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Report of Foreign Travel of A. P. Malinauskas to Austria

Foreign Trip Report

A. P. Malinauskas

October 20, 1981

Robert B. Minogue, Director
Division of Reactor Safety Research

This document was prepared primarily for preliminary or internal use. It has not received full review and approval. Since there may be substantive changes, this document should not be considered final.

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Oak Ridge, Tennessee 37830

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ORNL

FOREIGN TRIP REPORT

ORNL/FTR-1182

DATE: October 20, 1981

SUBJECT: Report of Foreign Travel of A. P. Malinauskas, Head, Chemical Development Section, Chemical Technology Division

TO: Herman Postma

FROM: A. P. Malinauskas

PURPOSE: To participate and present an invited paper at the IAEA Technical Committee Meeting on Airborne Fission Product Release Following Extensive Core Damage Accidents.

SITE VISITED: 10/12–16/81 Vienna, Austria Lester Epel

ABSTRACT: The report of the Technical Committee to the Agency, which presents a consensus summary of the Meeting on Airborne Fission Product Release Following Extensive Core Damage Accidents and recommendations for further actions by the Agency, is presented. Summaries of other presentations made during the meeting, but not included in the committee report, are also presented; these summaries include a report of the accident in the Lucens Reactor, a description of a proposed aerosol study using the Marviken Facility, and a discourse on the decision of the Government of Sweden to equip the Barsebäck Reactor with a filtered ventilation system.

Table of Contents

1. Introduction

The purpose of this trip was to participate in the International Atomic Energy Agency (IAEA) Technical Committee meeting on "Airborne Fission Product Release Following Extensive Core Damage Accidents" which was held October 12–16 in Vienna, Austria. The author of this report also presented an invited paper entitled "Fission Product Release from Fuel." The agenda of the meeting and a list of participants are included as Appendices to this report.

The purpose of the meeting was to review the state of the technology regarding fission product release and transport during nuclear reactor accidents (in general) and those accidents involving extensive core damage (in particular). The major question that was to be addressed by the participants concerned the role that the IAEA should have in this matter.

Summary statements of the Technical Committee were prepared in the areas entitled "Accident Scenarios," "Release of Fission Products," "Chemistry of Fission Products," and "Aerosols." These summaries are included in the report of the Committee which is presented in its entirety in Sect. 3 of this report.

As is shown in the Appendix, the original Meeting Agenda was revised to include presentations of (1) a description of the Lucens Reactor accident; (2) a French overview of reactor safety issues addressed at the meeting; (3) a proposed aerosol transport program to be directed by the Electric Power Research Institute (EPRI), utilizing the Marviken Facility in Sweden; and (4) the Swedish plan to incorporate vented containments in their reactors. Brief reports of these presentations are given in Sect. 2 of this report along with the general impressions of the traveler concerning the usefulness of the meeting.

2. Additional Meeting Topics and General Impressions

As indicated above, several topics were added to the Meeting Agenda, with only a few days' notice given to those who were asked to make these presentations. As a consequence, these presentations tended to be of less technical content and more poorly organized than the other presentations. Nonetheless, some information of value was presented. In this section, brief summaries of these presentations are given.

The Lucens Reactor Accident

This accident has been described in a recent issue of Nuclear Safety (January–February 1981). The incident involved a reactor that was cooled with carbon dioxide gas, but moderated with D_2O. Because the release pathway was through the D_2O moderator, it was noted that although all of the noble-gas fission products released from the affected fuel escaped into the reactor cavern, virtually quantitative holdup of all other fission products, including iodine, in the D_2O was experienced.

French Overview of Reactor Safety Issues Addressed at the Meeting

(It should be pointed out that all of the countries participating were given an opportunity to provide overview presentations. Some, notably the English, Swiss, and Argentinian representatives, presented such overviews in the form of remarks to the more formal presentations. Others, primarily the Czechoslovakian, Finnish, Indian, and Spanish delegations, chose not to comment extensively — possibly because they were not the proper ones to comment in the areas that were addressed.)

