4.1 STATUS OF THE ASTEC INTEGRAL CODE

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Abstract

The ASTEC integrated code is developed since 1997 in close collaboration by IPSN and GRS to predict an entire LWR severe accident sequence from the initiating event up to Fission Product (FP) release out of the containment. The applications of such a code are source term determination studies, scenario evaluations, accident management studies and Probabilistic Safety Assessment level 2 (PSA-2) studies.
The version V0 of ASTEC is based on the RCS modules of the ESCADRE integrated code (IPSN) and on the upgraded RALOC and FIPLOC codes (GRS) for containment thermalhydraulics and aerosol behaviour.
The latest version V0.2 includes the general feed-back from the overall validation performed in 1998 (25 separate-effect experiments, PHEBUS.FP FPT1 integrated experiment), some modelling improvements (i.e. silver-iodine reactions in the containment sump), and the implementation of the main safety systems for Severe Accident Management. Several reactor-applications are under way on French and German PWR , and on VVER-1000, all with a multi-compartment configuration of the containment.
The total IPSN-GRS manpower involved in ASTEC project is today about 20 men/year.
The main evolution of the next version V1, foreseen end of 2001, concerns the integration of the front-end phase and the improvement of the in-vessel degradation late-phase modelling.

Keywords : Integrated code – Severe accident – ASTEC – PSA2 – Source term

1 Introduction

The integrated code ASTEC (Accident Source Term Evaluation Code) is being developed by IPSN (Institut de Protection et de Sûreté Nucléaire), France, and GRS (Gesellschaft für Anlagen- und Reaktorsicherheit), Germany, since 1994 /1/. The aim of this close co-operation of both companies is the creation of a fast running integrated code which allows the calculation of the entire sequence of a severe accident in a light water reactor from the initiating event up to the release of fission products into the environment, covering all important in-vessel and ex-vessel phenomena. The main fields of application of this code are probabilistic safety analysis level 2 studies, accident sequence studies, uncertainty and sensitivity studies and support to experiments.

Since the 1980s, a two tier approach has been applied by IPSN and GRS based on the simultaneous but independent development of both integrated and detailed mechanistic codes. During this time IPSN has developed the integrated code ESCADRE, and GRS has modelled the containment behaviour using two codes, RALOC for the thermal hydraulics and the hydrogen distribution and FIPLOC for the aerosol behaviour. For the first ASTEC version (called V0), it has been decided to gather in the same system the best candidates which can be provided by the two companies. Thus, ASTEC V0 consists in a combination of some modules of ESCADRE (for the reactor cooling system, core degradation, fission product release and transport, corium ejection from the vessel, direct containment heating and iodine chemistry in the containment), and of the module CPA (Containment Part of ASTEC), which combines the RALOC and FIPLOC codes.

2 Status of ASTEC V0

The first version V0.1 was used intensively in 1998 by IPSN and GRS. A general feed-back came from multi-compartment reactor calculations and from the overall validation on 25 separate-effect experiments (see the validation matrix in Fig.1), and on the FPT1 experiment of the Phebus.FP programme implying most of the code modules in a coupled mode /2/.

This intensive use led to a recent version, V0.2, released in October 1999 to IPSN and GRS users, which includes the following modules:

