ORGANISATION FOR ECONOMIC
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Paris, drafted: 18th February 1994
OLIS: 21-Feb-1994
dist.: 23-Feb-1994

NEA/CSNI/R(94)7

English text only

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

PRINCIPAL WORKING GROUP ON
CONFINEMENT OF ACCIDENTAL RADIOACTIVE RELEASES (PWG4)

NON-CONDENSIBLE GASES IN BOILING WATER REACTORS

011996

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NEA/CSNI/R(94)7

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NON-CONDENSIBLE GASES IN BOILING WATER REACTORS

Report by a Group of Experts

Lead Author : T. OKKONEN

February 1994

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS
OECD NUCLEAR ENERGY AGENCY
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O E C D

The Convention establishing the Organisation for Economic Co-operation and Development (OECD) was signed on 14th December 1960.

Pursuant to article 1 of the Convention, the OECD shall promote policies designed:

-- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and this to contribute to the development of the world economy;

-- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and

-- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The current Signatories of the Convention are Australia, Austria, Belgium, Canada, Denmark, Finland, France, the Federal Republic of Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States.

N E A

The OECD Nuclear Energy Agency (NEA) now groups all the European Member countries of OECD and Australia, Canada, Japan, the Republic of Korea and the United States. The Commission of the European Communities takes part in the work of the Agency.

The primary objectives of NEA are to promote co-operation between its Member governments on the safety and regulatory aspects of nuclear development, and on assessing the future role of nuclear energy as a contributor to economic progress.

NEA works in close collaboration with the International Atomic Energy Agency, with which it has concluded a Co-operation Agreement, as well as with other international organisations in the nuclear field.

C S N I

The NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made up of scientists and engineers. It was set up in 1973 to develop and coordinate the activities of the OECD Nuclear Energy Agency concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations. The Committee's purpose is to foster international co-operation in nuclear safety amongst the OECD Member countries.

FOREWORD

At the CAM meeting held on 19th-20th March 1992, Mr. T. Okkonen (STUK, Finland) presented a brief note on non-condensible gases in boiling water reactors. The note was discussed further at the following CAM meeting, held on 29th-30th April 1993, and endorsed by the Task Group.

A slightly revised version was endorsed on 27th-28th September 1993 by CSNI's Principal Working Group No. 4 on the Confinement of Accidental Radioactive Releases, who recommended publication in the series of CSNI Technical Reports on the understanding that, in due course, the note would be appended to the report entitled "Advantages/Disadvantages of Current Accident Management Strategies With Respect to the Use of Water to Cool a Molten Core in the Containment", still under preparation.

CSNI approved the note for publication at a meeting held on 1st December 1993, subject to additional comments to be made before 31st January 1994. No new comments were received.

The CSNI and the Secretariat thank Mr. Okkonen for his work on this paper, and STUK for its support.

NON-CONDENSIBLE GASES IN BOILING WATER REACTORS

A short note prepared by

T. Okkonen*
May 28, 1993

on behalf of the CSNI-PWG4 Task Group on
Containment Aspects of Severe Accident Management (CAM)

1 BACKGROUND

In most boiling water reactors (BWR's) the containment volume is relatively small. In addition, the pressure suppression principle of a BWR containment relies on blow-down pipes which relieve the steam-induced pressure build-up in drywell into the suppression pool in wetwell (see figure 1). Consequently, the drywell may be filled with steam and most non-condensible gases (NCG's) packed into the wetwell atmosphere, which is usually less than half of the total containment volume. Since in a severe accident the amount of NCG's that could be produced from hot core metals (zirconium, steel) is large, the NCG accumulation into wetwell could lead to high containment pressures early into the accident.

2 POTENTIAL EFFECTS

Examples of possible conditions are included in table 1; the pressures can be scaled by volume ratios to specific applications*. The design pressure of a BWR containment varies typically from 4 to 6 bar and the failure (leakage) pressure is usually estimated to be of the order of twice the design pressure, that is, from 8 to 12 bar. If venting is used as the containment pressure control, the initiation pressure is set between the design and failure levels.

From table 1 it can be seen that a uniform NCG distribution in a BWR containment is not of great concern, until the partial pressure of steam sums up with the NCG pressure due to decay heat transfer into water pools. This is usually a slow process - except in sequences without a reactor scram - because of the large water inventory of a BWR containment.