The French programs appear to be somewhat more heavily oriented toward studies of degraded core accidents as opposed to core meltdown accidents. In addition, unlike the other European countries represented who voiced concern that the United States is overemphasizing the significance of fission product iodine, the French are conducting studies of iodine aqueous chemistry, particularly with regard to radiolysis effects. Otherwise, the French program is similar to that of the other countries participating.

The Aerosol Transport Experiment in the Marviken Facility

The EPRI is proposing the use of an abandoned test reactor, the Marviken Reactor, in studies of aerosol behavior in reactor primary circuits. A $7 million program is proposed, and EPRI would like to have the participation of six other organizations at $1 million each, in the conduct of the program. It was clear from the brief presentation that the program will undoubtedly undergo a period of evolution, so that while the author has many reservations concerning the program as presently conceived, it is likely that these concerns will be addressed as the program develops. (A detailed description of the Marviken facility and proposed experiments is available from the author.)

Vented Containments

The Swedish Government has enacted a bill requiring the use of a filtered vented containment system in the Barsebäck Reactor no later than 1985. The bill also states that unless an updated technical data base or the design of other methods indicates otherwise, a decision to provide vented containments at Ringhalls, Oskarshamn, and Forsmark must be made by 1989. All of these reactors are similar to the General Electric Mark II Boiling Water Reactor design, but are manufactured by ASEATOM. A set of viewgraphs which outlines the Swedish vented containment concept (FILTRA), is available from the author. Mr. Johannson, who made the vented containment presentation, took this as an opportunity to state that the Swedish position is to regard both containment failure by steam explosion and core meltdown as incredible events.

General Impressions

The British are to embark upon a Public Inquiry regarding the safety of Pressurized Water Reactors within about 18 months. As a consequence,

they pushed very hard for another meeting of the Technical Committee within 1 year, with two aims in mind: (1) to be made aware of the most current status of research results concerning source-term development, and (2) to utilize the expertise of the Technical Committee in a review of the presentations which the British staff are expected to make at their Inquiry.

The Technical Committee Meeting can serve as an excellent forum, not only for an exchange of technical information concerning the development of nuclear reactor source terms, but also for the evolution of technically sound and consistent regulatory guides which are based upon these source terms. In anticipation of a broader exchange of technical information and regulatory perspectives at the next meeting, a set of recommendations has been forwarded by the Technical Committee to the IAEA (See Sect. 3). The implementation of some of these may, however, require modifications of existing bilateral exchanges which currently exist between the U.S. NRC and foreign governments. In addition, it may be necessary to review the DOE position with regard to the dissemination of information concerning fission product behavior at the Three Mile Island Reactor.

3. Report of the Technical Committee to the Agency

This section contains a draft report of the Technical Committee to the IAEA. The report is given here in its entirety (with the exception of the summaries of the papers presented, as these are not yet available) because it reflects a consensus view of representatives of many countries regarding the status and direction of nuclear-source-term development.

Report of the Technical Committee on the Meeting on Airborne Fission Product Release Following Extensive Core Damage Accidents, Vienna, Austria, October 12–16, 1981

Introduction

During the week 12–16 October 1981, the IAEA convened a meeting on Airborne Fission Product Release Following Extensive Core Damage Accidents. The meeting was attended by experts from 14 member states and one international organization. The major purpose was to review a central and current issue of the nuclear reactor safety community — the matter of the size of the "source term" in view of recent developments questioning the validity of traditionally used values — in a broad international setting. A second purpose was to ascertain whether the IAEA had a role to play in this area, and if so, to define the role and to decide when it should be implemented.

The subject matter is not only controversial among member states but also within the member states themselves, and it is furthermore very broad in its need for expertise in many disciplines. An attempt was

made, however, to reach a consensus on certain aspects. In areas where no consensus seemed possible, the differences of opinion were isolated and highlighted.

