

ORGANISATION FOR ECONOMIC
CO-OPERATION AND DEVELOPMENT

NUCLEAR ENERGY AGENCY

STEERING COMMITTEE
FOR NUCLEAR ENERGY

RESTRICTED

Paris, drafted: 7th February 1994

OLIS: 10-Feb-1994

dist.: 15-Feb-1994

NEA/CSNI/R(94)4

English text only

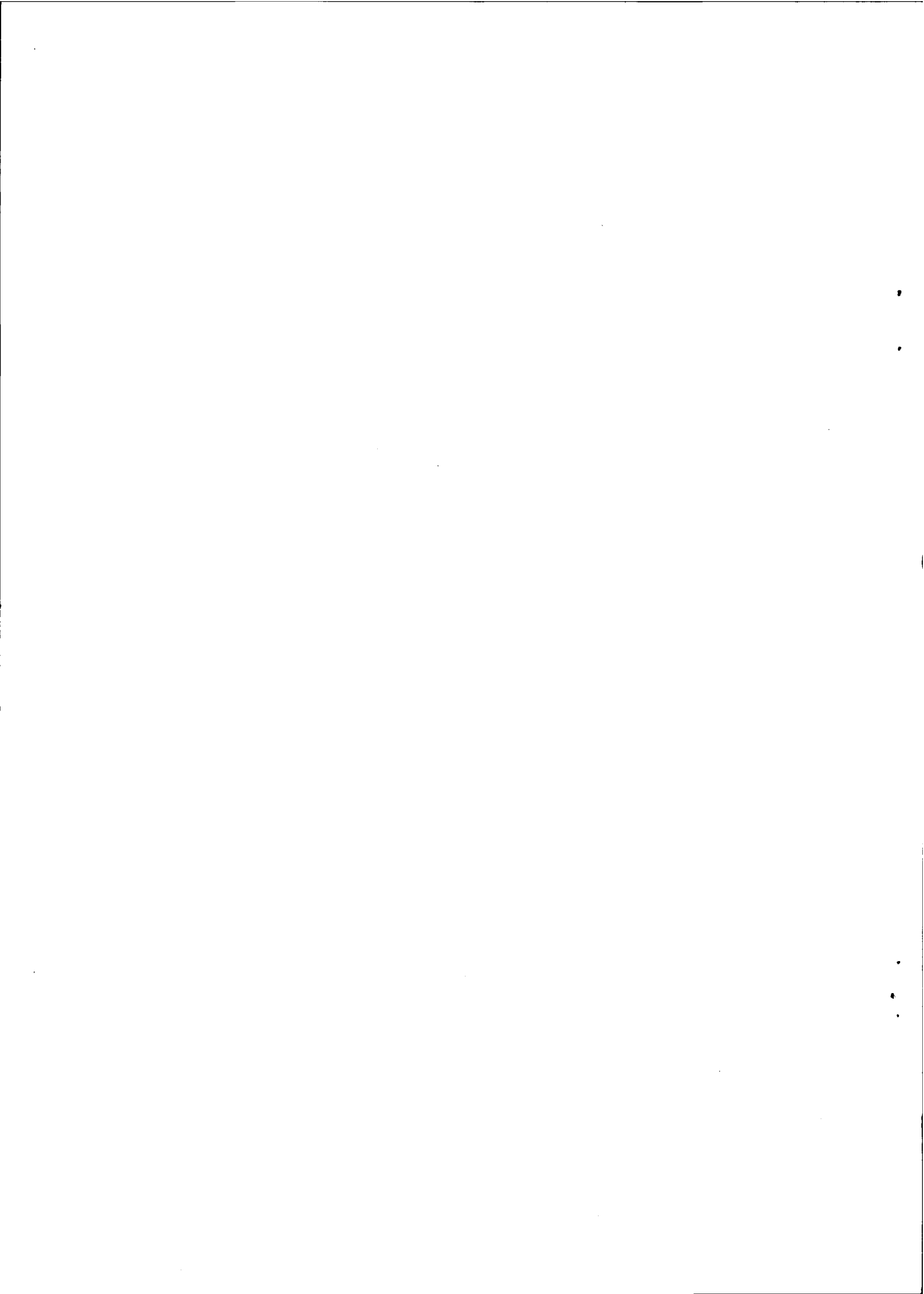
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

