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Science and Technology of Nuclear Installations

Science and Technology of Nuclear Installations
Volume 2008 (2008), Article ID 681847, 8 pages
doi:10.1155/2008/681847

Research Article

Decay Heat Removal and Transient Anal Accidental Conditions in the EFIT Reacto

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Received 10 March 2008; Revised 14 July 2008; Accepted 8 Augus

Academic Editor: Ivo Kljenak

Abstract

The development of a conceptual design of an industrial-scale thermal power based on accelerator-driven system (ADS) is add Integral Project. In normal operation, the core power of EFIT rea secondary loops fed by water. A safety-related decay heat remo inherently safe loops is installed in the primary vessel to remove under accidental conditions which are caused by a loss-of-heat sir adopted solution for decay heat removal in accidental conditions, the SIMMER-III code. The results of the SIMMER-III code ha representation of the natural circulation flow paths in the reactor has been employed for the analysis of LOHS accidental scenarios.

1. Introduction

Within the EURATOM Sixth Framework Program (FP6), the EUROTF

significant contribution to the demonstration of the industrial tra
route. The goal will be reached through two phases: the realizatio
50 to 100 MWth power which shows the technical feasibility of tr
time, the development of a conceptual design of a generic Europ
hundreds of MWth, to be realized in the long term (EFIT).

The EFIT reactor should be able to produce energy at reasonable
maintaining as much as possible the high safety level. Modificati
smaller facilities contribute for a more compact primary system a
intermediate loops by installation of steam generators inside
mechanical pumps for forced circulation.

In order to assure a high safety level, a DHR system provided wit
in the primary vessel to remove the decay heat by natural conve
are caused by a loss of heat removal by the secondary side throug

In the present study, performed in the frame of a collaboration
multi-D SIMMER-III code has been applied to confirm the adequa
of the 1D RELAP5 model to be used for T/H transient analysis of EF

2. The EFIT Reactor

The EFIT reactor [2] is a pool-type reactor which uses pure melt
means of 4 mechanical pumps placed in the hot collector zone. The
MW, is removed in normal operation by 8 helical-coil tube bundl
part of the primary vessel to enhance natural circulation in case
reactor block is depicted in Figure 1.

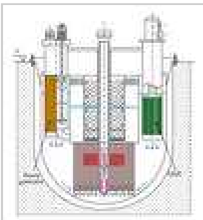

Figure 1: Scheme of the EFIT reactor block.

The main thermal-hydraulic parameters of the EFIT reactor are giv
tons of lead working between 673 K and 753 K. The primary co
inside the steam generators, then comes out and flows towards t
core. So the vessel will be in contact with the coolant at its mir
stresses due to high lead temperature at core outlet.

Table 1: Main EFIT thermal-hydraulic paramet

In the upper annular space between the inner cylindrical vessel a
the DHR system are placed for core decay heat removal under acci

2.1. The Decay Heat Removal System

The DHR system is conceived for inherently safe decay heat ren circulation and with passive mode actuation. The system consists c fluid (oil) that dissipate the decay heat to the atmosphere by natu one DHR loop is depicted in Figure 2. Each loop consists of a dip (the lead, where the oil partially vaporizes (oil boiling point determi air-vapour condenser with stack chimney and interconnecting pi window in the cylindrical shell and leaves axially the DHX through t

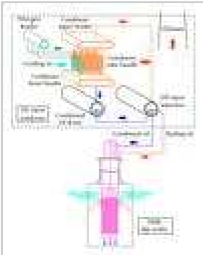

Figure 2: Functional scheme of one DHR loop.