The more formal presentations made by the participants are given in the following section. In this section, the Secretariat has attempted to summarize the discussions that took place during the week and, hopefully, to retain the flavor of the meeting. The distillation of many hours of technical discussion into a few readable pages necessarily requires that many details be lost. It is hoped that the inclusion of the summary presentations in the next section will make up for that loss.

It was recognized that whereas one source term might be appropriate for siting, for example, another one may be more meaningful in emergency planning considerations or in the design of engineered safety features. There was also the alternative of adopting the probabilistic risk assessment approach for all three aspects.

Another important consideration that was brought out was the impact of plant design on source term. The inherent differences in the size of the containment volume or in mitigating devices between PWRs and BWRs will lead to significant differences in source term for many accident sequences.

The coalescence of the week-long discussions into a finite framework as presented in this section was achieved through the guidance of the chairman, Mr. Gilby, and with the cooperation of the experts in all of the scientific disciplines from the various member states. It is from this summary of the week's discussions that the recommendations to the Agency have been gleaned.

Summary of Presentations

(These summaries, to be prepared by the respective authors of the oral presentations, are not available at this time.)

Examination of the Magnitude of the Source Term Relation to Fission Product Chemistry and Aerosol Behavior

The incorporation of realistic descriptions of aerosol behavior and fission product chemistry into particular LWR accident sequences is still in an early stage. There is general agreement that there will be reductions in the source terms developed in earlier U.S. and German Risk Studies, but there is also uncertainty in the amount of these reductions. For sequences where the (1) water or wet steam is present in the flow path, (2) the containment remains intact, or (3) failure is delayed for some hours or more, the reduction in source term could well be several orders of magnitude. These reductions could be important in the consideration of emergency planning and siting but possibly would not significantly affect overall risks as currently evaluated. For sequences involving early containment failure, it is less clear that such

significant reductions in source term will result from new assessments. However, even a breached containment may delay the release of aerosols for many tens of minutes and so give an order of magnitude attenuation factor. This is especially so if condensing conditions are predominant. Major uncertainties exist in the current ability to predict the mode and timing of containment failure. A point of major difficulty concerns the behavior in the primary circuit where aerosol densities and steam temperatures and flow rates are very different from those in which aerosol codes are usually applied.

The Committee recognizes the great importance of developing a fuller understanding of the source term and of reducing unnecessary conservatism. To achieve this desirable objective, the following items arose in the work of the Committee:

1. A better understanding of thermal hydraulic conditions for an appropriate range of accident scenarios is required.

2. Application of aerosol codes to conditions representative of the primary circuit is needed, and an experimental program designed to validate predictions is required. These studies should allow for the appropriate chemistry, water, and steam conditions.

Accident Scenarios

The general understanding of the timing and progress of the major stages of core meltdown scenarios in LWRs is good, although there are uncertainties associated with human factors. The release and transport of radioactive material is, however, closely influenced by the details of the thermal and hydraulic behavior of the scenarios. The current ability to predict the timing of the release of fission products from the fuel, the formation of aerosols, the transport of radioactive materials through the reactor coolant system and the containment, the effect of possible retention mechanisms, and ultimately the magnitude of release to the environment is limited by the accuracy of thermal, hydraulic, and structural analyses. Although the description of the physical processes of reactor accidents does not fall within the primary purpose of the meeting, the Committee feels that the following areas of deficiency should be identified that have a direct influence on the magnitude of the source term to the environment:

1. The estimation of the core temperature profile vs time.

2. The prediction of surface temperatures, flows, water content, and condensation in the reactor coolant system and in the containment system.