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

LOW TEMPERATURE/LOW PRESSURE CHEMISTRY
INSIDE THE CONTAINMENT

011820

FOR TECHNICAL REASONS, THIS DOCUMENT IS NOT AVAILABLE ON OLIS



OECD

NEA

**LOW TEMPERATURE/LOW PRESSURE CHEMISTRY
INSIDE THE CONTAINMENT**

Note by a Group of Experts

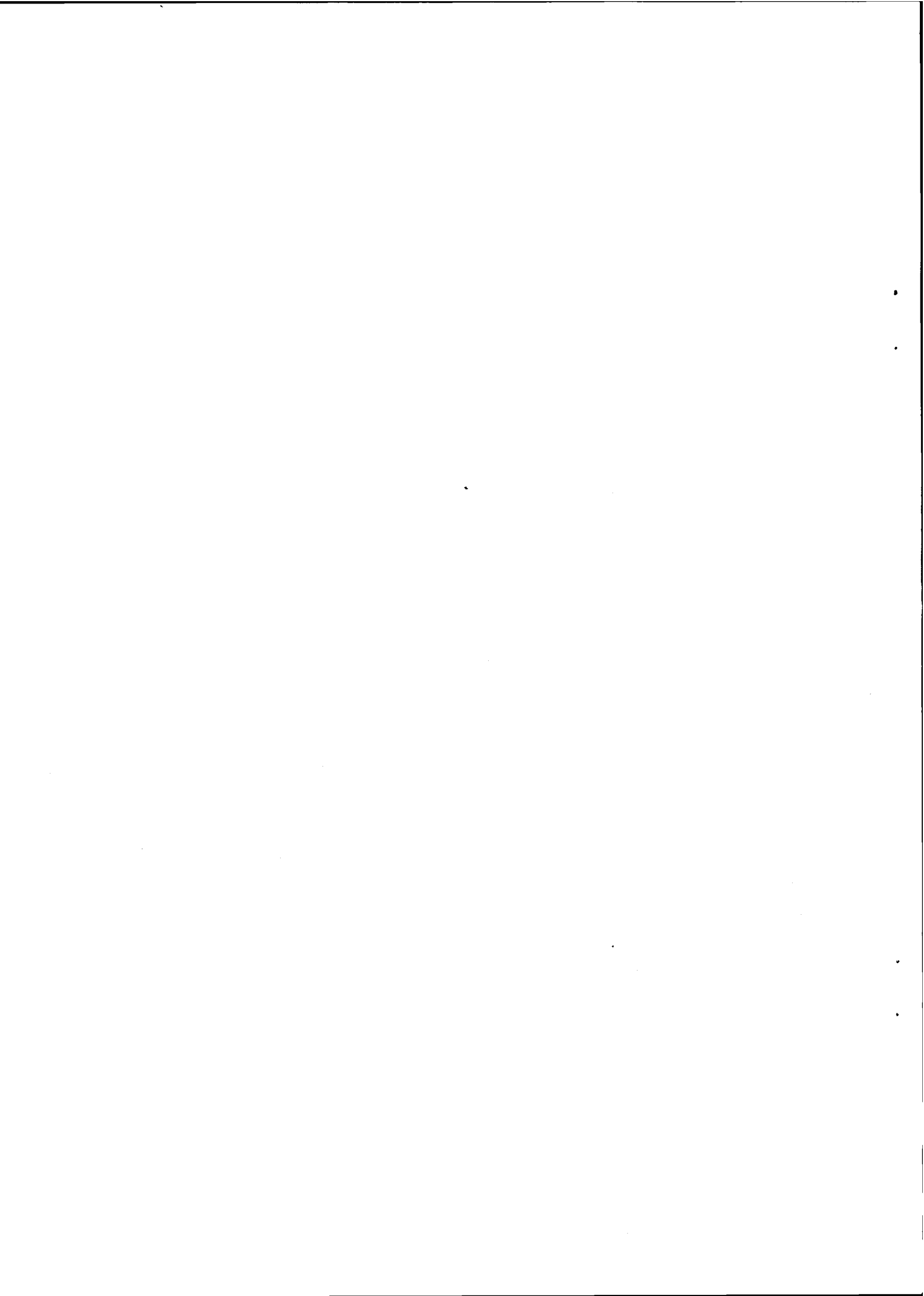
Compiled by : E. BORIOLI

February 1994



**COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS
OECD NUCLEAR ENERGY AGENCY**

Le Seine Saint Germain - 12 Boulevard des Iles
F-92130 Issy-les-Moulineaux (France)



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.



ENEL

NOTE ON
LOW TEMPERATURE/LOW PRESSURE CHEMISTRY
INSIDE THE CONTAINMENT

E. Borioli
ENEL/DSR/VDN, Italy

1 October 1993

DSR-VDN

TABLE OF CONTENTS

Background	1
Iodine	2
Iodine Organic Forms	5
Cesium	6
Tellurium	6
Other Fission Products	8
Programs Currently Underway in Europe	8
Table I - Physical Properties of Inorganic Compounds	11
References	12
Appendix: List of Members of the CSNI-PWG4 Task Group on Fission Product Phenomena in the Containment (FPC)	15

FOREWORD

At the FPC meeting held on 9th-10th April 1991, Dr. G.C. Sandrelli volunteered to prepare a note summarizing the whole issue of low temperature/low pressure chemistry inside the containment. This was done for the following meeting (9th-10th September 1991). The FPC welcomed an offer, made by Dr. Sandrelli on behalf of ENEL, that Dr. E. Borioli would draft a more extensive paper with the assistance of Task Group members.