At normal operating conditions, the oil is below its boiling point a steam generators and inner vessel (a few 100 kW) to keep cold conditions (e.g., LOHS), when the lead temperature increases in t oil starts to boil enhancing heat transfer in the DHR and thus t secondary sides. Each DHX is rated at approximately 6.7 MW in d

3. Simulation of DHR Operation with the SIMMER-I

The SIMMER-III code [3], jointly developed by JNC (J), FZK (I computer code originally developed to investigate postulated core SIMMER-III is a two-dimensional, three-velocity field, multiphas coupled with a space-dependent neutron kinetics model. By integr now applicable to a large variety of reactor calculations and othe provided with a turbulent diffusion model to evaluate the effects than classical turbulent models of CFD codes, has been applied in t

The EFIT reactor has been modelled in 2D cylindrical geomet represented by 6 radial fuel rod rings plus the reflector and byp primary pump section, the steam generators, and the DHR heat (equivalent cross flow area. The simulation of DHR loops is limited removal is calculated as a function of the temperature difference b in the secondary side. As a conservative assumption in the ac degraded conditions with 3 out of 4 loops in service.

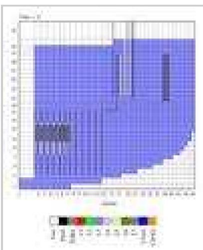

Figure 3: SIMMER-III nodalization scheme of t

A protected LOHS scenario has been simulated with the SIMMER DHR system for decay heat removal in transient conditions by n

lead is assumed inside the primary vessel at transient initiation w
generator heat removal function. Initial lead and core temperat
steady-state results for reactor operation at 384 MW nominal pow

The distribution of lead temperature in the primary vessel calcula
the beginning up to 1 hour transient. Initially, the release of heat
recirculation in the upper plenum. Due to the different density anc
generator outlet moves upward in the annular external region be
vessel where the DHR heat exchangers are located. A natural circu
cooled by efficient heat transfer to the boiling oil of the secondar
evidenced below the DHX and the steam generator resulting in ter
the DHX outlet towards the core inlet. Enhanced temperature stra
quasi steady-state conditions are reached, and the core decay p
through the core and the DHR system with limited lead temperatur

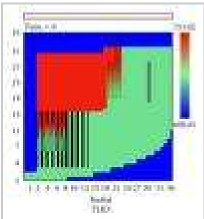

Figure 4: Time evolution of lead temperature

At present, the SIMMER-III code is not validated for this kind
circulation experiments, which are foreseen in the integral CIRCE f
used to confirm the capabilities of the code in this area and propos

4. Calibration of the RELAP5 Model on SIMMER-III I

The RELAP5 code [4], developed by INEEL for the US-NRC, is
thermal-hydraulic (T/H) transient analysis in light water reactors.
(including lead properties) to be used for lead-cooled ADS analy
transfer correlations for heavy liquid metal in different geometries
studies and introduced in the modified code [5]. Conservative ass
core bundle geometry, and new correlations have been develop
modified RELAP5 code has been applied in previous ADS plant t
results have been successfully compared with other codes. Fu
experimental data from tests conducted on the CHEOPE and CIRCI
experimental program to be conducted on the large-scale integral
code validation and verification. This modified version of RELAP5
between ENEA Centre and the Department of Nuclear Engineering
analysis of EFIT.

The RELAP5 nodalization scheme of the EFIT reactor employed for
model, the lead mass inventory distribution and the major flow pa
zones, each one represented with average and hot channel with e
thermal structures. The reflector and bypass zone is represented b
unit is not simulated. Primary pumps are modelled according to
primary (shell) and secondary side (straight and helical tubes) are
are used for the secondary loop. The DHR system model is limite
power as a function of the lead temperature at the DHX inlet.