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* The volumes used in table 1 are close to the average of Mark-I containments (and eg. older ABB designs). Mark-II containments (and eg. newer ABB designs) are usually a bit larger. In the Advanced BWR (ABWR) design, the volumes are almost doubled from table 1. Mark-III containments are exceptional: large and non-inerted.

On the other hand, large amounts of NCG's coupled with effective steaming into the drywell and NCG accumulation into the wetwell could (rather fast) lead to containment pressures up to the venting and failure levels. Possible pressurization scenarios include the following ones:

(1) Steam produced during in-vessel fuel-coolant interactions leaks into the drywell through a primary break; this includes also a late initiation of core cooling (recovery actions).

(2) Steam flows into the drywell through a vessel failure, caused by a core melt attack at a high primary system pressure.

(3) Steam produced during ex-vessel fuel-coolant interactions fills the drywell; includes also a late initiation of coolant injection onto the corium pool.

These mechanisms should be taken into account, especially when accident management measures are developed. The initiation criteria, the capacity and the operator instructions related to containment venting should be carefully assessed. For future plants, a more reliable elimination of severe accident problems, by a combination of plant design and accident management, should be strived for.

Plant design, the accident sequence in question and the actions taken by the operators affect the containment pressurization as described above. In addition, several physical uncertainties are involved in core degradation, steam/NCG production, primary system behaviour, pressure vessel failure and containment gas flows. No accurate analyses can be performed with the available analytical tools and thus, at least for new plants and new mitigation measures of the existing plants, bounding analyses should be conducted.

3 FINAL REMARKS

The containment pressurization due to NCG's is primarily an accident management aspect in the existing BWR plants, and it can be discussed as a sub-issue of potential advantages/disadvantages when using water to cool a degraded core or molten corium.

Table 1. Partial pressure of NCG's in a BWR containment.

Condition *)	2200 MWt core			3300 MWt core		
	Equiv tot-Zr oxid fr			Equiv tot-Zr oxid fr		
	40 %	70 %	100 %	40 %	70 %	100 %
	Equiv clad oxid fr			Equiv clad oxid fr		
	72 %	126 %	180 %	72 %	126 %	180 %
Zr: clad + can	25'000 + 20'000 kg			35'000 + 28'000 kg		
Max H2 volume **)	26'500 m³			37'100 m³		
Uniform gas distr.						
N2 pressure (bar)	1.00	1.00	1.00	1.00	1.00	1.00
H2 pressure (bar)	1.45	2.54	3.63	2.03	3.56	5.08
-> total NCG press	2.45	3.54	4.63	3.03	4.56	6.08
All NCG's in WW:						
N2 pressure (bar)	2.43	2.43	2.43	2.43	2.43	2.43
H2 pressure (bar)	3.54	6.19	8.84	4.95	8.66	12.37
-> total NCG press	5.97	8.62	11.27	7.38	11.09	14.80
Sat temp (°C) ***)	159.	174.	185.	167.	184.	198.
DW steam mass (kg) - DW saturated	13600.	19200.	24800.	16600.	24400.	32200.

Note

*) Hydrogen production as equivalent oxidation fraction of all core zirconium or zirconium in clad.
**) Hydrogen volume at (p, T) = 1 bar, 50 °C. (NCG pressure at 50 °C.)
***) Saturation temperature and saturated steam mass in DW: evaluated at total NCG pressure in wetwell.

Plant parameters

Free containment volumes: drywell 4300 m³, wetwell 3000 m³.
Initial conditions: 1 bar , 50 °C, nitrogen-inerted.