3. The prediction of the mode and timing of containment failure, and the release pathways which result.

Release of Fission Products

The release of fission products from defected fuel rods is well understood to fuel temperatures of about 1200°C. Release data from 1200°C to the appearance of molten material (about 1800°C), however, are sparse; additionally, no adequate mechanistic description has been developed. This temperature range is important for the release of the noble gases and the semivolatile fission products, such as the chemical species of cesium, iodine, and tellurium. With the possible exception of scaling effects, a knowledge of the release from molten material appears to be adequate, but it is based upon experiments with simulants and needs to be confirmed by tests with irradiated fuel.

Little information is available on the later stages of the accident scenario, such as release from hot fuel as it is quenched and leached by water, release during interaction of the molten core with the concrete basemat, and release from dispersed fuel material under possible oxidizing conditions. With the possible exception of ruthenium, releases in the latter two situations will impact on the source term only through their effect on aerosol behavior.

The Committee recognizes the lack of experimental data in some areas, particularly of the release of the semivolatile species over the approximate temperature range 1200 to 1800°C. These data are especially appropriate in determining the extent to which several radiologically important fission product nuclides (such as cesium, iodine, and tellurium) are associated with particulates. Also, it has been noted elsewhere that aerosol characteristics depend to some extent on the chemical forms and rates of fission product release from the fuel. Other than these areas, however, the Committee notes that only a limited effect on source terms could be expected by additional results of fission product release.

Chemistry of Fission Products

Recent studies have led to a better understanding of iodine behavior under accident conditions. These studies may explain the small iodine releases described in the paper reviewing accidents.

Major uncertainties are associated with organic iodide formation, and, although total iodine partitioning into the gas phase is small, organic iodides may be the dominant airborne chemical forms.

Equilibrium thermodynamic calculations for reducing steam conditions in the primary system indicate that CsI is the dominant iodine chemical form. Similar calculations for cesium show that CsOH and CsI are the most stable species. Tellurium is predicted to appear as elemental Te at temepratures below ~500°C, and as Te_2, Te, and H_2Te at higher temperatures. Since reaction rates are fast at high temperatures, the equilibrium calculations may give a reasonably accurate description of primary system chemistry. Below ~500°C, the vapor pressures of the I, Cs, and Te species will be low, and very little will be in the gaseous state.

If water is contacted in the primary system, iodine and cesium will be converted to nonvolatile I^- and Cs^+. The Cs^+ does not form volatile aqueous species and will not be transported to the gaseous state. Iodine, in dilute solutions, exists primarily as nonvolatile I^- or IO_3^- over a broad range of conditions, and little partitioning into the gas phase is expected if proper water chemistry conditions are established. In this regard, it was noted that dissolved impurities were unlikely to lead to oxidizing conditions.

In dilute solution, radiation effects are not expected to be important, but for the high concentrations of cesium iodide which may be expected in aerosols, there is a possibility of formation of some elemental iodine.

In most reactor accident scenarios, particularly those involving aqueous conditions, other fission products (except for the noble gases) will not be volatile and will not be expected to occur in a gaseous form.

The Committee recognizes that there are some major conservatisms in the treatment of fission product chemistry in existing risk studies and believes that much of the necessary work has already been carried out to enable a more realistic assessment to be made, which should result in a major reduction of the source term for all scenarios involving nonoxidizing and aqueous conditions. Some further work is still necessary, however, in the following areas:

1. organic iodide production;

2. reaction rate measurements to assess the relevancy of thermodynamic prediction at low temperatures;

3. radiation effects in CsI solutions;

4. water chemistry between ~200°C and the critical point;

5. chemistry of other fission products such as Te.

Aerosols

There is a good general understanding of aerosol physics, and quantitative calculations using existing codes have been validated in a range of conditions including initial concentrations up to some tens of g/m^3. However, aerosol production and behavior can be very dependent on the particular scenario and may well vary with changes in temperature, flow rate, and the various parameters associated with the thermal hydraulic conditions in the various event sequences.

Recent review papers have suggested that for short times in a fuel melting accident there may be extraordinarily high-density aerosols (kg/m^3) in and near the damaged core. Some recent papers have suggested that large decreases in aerosol concentration must occur if due account

is taken of the very large aerosol densities, the extensive surface area available, and the presence of water and steam in many scenarios.