- VULCAIN 7.1: RCS thermal hydraulics and core degradation, up to vessel lower head failure. The late-phase degradation simulates corium pool formation and evolution, corium slump into the lower head and (with more crude modelling) corium behaviour in the lower head and vessel failure.
- ELSA 1.1 rev.2: FP release from the fuel rods. The semi-empirical approach deals with three FP classes in an intact geometry : volatile, semi-volatile and non-volatile FPs. When the geometry becomes degraded, the modelling switches from ELSA to a CORSOR-type one.
- SOPHAEROS 1.1 rev.1: FP vapour and aerosol transport in the RCS. With twelve families of species and five states (suspended aerosols, vapour on walls, etc.), the main phenomena are modelled : aerosol deposition (thermophoresis,...), aerosol coagulation (gravitational,...), vapour interactions (condensation on aerosols,...).
- RUPUICUV 1.1: DCH (Direct Containment Heating). This module predicts the ex-vessel corium discharge into the cavity (vessel blow-down, cavity pressurisation) and the potential corium oxidation and entrainment from the cavity to the containment.
- WECHSL 3.5: molten-core concrete interaction (MCCI) in the cavity. It assumes either well-mixed or stratified (oxide, metal) corium, and calculates concrete ablation and corium oxidation.
- CPA, consisting of two main sub-modules :
  - THY for thermal hydraulics inside the containment. It describes phenomena such as gas distribution, pressure build up, hydrogen combustion, behaviour of safety systems etc. It is based on the containment code RALOC Mod4 and the thermal hydraulic part of FIPLOC.
  - AFP for aerosol and FP behaviour in the containment. The models for the aerosol and FP behaviour (transport and depletion) are based on the corresponding models of FIPLOC. The FP transport model FIPHOST is included. The aerosol transport through water pools is simulated with the pool scrubbing model SPARC-B.
- IODE 4.2 for iodine behaviour in the containment (sump and gas phase), including for instance the silver-iodine reactions in the sump.
- ISODOP: decay of FP and actinide isotopes. It starts the calculation using an initial isotope inventory generated by the CEA code PEPIN and allows decay heat and activity in the core, in the

RCS, in the containment and in the environment to be estimated. It is based on a CEA database containing a description of all isotopes.

- SYSINT: management of engineered safety features (for instance spray,...).

The whole documentation of the V0.2 is now ready, and gathered on a Web site: description of all the physical models, on-line hypertext user's manual, minimal validation report.

As for informatics, the ASTEC modules communicate with each other through a database. This allows two different running modes :

- stand-alone mode for running each module independently, useful for module validation,
- coupled mode where all (or a subset) of the modules are run sequentially within a macro-time step. This mode allows explicit feed-back between modules.

The computer interface includes :

- automatic data checkers for pre-processing,
- on-line visualisation tool, including a specific development for visualisation of RCS,
- post-processing of the graphical files with the TIC tool,
- coupling to the statistical analysis tool SUNSET (developed by IPSN) , in order to provide the confidence the user may expect from the code results.

Improvements are under way in order to lead to the version ASTEC V0.3 mid-2000, mainly on extension of the IODE module to deal with several compartments and on integration of the latest version of the SOPHAEROS module (gas phase chemistry, homogeneous nucleation, aerosol mechanical resuspension,...).

3 ASTEC V0 applications

Several reactor applications are currently being performed :

- on the one hand to "consolidate" the code through numerous reactor applications, in order to check all models and their coupling in various conditions and ranges of physical parameters, as well as the activation and correct behaviour of main safety systems.

- on the other hand to compare its results with reference integrated codes such ESCADRE (former IPSN integrated reference code), MELCOR on German Konvoï PWR 1300 MWe and on VVER-1000, and MAAP4 on VVER-440.

As an example of current operationality application, the results of a high-pressure reactor-case for a French 900 MWe PWR are presented in the Figures 3 to 5. The reactor nodalization is (Fig.2) : 24 axial meshes and 5 radial rings for the core, 35 volumes for RCS, and 11 compartments for containment.

The scenario is a TMLB sequence, characterized by a total loss of SG feedwater, PORV regulation, no accumulator discharge, and ECCS not available. The hydrogen and steam source is injected in the compartment where is the pressurizer relief tank zone (number C10 on Fig.2). The results show that different models are now operative, mainly DCH after vessel lower head rupture, activation of spray system, first in direct mode then in recirculation mode, and transport of FP and aerosols through the containment compartments.

4 Development of ASTEC V1

A main drawback of ASTEC V0 is the absence of a model for the front end phase of a severe accident, i.e. the phase from the initiating event through vessel blow-down up to the beginning of core uncovery. This leads to the necessity of calculating the RCS behaviour during the front end with an adequate thermalhydraulic code, like CATHARE or ATHLET, in order to obtain the initial conditions at the beginning of core uncovery and the sources to the containment during the front end phase.