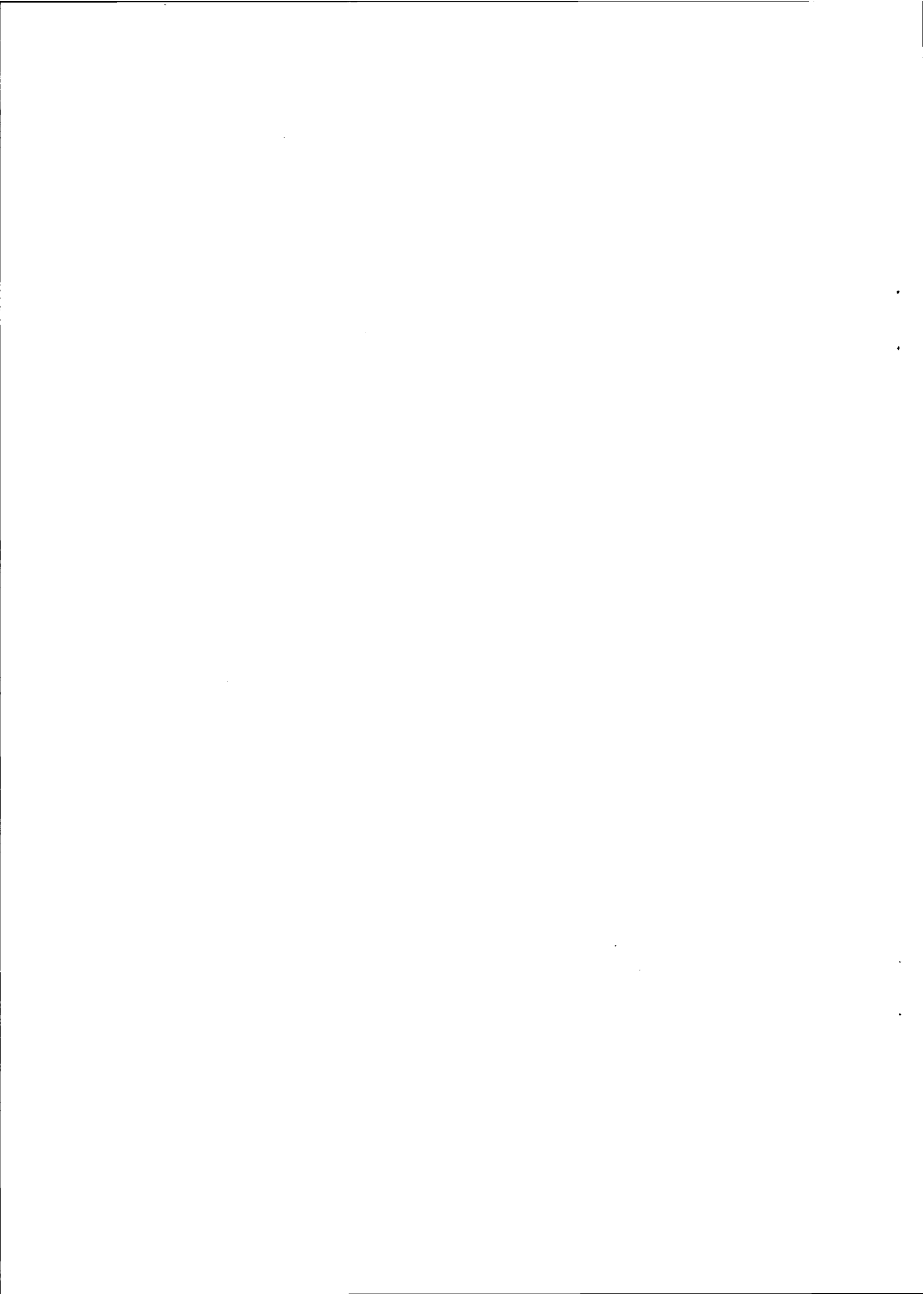
A first draft was discussed by the FPC at its meeting on 22nd March 1993. The note summarized recent information on the chemical characteristics and behaviour of the elements most important from a radiological point of view: iodine (including organic forms), cesium and tellurium. The note was endorsed by the FPC with a few modifications and additional information.

The final draft was endorsed by CSNI's Principal Working Group No. 4 on the Confinement of Accidental Radioactive Releases on 27th-28th September 1993. A slightly amended version, prepared on 1st October 1993, was approved for publication in the series of CSNI Reports at a meeting of the Committee 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 Dr. Borioli and Dr. Sandrelli for their work on this report, and ENEL for its support.

Caution

The contents of this note are mostly applicable to PWR's.



BACKGROUND

During the course of a severe accident, the core overheats and the more volatile species, such as noble gases, iodine, cesium and tellurium, are released from the failed fuel rods.

As the core temperature continues to rise, other less volatile fission products, such as strontium, barium and ruthenium, control rod materials, such as silver, indium and cadmium, structural materials, such as tin from zircaloy and manganese from stainless steel, are released into the core region, where the evolution of a reaction between zirconium and steam is impacting the overall thermal-hydraulics.

At the same time, vaporized fission products and core materials (tin, control rod materials, etc.) mix and react chemically inside the surrounding gas composed of steam and hydrogen, flowing upward along the channels between the fuel rods towards the upper plenum, and then into the reactor containment atmosphere via coolant system ruptures or pressure relief valves. Alternatively, some of them can interact with surfaces in the primary coolant system and be retained temporarily or permanently.

Chemical speciation is important as it will certainly affect the aerosol transport phase. Volatile species released from the fuel might be present in the warmest regions of the plant as gases and their behavior will be influenced by the presence of surfaces either as plant structures or as aerosol particles, by the operation of ESFs like containment sprays, by the hydrogen ignitors etc. Less volatile species released from the fuel, although often initially present as gases, would tend to condense into aerosol particles and/or onto surfaces as they are transported to cooler regions. Some aerosol properties, like elemental composition, shape and density, are determined by chemistry. The particles that form will experience the usual removal processes, like gravitational settling, thermophoresis, etc. Hygroscopicity of the aerosol enhances the particle growth and thus the removal through deposition. A significant area of uncertainty is associated with the possible bulk condensation of steam and how it can affect the aerosol growth.