It has been suggested that the aerosols would carry much of the airborne fission product inventory in fuel-melting accidents.

While the physics of aerosol behavior, once airborne, is reasonably well understood, the following matters of importance are in need of definition:

1. the rate of production of aerosols as a function of temperature, heating rate, pressure, steam flow, and time;

2. the relative timing of the escape of fission products (especially cesium, iodine, and tellurium) and the production of aerosols;

3. the use of thermal hydraulic computer programs as input for the movement and behavior of aerosols;

4. experimental validation of aerosol code predictions for appropriate conditions;

5. the possible existence of very dense aerosols in some accidents and their resultant stability;

6. an investigation of a number of specific effects associated with LWR accidents which have not yet been adequately studied, including:
   a. effect of hydrogen combustion on aerosol behavior;
   b. possible resuspension of aerosol and fission products at various stages of the accident;
   c. effects of steam condensation on aerosol and fission product behavior;
   d. effect of small steam explosions on aerosol behavior.

Recommendations to IAEA

The Technical Committee agreed that the first meeting had led to a useful exchange of information and of participants' views on airborne fission product release following extensive core damage accidents. Attention was concentrated on the source term which was to be used in the assessment of the radiological consequences of airborne releases to the environment. Information on this topic is required for quantitative risk assessment, siting issues, and emergency procedures.

The discussion showed that there was active consideration of the topic in many countries, and research and development programs were being organized in many centers. It was also noted that licensing and regulatory policies were under active development in many countries.

The main technical report shows that it is likely that reductions in the conservation in current source terms will be achieved, and useful progress has already been made in this area. In addition, special areas in which further work will be required have been noted.

Although the Committee structures its work around a series of separate topics, it was clearly recognized that fission product behavior in accident conditions involves complex interactions of many phenomena (e.g., aerosol behavior in both primary circuit and containment cannot be treated separately from the chemical considerations and may also depend on the whole history of the fission products from release onwards). It was emphasized that the presence of water and/or steam at various stages of the accident sequence could be of dominant importance.

The Technical Committee recommends that a second meeting should be held in about 1 year. Items that should be included in the agenda include:

1. review of research programs and results to date, including an update on TMI;

2. update of current licensing and regulatory perspectives on siting and emergency planning as related to source-term specifications;

3. review of the NEA aerosol group (if established);

4. report of the Advisory Group on Accident Experience (if established).

The Agency was asked to encourage further participation in the work of the Committee and to maintain the current balance between R&D and regulatory interests.

The IAEA was also asked to undertake the following activities:

1. Member states was requested to review their countries' events (accident, destructive tests, etc.) involving fission product release to see if these contribute to the understanding of behavior in the case of water reactor accidents. If support from the member countries justifies it, the Agency should convene a small Advisory Group Meeting in the Spring of 1982 that would report to the next Technical Committee meeting.

2. Delegates were requested to make suitable information available on planned and ongoing experimental work for preparation of a report by the Secretariat for distribution to Committee members. The Secretary would circulate proposals for the form of the contributed items. Typical headings include (a) Fission Product Release, (b) Fission Product Chemistry, (c) Aerosol Behavior, and (d) Integral Experiments.

3. The Committee noted that the current uncertainties in aerosol behavior justified further expert discussion and suggested that as an initial approach NEA should be asked to reconvene the existing Expert Group on this topic. They cautioned that the terms of reference should not be set so narrowly as to exclude other aspects important for aerosol behavior.

4. The Secretariat was asked to contact Committee members to prepare a bibliography of recent reports and papers on topics discussed at the meeting.