The development activities for the ASTEC version V1 are concentrated on overcoming this drawback. Feasibility studies have led to replace the VULCAIN module, dealing with the primary circuit thermal hydraulics and core degradation in version V0, by two new modules, CESAR (Circuit Evolution under Severe Accidents in Reactors) and DIVA (Degradation In-Vessel during Accidents).

The module CESAR is based on a plant simulator French code. This module covers the 2-phase thermal hydraulics in the reactor coolant system. It is based on a lumped parameter approach with zero- and one-dimensional nodes and with 5 conservation equations for the liquid and gas mass and energy and for the mixture momentum.

The module DIVA is based on ICARE2 V3, the mechanistic reference code for core degradation during severe accidents at IPSN. To fulfil the fast running requirements of ASTEC, CPU-time intensive models of ICARE2 will be replaced by simple models if necessary.
Efforts are currently focusing on coupling both modules, testing different strategies.

Additionally, the ASTEC version V1 will bring improvements in the following areas:

- updates of the modules ELSA (release of fission products from degraded geometry), SOPHAEROS (pool scrubbing) and IODE (formation of iodides from painted walls),
- improvements of ex-vessel models (MCCI) and containment models (H2 combustion, catalytic recombiner models,...).
- standardisation of material properties through a common material data bank.

5 External use and validation of ASTEC

The international distribution of ASTEC V0 has already been initiated, with a release to ENEA (Italy), VUJE (Slovaquia), KI and GAN (Russia).

A larger international contribution to the ASTEC code validation is expected within the 5th EC framework programme, in the frame of a shared cost action entitled EVITA (European Validation of the Integrated Code ASTEC). The integrated code ASTEC will be distributed to European partners (16 partners from 8 countries plus JRC Ispra) in order to apply on this code the risk-oriented validation strategy issued from the VASA project (4th EC framework programme, just ended).

Key experiments and severe accidents sequences, which form the basis of analysis, will be selected and defined. A guidance for the ASTEC validation process fitting for specific end-user needs as well as for research requirements will be established. Furthermore, plant applications with ASTEC for the severe accident sequences defined before will demonstrate the capability for studying accident management measures.

EVITA will increase the extension and quality of the ASTEC validation considerably. The validation status reached and the needs for further ASTEC development will be defined by the partners with special attention to specific end-users needs. Beyond the project, the final intention is to dispose of a well validated European integrated code for the simulation of severe accident sequences in nuclear power plants.

6 Outlook

High efforts are currently devoted to the development and validation of the integrated code ASTEC: the total amount of manpower involved at IPSN and GRS represents about 20 men per year.

The reactor applications will continue in 2000 on PWR (German 1300 MWe, French 900 MWe in support to IPSN PSA2) and on VVER. These will allow fruitful comparisons with reference codes such as ESCADRE, MELCOR and MAAP4.

The EVITA Project, devoted to ASTEC validation by European partners, will be an important step in the code progress.

In parallel to ASTEC V0 use and improvement, milestones in the development of the next version ASTEC V1, including the front-end phase, are the release end of 2000 of a first version including all new modules for IPSN-GRS use, and the release end of 2001 of a version for external use.