In case of vessel failure, decomposition of the concrete provides a large amount of water steam and carbon dioxide that react with the molten metals increasing temperature and pressure inside the containment.

During the accident, the environment conditions within the plant change in a very wide range depending on time and location: for example, the temperature falls from several thousand degrees Kelvin near the melting fuel to about four hundred K in the containment; the pressure can fall from 17 MPa in the primary system to a value close to the atmospheric one in the containment; the atmosphere can be oxidizing or reducing depending on time and location, etc.

Because of this wide range of conditions, there can be significant differences between the FP chemical forms either at different locations and the same time, or at the same location and different times. Further, some chemical forms could be more related to their history (like pathways, temperatures encountered, etc.) than to the current environment.

Finally, even if favored by thermodynamics, some chemical forms might not be present in certain locations because of kinetic limitations. These limitations can be taken as negligible in very hot regions, like near the core, because of the very high temperatures involved, and this makes possible to perform equilibrium analyses on the chemical compounds that can be originated here.

On the contrary, due to the relatively low temperatures encountered, in the containment the kinetics of the reactions between the chemical species leaving the primary system is so slow that it is likely to be only of secondary importance, even if the time scale of interest is much longer.

Nevertheless there is a variety of chemical and physical phenomena that can affect the behavior and the distribution of the fission products and aerosols in the containment. The most important ones are related to the presence of large amounts of water, steam, structural materials, paints and to the presence of radiation fields.

Many radiologically important fission products can form water-soluble compounds, as shown in Tab I. In particular, Iodine, CsI and CsOH are soluble, while less soluble fission products may exist in solid particles which are easily transported by liquids in addition to the gas streams: this means that liquid water may play an important role in the transport and distribution of fission products. Further, pools of water can provide an efficient retention mechanism (scrubbing).

In a PWR plant, the main sources of water are the primary coolant itself and, in sequences where ECC systems

operate at least partially, the refuelling water storage tank. Some sources may be borated for reactivity control, and contain other chemicals to adjust pH, etc. In the containment changes in water chemistry occur naturally, and continuous evaporation/condensation provides a mechanism that causes water in different parts of the containment to have different chemical compositions.

A quick picture of the containment shows water existing in the following forms and locations: a) liquid pools on the containment floor and in the sump; b) liquid water in drops or films on the surfaces; c) large drops due to sprays, falling from horizontal upper surfaces through the containment atmosphere, and due to growth of aerosol droplets by agglomeration or condensation; d) droplets and steam in the containment atmosphere.

Containment buildings contain a wide variety of organic materials present in relatively large concentrations. Materials such as paints, seals, cable insulation, plastics and others may release different types of organic compounds. This is especially true if a high radiation field is present, as it causes extensive degradation and changes in the material chemical structure, etc. [1]. Thus, there is the possibility of reactions between iodine and organic materials. Measurements performed at TMI-2 after the 1979 accident indicated that organic iodides were the predominant iodine species in the containment building atmosphere [2]. The presence of organic iodides has also been observed in large-scale tests simulating reactor accidents [3].

Finally, in many regions of the plant, the chemical forms of some elements could be significantly impacted by the local radiation fields that could lead to the formation of intermediates that promote chemical reactions [4].

In the following is reported a brief description of the characteristics and the behavior of the most radiologically important elements.

IODINE

Iodine is a member of group VII of the periodic table. It melts at 113.5 C and vaporizes at 184.35 C at 1 atmosphere [5]. On condensation it adheres to anything in sight. Being highly reactive, it combines readily with other elements to form compounds, most of which are soluble in water. It can exist in a variety of volatile and non-volatile chemical forms. Non-volatile forms are, for example, anions like iodide (I-) and iodate (IO₃-), which will be completely dissolved in water in the

postaccident situation, while volatile species are the elemental iodine I₂, the hydrogen iodide HI, and organic iodides like CH₃I. The volatile species are soluble in water to different degrees and will be partitioned between the gaseous and the aqueous phases [6].

HI is a product of the CsI/boric acid reaction. In the RCS it interacts very rapidly with every metallic constituent (e.g. Fe, Ni, Zr, Sn, etc), and in the containment it interacts with the surfaces of the structures and will partition with any aqueous aerosol and with any water present.

CsI is among the most probable chemical forms of iodine leaving the primary circuit [7,8]. When entering the containment most of it will condense and will be associated with the behavior of the aerosol. Significant decomposition of the CsI in the containment is not expected, unless high temperatures are again encountered as in the case of hydrogen burning. I₂ formed as a result of the combustion will distribute in part to aqueous phases that may be present, and in part to structure and aerosol surfaces.

Although in principle iodine can exist in an aqueous phase in any oxidation state between -1 and +7, the predominant ones under accident conditions are I⁻, I₂ and IO₃⁻, and the major determinant of the aqueous iodine species is the pH of the solution [9]. Each accident sequence has unique conditions that will determine the pH of water pools that form in the containment. It is possible for the pH to vary approximately in the range 3-9. Low pH and ionizing radiation are favorable conditions for formation of I₂ by radiolytic oxidation processes [10].

