAREL
DPS/FAR + DPS/DOC : Mme BEAU
DPT/FAR
DSMN/FAR
CDSN/FAR : Mme PENNANEAC'H
UDIN/VALRHO
DEDR Saclay
DRNR Cadarache
DRE Cadarache
DER Cadarache
DEMT Saclay
DMECN/DIR Cadarache
DMECN Saclay
DRE/STT Grenoble
DRE/SETH Grenoble
Service Documentation Saclay :
Mme COTTON (3 ex.)
Service Documentation Cadarache :
Mme REY

**DIFFUSION HORS CEA**

Secrétariat Général du Comité Interministériel de la Sécurité Nucléaire : M. CUREAU
Conseil Général des Mines : M. DE TORQUAT
Service Central de Sûreté des Installations Nucléaires : M. LAVERIE (+ 3 ex.)
Service Central de Sûreté des Installations Nucléaires - FAR
Monsieur le Président du G.P.d. : M. GUILLAUMONT
Direction Générale de l'Energie et des Matières Premières : Mlle TISSIER
FRAMATOME : M. le Directeur Général
NOVATOME : M. le Directeur Général
TECHNICATOME : M. le Directeur Général
TECHNICATOME : Service Documentation
EDF / L'inspecteur général de sûreté et de sécurité nucléaires : M. TANGUY
EDF / SEPTEN (2 ex.)
EDF / SPT
M. HOHLEFELDER } Bundes Ministerium für UMWELT, NATURSCHUTZ
M. BREEST } und REAKTORSICHERHEIT - BONN (RFA)
M. KREWER - Bundes Ministerium für Forschung und Technologie - BONN (RFA)
M. BIRKHOFER - Gesellschaft für Reaktorsicherheit - KOLN (RFA)
M. JAHNS - Gesellschaft für Reaktorsicherheit - KOLN (RFA)
M. HAUBER - U.S.N.R.C. - WASHINGTON (E.U.)
M. BECKJORD - U.S.N.R.C. - WASHINGTON (E.U.)
M. E.A. RYDER - U.K.A.E.A. - Safety and Reliability Directorate - RISLEY (G.B.)
M. J.S. Mc LEOD - Nuclear Installations Inspectorate - LIVERPOOL (G.B.)
M. GONZALES - Consejo de Seguridad Nuclear - MADRID (ESPAGNE)
M. José DE CARLOS - Consejo de Seguridad Nuclear - MADRID (ESPAGNE)
M. C. BORREGO - Département de l'Environnement - Université d'AVEIRO (PORTUGAL)
M. E. HELLSTRAND - STUDSVIK ENERGITEKNIK AB -
Nuclear Division, Safety and System Analysis - NYKOPING (SUEDE)

Novembre 1987

M. NASCHI - Direttore Centrale della Sicurezza Nucleara e della Protezione Sanitaria - ENEA - ROMA (ITALIE)
M. P. VANNI - Direttore relazioni esterne e informazione - ENEA - ROMA (ITALIE)
M. ZHANG YU MAN - National Nuclear Safety Administration (CHINE)
M. MA FUBANG, Director of the Nuclear Electricty Office - MIN (CHINE)
M. KANDA - MITI (JAPON)
M. EIICHI TSUJI - Science & Technology Agency - Director of the Nuclear Safety Division (JAPON)
M. OKASAKI - Science & Technology Agency - Nuclear Safety Division (JAPON)
M. FUKETA - JAERI - Center of Safety Research (JAPON)

M. CHAVARDES (Attaché près de l'Ambassade de France aux Etats-Unis)
M. MORIETTE (Attaché près de l'Ambassade de France au Japon)
M. GOURIEVIDIS (Attaché près de l'ambassade de France en Chine)

**COPIE (SANS P.J.)**

SRDE
LEFH
BAIN
GCSR
SASR
SACP
SAEP
SGNR
SAREP
SAPN
SASICC
SASLU
SASLU/VALRHO
SEC
SAET
SAED
STAS
SASC
SAEG
SAM
SPI

M. WUSTNER (Attaché près de l'Ambassade de France en RFA)