7 References

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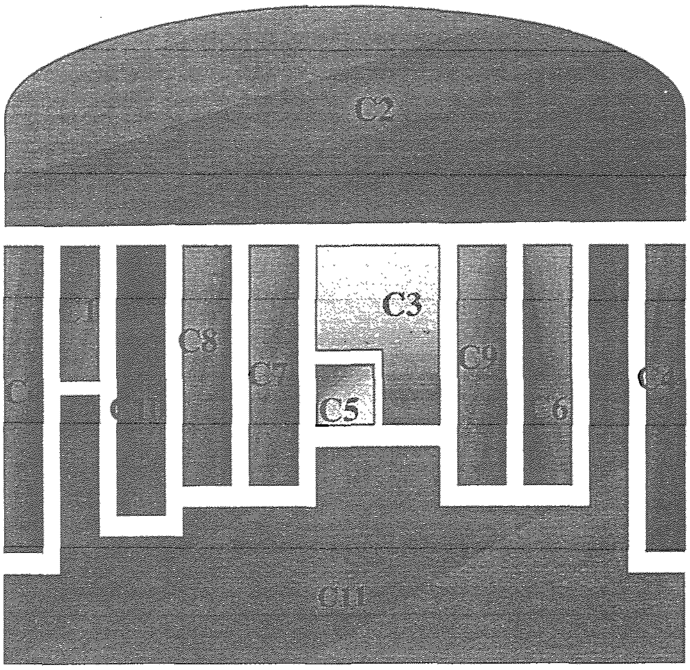
Figure 1: ASTEC V0 - Basic Validation Matrix 15.4.98

	HDR E11.2 E11.4	HDR E12.3	BMC Gx4	VAN AM M3	KAEV ER 148-149, 151	NUPEC M7.1	PHEBUS /TH/	PITEAS SPIPA1	ORNL Hydrolysis	SREAS Radiolysis	ACE RTF 3B	PHEBUS RTF3	PHEBUS RTF5	HIVI 1-6	HEVA 6	VERCORS 4	VERCORS 1-2	CORA 13	PHEBUS B9*	PBF SFD 1.4	LOFT FP2	ACRR MP2	PHEBUS FPT0 FPT1*
CPA-THY-RALOC																							
H_2 Combustion		O,D																					
Pass.Autocat Recomb.			O																				
Temperature distribution	O	O,D	O	O,D		O,D	O																V
Light gas distribution	O		O	O,D		O,D																	V
Steam distribution	O		O	O,D		O,D	O																V
Convection pattern	O		O	O,D		O,D	O																V
Steam cond. on wall	O		O	O,D	O,V	O,D	O	O, V															V
Sensible heat transfer	O	O,D	O	O,D	O,V	O,D	O	O, V															V
Spray system	O					O,D		O,V															
Sump evaporation	O					O,D	O																V
FP decay heating																							V
Boiling																							
CPA-AFP-FIPLOC																							
Agglomeration				O,D	O,V																		V
Sedimentation				O,D	O,V																		V
Diffusion deposition				O,D	O,V																		V
Diffusiophoresis				O,D	O,V																		V
Condensation on aerosols				O,D	O,V																		V
Condensation on hygros. aerosols				O,D																			V
Multi-comp. effects				O,D																			
Turbulent diffusion																							
Resuspension																							
CPA-IODE																							
Thermal reactions in water									O														V
Radiolytic Reactions in sump										O	O,D	V	V										V
Reactions AgI in Sump												V											V
Radiolytic reaction atmosphere																							V
Uorganic iodides																							
Oganic iodides											O,D	V	V										V
Sump-atm. volatile mass transfer											O,D	V	V										V
Deposition on solid surfaces											O,D	V	V										V
Efect of steam cond. on walls													V										V
Water droplets-atmosphere mass transfer																							
Particulate iodine behaviour																							V
Multi compartments aspects																							
VULCAIN																							
Clad ballooning																				V	V		V
Oxidation																				V	V		V
Eutectic melts																				V	V		V
Fuel dissolution																		V	M	V	V		V
Ceramic melts																				V	V	M	V
Particulate debris																		V		V	V	M	
Molten pool																				V		M	V
Core reflooding																		V			V		
Crust failure																				V		M	
Structure ablation																							V
FP release and transport																				V	V		V
ELSA																							
Volatile FP														O	D	D	O,M						V
Low volatile FP														O	D	D	O,M						V
No volatile FP																							