The iodine partition coefficient, defined as the ratio of the concentration of all iodine species in solution to the corresponding concentration in the gas phase, is a measure of the extent to which iodine can be liberated from solutions.

Experimental data demonstrate that at alkaline conditions (pH= 8-9) and in the presence of a strong radiation field, the partition coefficient is in the range 1.E4 to 1.E6, while under acid conditions (pH=4-6) it drops by a factor of about 100 [11]. Thus, in order to reduce the potential of iodine release to the environment, it is important to maintain a well-buffered high pH value in water pools.

The pH of a water pool is influenced by a variety of factors, like boric acid concentration, additives for pH

control (basic), amount of HI (acidic), amount of CsOH or cesium borates (basic), amount of core-concrete interaction that produces aerosols containing alkali metal oxides, such as K_2O , Na_2O , CaO (basic), radiation-induced nitric acid, etc.

The potential for iodine species to be released to the environment depends on what is their distribution among the gaseous phase, made of volatile forms and available for immediate release, the aerosol phase, containing both volatile and non-volatile iodine species and also available for immediate release, and the bulk condensed phase that is the part of the iodine adsorbed onto the containment surfaces or in the water pools in the containment. As iodine in this phase is less mobile than iodine in the other phases, in sequences with the interception of the release pathway by water, as in BWRs if the suppression pool is not bypassed, or in the case of actuation of sprays, ECCS, etc., the behavior of iodine in aqueous systems will play a key role in determining the iodine Source Term.

Finally, as experiments have shown that iodine in boric acid solutions will react with elemental silver forming insoluble AgI [10,12], there is the possibility that part of iodine will be definitely immobilized in this way by the silver of the control rods transported with other aerosols in water pools.

Iodine organic forms

The formation of organic iodides is recognized as having an important impact on the volatility of iodine under nuclear reactor accidents: organic iodides with low molecular weight are quite volatile and are less reactive and more difficult to confine than inorganic forms of iodine such as I_2 . As an example, methyl iodide has a liquid/gas partition coefficient of 3.4 at 25 C [13] compared to 80 for I_2 at the same temperature [14]. Thus, even a small amount of organic iodides can have a large impact on the partitioning of iodine between an aqueous and gaseous phase.

Volatile organic iodides would form in the containment building following a severe accident, and not in the fuel or in the primary system, due to their instability at high temperature [1]. However, thermodynamic and kinetic calculations between iodine species and carbon sources normally present in a containment atmosphere indicate that thermal reactions in the gas phase are not a major source of organic iodides following a reactor accident [15,16,17]. Instead, organic forms of iodine would be produced primarily by reactions with organic compounds on

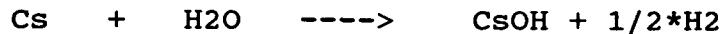
containment surfaces. In addition, volatile forms of organic iodides can form with organic impurities dissolved in water pools, coming from paints, lubricants, coatings, etc.

The speciation of the organic iodide forms is not definitely determined, and although it is widely believed that methyl iodide is the predominant one, numerous other volatile organic iodides may be present: the actual distribution of the organic iodides will depend on the presence of organics, which will vary from plant to plant, time to time, and accident to accident.

Most of the present estimates of methyl iodide formation are between 0.03% and 1% of the total amount of iodine available [18].

CESIUM

Cesium is a member of group I A of the periodic table. In the pure state it melts at 28.4 C, and boils at 669.3 C [5]. It shows very high reactivity and reacts with water, giving off hydrogen and CsOH:



Cesium hydroxide is a highly deliquescent compound, with a melting point of 272.3 C. It reacts with structural material aerosols and these reactions could provide a mechanism for the transport into the containment [19]. Cesium has high affinity for oxygen, giving a number of compounds whose compositions include oxygen in varying amounts relative to cesium. The oxides are generally soluble in water and, although Cs₂O has been postulated in the release of irradiated fuel in air, it is unlikely to exist in the steam environment of a severe accident [20].

CsI melts at 626 C and has a boiling point of 1280 C. It is soluble in cold water and about 4 more times more soluble in hot water.

As CsOH and CsI are expected to form in a considerable amount during a severe accident and as they easily dissociate on contact with water to form Cs+(aq) ions, it is expected that the most of cesium will remain in the containment building.

TELLURIUM

Tellurium belongs to group VI B of the periodic table. It is insoluble in water, melts at 452 C and vaporizes at 1390 C [5].

Tellurium has three oxide states, tri-, di-, and mono. The trioxide, TeO_3 , is a strong oxidizing agent. It decomposes to dioxide at temperatures higher than 350-400 C. The dioxide, TeO_2 , is the most stable oxide and has a boiling temperature of 1245 C. To date, there has been no successful synthesis to TeO in the solid phase; however, there is evidence of its existence in the vapor phase [21]. All the oxides are insoluble in water.

Thermodynamic calculations [22] show that tellurium would be found mainly as elemental tellurium and hydrogen telluride in the reducing atmosphere of the primary system. H_2Te is a very reactive colorless gas that condenses at -2 C to a colorless liquid. It is soluble in water. Other likely aerosol species are the metal telluride aerosols, that originate by reactions of H_2Te and Te_2 with structural materials, like manganese, tin and cadmium. When entering the oxidizing environment of the containment these aerosols may react with steam, releasing tellurium in a volatile form [19]. Further, it is reported by Mills [23] that cadmium telluride may sublime by the reaction:



and evidence for this decomposition reaction has been provided by mass spectrometric studies, in which the vapor over CdTe at 500 C was found to contain only Cd, Te and Te_2 , with no evidence for CdTe as a vapor-phase molecule.