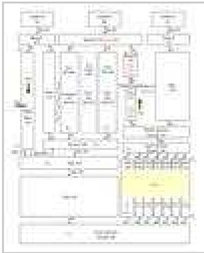

Figure 5: RELAP5 nodalization scheme of EFIT

In case of loss of primary pumps and LOHS scenario with operati
paths in the 1D RELAP5 representation of EFIT are arbitrarily de
mixing effects at steam generator and DHX outlets and inside ple
detailed SIMMER-III analysis, are not taken into account. These p
rate in natural circulation through the core and the DHR syste
comparing SIMMER-III and RELAP5 results under the same transie
lead mass flow rate than SIMMER-III through the core and the DHI

The RELAP5 model has been calibrated in order to reproduce as clo
nomenclature in Figure 5 (green characters), fluid mixing in the vo
the fraction of lead mass flow rate ($x = 17\,\%$) entering this volume
SIMMER-III results by mass and energy balances for the volume a

$$y = \frac{m_C(T_{Ci} - T_{Do})}{(T_{Di} - T_{Do})}, \quad x = y$$

where C and D denote, respectively, core and DHX parameters (inle

Additional pressure drop coefficients have been implemented in th
pump and DHX outlet locations) to reproduce the natural circulat
code in the medium term.

The lead mass flow rate and decay heat removal in the DHR sys
Figure 6. Both codes predict efficient removal of decay power afte
core and the DHR heat exchangers are equivalent in the mediu
owing to the different modelling.

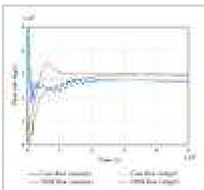

Figure 6: Lead mass flow rates (core and DHR

5. LOHS Accident Analysis with RELAP5

The LOHS accidental transient has been analysed with the revised
of feedwater of secondary loops. The following lead temperature ir
reactor trip on high core outlet temperature signal by the protec
beam switch-off, is assumed with 1 second delay after the avera
above the nominal outlet temperature). As a conservative assump
same time as the reactor trip and no pump inertia is considered (p
maximize core peak temperature just after reactor trip.

The results of the analysis are presented in Figures 7 and 8. React
some initial oscillations induced by free level movements (see Fig
and the DHR system become stable and the DHR attains maximum
be in operation) after about 700 seconds.

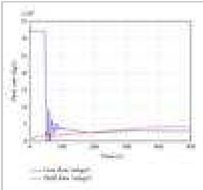

Figure 7: Lead mass flow rates (core and DHR

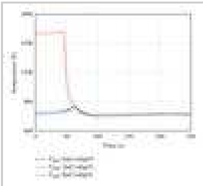

Figure 8: Maximum core (lead, clad, and fuel)

The peak clad temperature reaches 862 K in the hottest channel
safety limit in normal operation of 823 K is exceeded for few sec
from 5000 seconds at acceptable values. The reactor vessel wall
around 2200 s during the transient, then it stabilizes at 713 K in
value of 723 K. This vessel temperature limit has been defined to
plant. The vessel wall temperature peak of 724 K is not a criti
Furthermore, an improved DHX solution now implemented in the
wall and reduced pressure drops, which facilitate the natural circul
of about 15% of the lead mass flow rate, thus reducing significantl

The flow path imposed in the RELAP5 model accelerates the sta
respect to the SIMMER-III simulation (see comparison of mass fl
however, the integral power removed by the DHR system at 220
with the RELAP5 value, therefore, no appreciable increase of the
time by SIMMER-III with respect to RELAP5 analysis.

6. Conclusions

The performances of the DHR system provided in the EFIT reacto
analyses of accidental conditions with complete loss of heat remo
circulation in the primary circuit through the core and the DHR sys
of four DHR units are sufficient to adequately remove the core deca

The 1D RELAP5 model of EFIT has been successfully calibrated or
the amplitude of hot and cold lead mixing at steam generator
phenomena and recirculating flows in the upper and lower plena o
the results obtained with the revised RELAP5 model are close to th
this kind of applications is still in progress, and limited for SIMMER
performance analysis will be precised after further validation of th
facilities.

Finally, the application of RELAP5 to the LOHS accident analysis l
accidental situations with sudden total loss of heat removal by

temperature and brings the plant in safe conditions in the mediur
limited below acceptable value in the medium term with adequa
design improvements not addressed in this study.

Acknowledgments

The authors appreciate the efforts and support of all the scientist
presented work as well as the financial support of the Europear
516520.

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