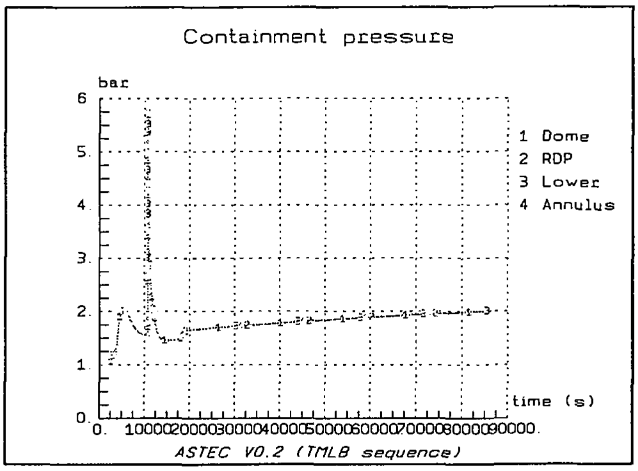
	ACE L2/5/7	BETA 1.8	ANL U2	ANL U1A UB	ANL IET3	ANL IET7	SNL IET4	SNL IET6 IET10	SNL IET8B	SNL IET11	KAERI	TUBA TT28	TUBA TD7	DEVAP 08	AERODEVAP 04	TRANSAT TR2	FALCON 18	PHEBUS FPTO, FPT1*
RUPUICUV																		
Prototypic corium			O,D	O,D							V							
H_2 burning			O,D				O	O		M	V							
Scale effect						O		O			V							
Entrainment (driving press.)			O,D	O,D	O	O	O	O			V							
Cavity water mitigation.									M									
Insulat.disrupt.mitig.										M								
SOPHAEROS																		
Aerosols settling																M		V
Laminar diffusion												M						V
Turbulent diffusion																M		V
Eddy impaction																M		
Bend impaction																M		V
Thermophoresis												M						V
Diffusiophoresis													D					V
Vapor FP cond./evap. on walls														O	M		D	V
Vapor FP cond./evap on aerosols															M			V
Sorbtion														O	M		D	V
WECHSL/CALTHER																		
Zirconium content	O,D	O,D																
R H C upper surface		O,D																
2 layers (oxide/metal)		O,D																
1layer (mixed)	O,D																	
Siliceous concrete	O,D	O,D																
Limest. sand concrete	O,D	O,D																

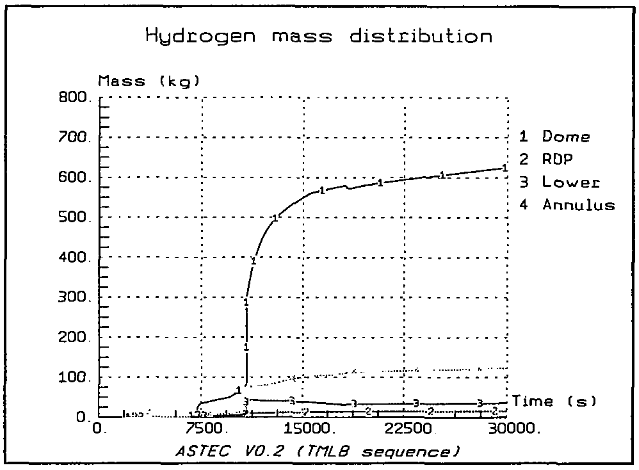
O : means validation performed with an old (stand alone) version
D : means valid. calculation performed with ASTEC V0 as ***Delivering Case*** which were performed until the delivering of ASTEC V0;
M: ***Minimum Validation stage*** to be performed to allow first reactor applications for instance for PSA. Milestone mid 1998
V : means complementary validation calculations intended for ASTEC V0 , but not necessarily until mid 1998
* : global validation calculation for PHEBUS FPT0, FPT1, and TMI2 which serves simultaneously as demonstration calcul



C1 : pressurizer zone
C2 : dome
C3 : discharge pool zone
C4 : annular space
C5 : lower zone
C6 : vessel upper head zone
C7 : loop n°1 zone
C8 : loop n°2 zone
C9 : loop n°3 zone
C10 : pressurizer relief tank zone (RDP)
C11 : zone around loops

Figure 2 : Containment nodalization for an operationality ASTEC calculation on a French PWR 900 MWe





Figures 3 to 5 : Containment results of an operationality ASTEC calculation on a French PWR 900 MWe