Tellurium chemistry in the containment is influenced by the higher oxygen potential in this steam-rich environment, as compared with the primary circuit. Any cesium telluride and hydrogen telluride that enters the containment will dissolve in condensing steam, decomposing to form elemental tellurium which will be oxidized to TeO and TeO_2 in the containment atmosphere [19]. Matrix isolation studies suggest that the volatility of these species is enhanced in the presence of steam, because of the formation of mixed oxide-hydroxide species TeO(OH)_2 [24]. Consequently it is improbable that H_2Te will be present in a vapor phase in the containment.

Also, because of the presence of organic radicals, formation of organic tellurides cannot be ignored. Elemental tellurium and Cs_2Te may react with methyl iodide to produce organic tellurides. Even if the yield of organic tellurides is unlikely to be high, some of them, like $(\text{CH}_3)_2\text{Te}$ and $(\text{CH}_3\text{CH}_2)_2\text{Te}$, have boiling points of 92 and 138 C respectively, and can evolve in the containment gas phase [25].

OTHER FISSION PRODUCTS

As it is expected that other fission products would be relatively non-volatile under the conditions characterizing the containment during a severe accident, they would behave mainly as aerosols. However, this oxidizing environment may lead to the formation of oxide and hydroxide species, which are soluble in water to different degrees, that could enhance the volatilities of specific elements. For example, ruthenium tetroxide (RuO₄) is volatile, and barium and strontium show enhanced volatility in steam, due to hydroxide formation [19].

PROGRAMS CURRENTLY UNDERWAY IN EUROPE

Here is a list of facilities and programs currently underway in Europe, related to the analysis of FP and aerosol behavior in the containment [26]:

CAIMAN (CEA-France): the facility has a 350-liter vessel, containing 20 liters of water, with provision for iodine injection and wall temperature control. Experiments will be performed on various paints and will examine the effects of radiolysis and temperature on partitioning between the gaseous and aqueous phases, speciation, retention by surfaces, etc.

PHEBUS-FP (CEA-France): this program is conducted in-pile with real fuel. A large part of instrumentation is dedicated to the analysis of the behavior of iodine in the containment vessel. Further, there is a proposal to divert part of the main flow to two small vessels (mini-containments) in order to assess the behavior of different paints, sump pHs, etc.

Siemens/KWU (Germany): the program involves these three different areas:

- a) organic iodine behavior;
- b) the iodine-silver reaction;
- c) the iodine-iron reaction.

AEA Technology (Harwell Laboratory-UK): the Harwell program involves three areas:

- a) the radiation chemistry of CsI and CsIO₃;
- b) organic iodine production;
- c) development of iodine modelling code (INSPECT)

AEA Technology (Winfrith Technology Centre-UK): a large program of separate effects and integral experiments is conducted in interaction with other laboratories (e.g.

Harwell, ECN Petten).

The integral experiments are conducted in the Falcon facility.

ECN Petten: the program is carried out in cooperation with other organizations (i.e Winfrith Technology Centre, Harwell Laboratory and the Free University of Brussels) and it is focused on the critical assessments of existing thermochemical data and the measurement of values for species for which there are no data.

CIEMAT (Spain): CIEMAT is involved in several international programs on containment iodine behavior, including PHEBUS-FP, LOFT-FP2 and ACE-Phase B. An experimental program is being set up to produce a reliable data base and improve existing models. Also, they are working on the development of a code (IODE) to model the containment iodine behavior.

PSI (Switzerland) [27]: PSI is heavily involved in Source Term Analysis of Swiss Nuclear Power Plants since 1988. The analysis is backed up with limited experimental work which delivers certain data to assess the computer programs being used for the analysis or to develop new models to be incorporated in them. Iodine related research has found a special place in experimental and analytical program. Following paragraphs summarize the iodine related research at PSI.

POSEIDON — 1: Pool Scrubbing Effect on Iodine Decontamination. An experimental program was conducted between 1987 and 1991 to generate a data base on elemental iodine removal from gas bubbles raising in water pools. The parameters investigated are the submergence (0.29 to 3 m), water temperature (20 - 60°C), and orifice size (0.5 to 20 mm). Iodine crystals were evaporated in nitrogen gas, and the saturated gas with iodine was fed through the orifice. The data indicated that the decontamination factor is a strong function of submergence and the orifice size which determines the initial bubble volume.

REFUND: revolatilization of the iodine from a sump evaporating to the dryness. An experimental program which was initiated in 1987 and the first phase was completed in 1992. It was believed that a volatile iodine specie (presumably HOI) would be extensively released during the evaporating sump when it is almost dried. The first phase of the program indicated that at low pH values an increased release was observed, however the release at pH values relevant to reactor sump conditions seems not to be excessive. The data contained a large scattering and mass errors. An extension of the program is envisaged to

provide a reliable data base under various boundary conditions (like additives and irradiation).