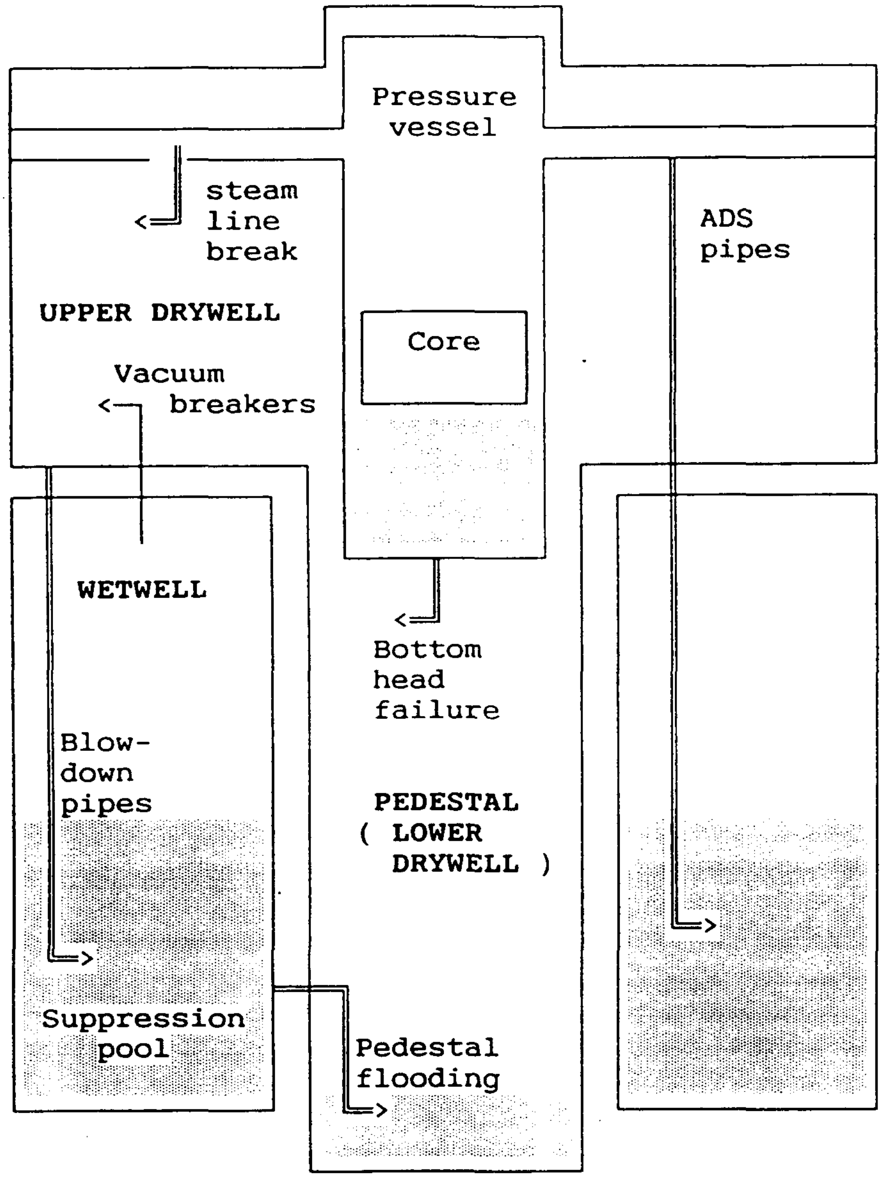

Figure 1. A schematic example of a BWR containment*.

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* Some topological differences exist, for example:
- in some plant designs, the blow-down pipes (downcomers, vents) exit from the pedestal into the wetwell
- in a Mark-II containment the suppression pool covers the whole containment cross-section (also below pedestal)
- in newer designs, neither blow-down nor ADS pipes pass through the wetwell atmosphere (in order to minimize the risk of a suppression pool bypass)
- pedestal flooding is implemented only in some plants.

APPENDIX

List of Members of the CSNI/PWG4's Task Group on Containment Aspects of Severe Accident Management (CAM)

(April 1993)

Belgium	**Mr. Benoît De Boeck (AVN)** **Dr. Jean Snoeck (Tractebel)**	
Finland	**Mr. Timo J. Okkonen* (STUK)**	
France	**Mr. Jacques Duco (CEA/IPSN)**	**Chairman**
Germany	**Mr. Jürgen Rohde (GRS)**	
Italy	**Mr. Giovanni Bava (ENEA/DISP)** **Mr. Arnaldo Turricchia (ENEL)**	
The Netherlands	**Mr. Simon Spoelstra (ECN)**	
Spain	**Mr. Fernando Robledo (CSN)**	
Sweden	**Dr. Veine Gustavsson (Vattenfall)** **Dr. Gustaf Löwenhielm (Vattenfall)**	
Switzerland	**Dr. Martin Baggenstos (HSK)**	
United States	**Dr. Tim M. Lee (USNRC)** **Mr. Walter F. Pasedag (USDOE)**	
CEC	**Mr. Enzo Della Loggia (DGXI)**	
OECD/NEA	**Dr. Jacques Royen**	**Secretary**

* Mr. Okkonen prepared the successive versions of the draft of this note.