Stability of silver iodide under irradiation: silver iodide may decompose under strong radiation fields producing volatile I_2 . This relation is considered in the IMPAIR 3 code with a rate constant (k26). An experimental program was initiated as a cooperation between KWU-Siemens (Germany) and PSI in 1992. The program will be continuing in 1994.

IMPAIR 3: a computer program which analyzes the iodine behavior in reactor containments modelled with one or more compartments. The code analyzes the iodine species build-up or depletion depending on the presence of sump, irradiation under given thermal hydraulic boundary conditions and iodine species external release (such as release from core-concrete interaction or release from the primary coolant system) as well as their release into the environment with the gas flow (as a result of containment leakage and/or containment failure). This code is an end product of IMPAIR 2 and IMPAIR 2/M codes with additional modelling capabilities. The code is also attempted to be integrated in severe accident codes like MAAP, CONTAIN etc..

POSEIDON - Loop: an aerosol experimental program, extension of POSEIDON -1, to include the effect of aerosol particles on the iodine removal from the gas bubbles. The presence of steam, which was not investigated during the POSEIDON - 1 experiments, will also be included. This program was initiated in 1990. The aerosol particles, soluble and nonsoluble, are produced with plasma torches. The aging of the particles takes place in a mixing chamber where steam and non-condensibles are fed as a carrier gas with a given proportion. Elemental iodine in gas form is produced with a generator, and the gas with a given flow rate is mixed with the main aerosol-gas flow. The aerosol and iodine gas concentrations and the aerosol size distribution are measured at the inlet and outlet of a test section to determine the decontamination factor. The parameters to be investigated are the flow rate, steam fraction, orifice size, submergence, etc..

TABLE I - PHYSICAL PROPERTIES OF INORGANIC COMPOUNDS [5]

Species	MP(°C)	BP(°C)	Solubility (g/l)
Cs	28.4	669.3	dcmp in water
CsOH	272.3	980 (a)	3955 @15C
CsI	626	1280	440 @ 0C; 1600 @ 61C
Cs2O	dcmp @ 400C		VS in cw, dcmp in hw
Cs2O2	400	650	S in cw, dcmp in hw
Cs2O3	400	---	dcmp in cw
I2	113.5	184.3	.29 @ 20C, .78 @ 50C
AgI	558	1506	
HI	-50.8	-35.38(@ 4atm)	425 cc @ 0C, VS in hw
BaI2	740	---	1700 @ 0C
BaO	1918	2000	34.8 @ 20C, 908 @ 100C
BaO2	450	800	VSS in cw, dcmp in hw
Ba(OH)2	78	780	56 @ 15C, 947 @ 78C
Mo	2610	5560	I in water
MoO3	795	1155 sbl	1.066 @ 18C, 20.55 @ 70C
SrI2	515	dcmp	1653 @ 0C, 3830 @ 100C
SrO	2430	3000	6.9 @ 20C, 228.5 @ 100C
SrO2	dcmp @ 215C		dcmp in cw
Sr(OH)2	---	710	4.1 @ 0C, 218.3 @ 100C
Ru	2310	3900	I in water
RuO2	dcmp	---	I in water
RuO4	25.5	dcmp @108C	20.33 @ 20C, 22.49 @ 76C
Te	452	1390	I in water
H2Te	-49	-2	S(unstable) in cw
TeI2	sbl		I in water
TeI4	280	dcmp	SS in cw, dcmp in hw
TeO2	733	1245	I in water
TeO3	dcmp @ 395C		I in water

Abbreviations:

- I = insoluble
- SS = slightly soluble
- VSS = very slightly soluble
- S = soluble
- VS = very soluble
- bw = boiling water
- cw = cold water
- hw = hot water
- sbl = sublimates
- dcmp = decomposes

(a): O.Knache et al. "Thermochemical Properties of Inorganic Substances", Springer-Verlag, 2nd Edition 1991, Vol I.

REFERENCES

1. J. Paquette, J.C. Wren, "The Formation of Organic Iodides Following Reactor Accidents" , Proceedings of the Symposium on Chemical Phenomena Associated with Radioactivity Releases During Severe Nuclear Plant Accidents, Anaheim (CA), September 9-12,1986, Report NUREG/CP-0078.
2. C.A. Pelletier, C.D. Thomas Jr, R.L. Ritzman, F. Tooper, "Iodine-131 Behavior During the TMI-2 Accident", Electrical Power Research Institute, Report NSAC 30 (1981).
3. A.K. Postma, R.W. Zavadosky, "Review of Organic Iodides Formation Under Reactor Accident Conditions in Water-Cooled Reactors", Atomic Energy Commission, Report WASH-1233 (1972).
4. S.J. Niemczyk, "In-Plant Chemical Phenomena Potentially Important to Nuclear Reactor Severe Accidents and Their Source Terms", Proceedings of the Symposium on Chemical Phenomena Associated with Radioactivity Releases During Severe Nuclear Plant Accidents, Anaheim (CA), September 9-12,1986, Report NUREG/CP-0078.
5. Handbook of Chemistry and Physics, 70th Edition 1989-1990.
6. D.J. Wren et al., "A Review of Iodine Chemistry in Containment Under Severe Accident Conditions", (1986).
7. E. Borioli, "Development of Computer Models on the Chemical and Physical Behavior of Fission Products and Aerosols in the Primary Coolant System of a LWR Plant During a Severe Accident. Part I: Fission Product Chemical Behavior", Work Performed Under the Shared-Cost Action Contract No. 3558-88-12 EL ISP I from the Commission of the European Communities, Report ENEL/DSR/CRTN N6/91/05/MI (1991).
8. E.C. Beahm et al., "Iodine Chemical Forms in LWR Severe Accidents", Report NUREG/CR-5732, ORNL/TM-11861, (1992).
9. J.T. Bell et al., Oak Ridge National Laboratory, Report ORNL-5824 (1982).
10. S.J. Wisbey et al., "Iodine Behavior in Containment Under LWR Accident Conditions", Proceedings of the Symposium on Chemical Phenomena Associated with Radioactivity Releases During Severe Nuclear Plant

Accidents, Anaheim (CA), September 9-12, 1986, Report NUREG/CP-0078.

11. R.L. Ritzman, "Overview of the ACE Iodine Project", Proceedings of the Third CSNI Workshop on Iodine Chemistry in Reactor Safety, Tokai-mura (Japan), September 11-13, 1991.

12. K. Kneeb, J.P. Hosemann, "Iodine Chemical Reactions Considered in German PWR Core-Melt Accident Risk Evaluation", Proceedings of the Symposium on Chemical Phenomena Associated with Radioactivity Releases During Severe Nuclear Plant Accidents, Anaheim (CA), September 9-12, 1986, Report NUREG/CP-0078.

13. R.A. Hasty, "Partition Coefficient of Methyl Iodide Between Vapor and Water", Can. J. Chem. 46, 1643 (1968).

14. R.J. Lemire et al., "Assessment of Iodine Behaviour in Reactor Containment Buildings from a Chemical Perspective", Atomic Energy of Canada Limited Report, Report AECL-6812 (1981).

15. R.H. Barnes et al., "Chemical Equilibrium Studies of Organic Iodides Compounds by Gas Chromatographic Conditions", Battelle Memorial Institute, Report BMI-1781 (1966).

16. R.H. Barnes et al., "Analytical Studies of Methyl Iodide Formation Under Nuclear Reactor Accident Conditions", Battelle Memorial Institute, Report BMI-1816 (1967).

17. W.S. Durant et al., "Activity Confinement System of the Savannah River Plant Reactors", E.I. Dupont de Nemours & Company, Report DP-1071 (1966).

18. "The Influence of Chemistry on Core Melt Accidents", Final Report of the NKA Project AKTI-150, September 1990.

19. A.T. Butland, B.R. Bowsher et al., "Report on Phase 2 of the PWR Severe Accident Containment Study", Report AEEW-R 1964, 1986.

20. B.R. Bowsher, D.M. Bruce, "Fission Product Chemistry in the Primary Circuit of a PWR During Severe Accident", DRAFT, March 1985.

21. "Fission Product Transport in Degraded Core Accidents", IDCOR Technical Report 11.3, December 1983.

22. F. Garisto, Report AECL-7782, 1982.

23. K.C. Mills, "Thermodynamic Data for Inorganic Sulphides, Selenides and Tellurides", Butterworths, London, 1974.
24. J.S.Ogden, B.R.Bowsher, Report AEEW-R 1700, 1984.
25. B.R. Bowsher et al., "Chemical Forms of Fission Product Tellurium in a Severe Reactor Accident", Proceedings of the Symposium on Chemical Phenomena Associated with Radioactivity Releases During Severe Nuclear Plant Accidents, Anaheim (CA), September 9-12, 1986, Report NUREG/CP-0078.
26. C. Benson's Note on the First Meeting of the European Severe Accident Chemistry Group (ESACG), July 1991.
27. S. Guntay, Private communication, September 1993.

APPENDIX

List of Members of
the CSNI-PWG4 Task Group on
Fission Product Phenomena in the Containment (FPC)

(March 1993)

Austria	Dr. Gert <u>Sdouz</u> (FZS)
Canada	Dr. Norman H. <u>Sagert</u> (AECL)
Finland	Dr. Jorma <u>Jokiniemi</u> (VTT)
France	Dr. Jean <u>Fernandjian</u> (IPSN) Dr. Jean-Pierre <u>L'Hériveau</u> (IPSN)
Germany	Dr. Eugen <u>Schrödl</u> (GRS)
Italy	Dr. Giancarlo <u>Sandrelli</u> (ENEL)
Japan	Mr. Kikuo <u>Akagane</u> (NUPEC) Dr. Jun <u>Sugimoto</u> (JAERI)
The Netherlands	Mr. Johan <u>Kanij</u> (N.V. KEMA) Mr. Simon <u>Spoelstra</u> (ECN)
Sweden	Mr. Lennart <u>Devell</u> (Studsvik Nuclear) Mr. Kjell O. <u>Johansson</u>
Switzerland	Mr. Salih <u>Güntay</u> (PSI) Dr. Günter <u>Prohaska</u> (HSK)
United Kingdom	Dr. Neil <u>Ketchell</u> (AEA Technology)
Commission of the European Communities	Mr. Enzo <u>Della Loggia</u> (DGXII/F) Mr. Iain <u>Shepherd</u> (JRC Ispra)
UNIPEDA	Mr. Michel <u>Lambert</u> (EDF)
OECD (NEA)	Mr. Jacques <u>Royen</u> - Secretary