Appendix A

Meeting Agenda

TECHNICAL COMMITTEE MEETING

on

AIRBORNE FISSION PRODUCT RELEASE FOLLOWING EXTENSIVE CORE DAMAGE ACCIDENTS

Tentative Agenda

12 - 16 October 1981

Monday	09.30-10.00	WELCOME and Adoption of Agenda - Chairman
	10.00-10.30	Discussion of Procedures & Organization of Working Groups
	10.30-11.15	Review of Past Reactor Accident Experience - Stratton
	11.15-11.30	COFFEE BREAK
	11.30-12.30	Discussion
		LUNCH
	14.30-15.15	Key Features of LWR Accident Sequences Which Effect the Consequences - Denning
	15.15-15.30	COFFEE BREAK
	15.30-17.00	Discussion
	19.30	FUHRGASSL HUBER - HEURIGER PARTY
Tuesday	9.00-9.45	Fission Product Release From Fuel - Malinauskas
	9.45-10.30	Discussion
	10.30-10.45	COFFEE BREAK
	10.45-11.30	Chemistry of Fission Products - Torgerson
	11.30-12.15	Discussion
		LUNCH
	14.00-14.45	Fission Product Transport & Depletion - Schock
	14.45-15.30	Discussion
	15.30-15.45	COFFEE BREAK
	15.45-16.30	Key Areas of Needed Research - Schikarski
	16.30-17.15	Panel Discussion

Wednesday	9.30-10.30	Regulatory/Licensing/Industry Perspective - Reading
	10.30-10.45	COFFEE BREAK
	10.45-12.00	Panel Discussion
		LUNCH
	14.00-15.45	Round Table Assessment of Where We Are, Role of IAEA, Desirability of Future Meetings and/or Other Activities (what Activities, Purpose of Meeting, etc.)
	15.45-16.00	COFFEE BREAK
	16.00-17.00	Convening of Working Groups
Thursday	Morning	Develop Draft of Presentations & Discussions
	Afternoon	Prepare Agenda/Participants for Next Meeting (if any)
Friday	Morning	Review Draft and Make Changes
	Afternoon	Review Final Draft.

Revised Agenda

Wednesday	9.00–10.00	Regulatory/Licensing/Industry Perspective- Pas. iag
	10.00–10.45	Discussion
	10.45–11.00	COFFEE BREAK
	11.00–11.45	LUCENS Experience - Chakraborty
		French Overview - Devillers
	11.45–12.15	Discussion
		LUNCH
	14.00–14.45	Proposed Aerosol Experiment at Marviken and ~~Vented Containments~~ - Johannson/Vogel Vented Containments
	14.45–15.30	Discussion
	15.30–15.45	COFFEE BREAK
	15.45–17.00	Possible Future Role of IAEA in this Subject Area Areas of Agreement/Disagreement Reached - Should This be Made Part of the Record (How?)
Thursday		Develop Draft of Technical Committee Recommendations to the Agency on Furthur Actions and Activities Develop Draft Summary of Areas Discerned in which Agreement/Disagreement has been Reached.
Friday	Morning	Review Drafts and Make Changes
		Closing of Meeting

Appendix B

Meeting Participants

Department TO
Division TONS

Issue No. 1
1JC1-10-07
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NOTIFICATION OF AN AGENCY SPONSORED MEETING

Title of Meeting : IAEA Technical Committee meeting on "Airborne Fission Product Release Following Extensive Core Damage Accidents"

Dates, inclusive : 12 - 16 October 1981

Opening time of meeting : 9.30 a.m.
Responsible Officer : Lester Epel
Ext. 2694, Room A2617

Place : IAEA Headquarters, Meeting Room IV, ext. 1341

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ARGENTINA			
Mr. D. Beninson	Comision Nacional de Energia Atomica Avenida Liberatodor Buenos Aires		12 - 16 October
AUSTRIA			
Mr. Milos Komurka	Oesterreichisches Forschungszentrum Seibersdorf Ges.m.b.H Seibersdorf,		"
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Mr. D. Torgerson	Research Chemistry Branch Atomic Energy of Canada Limited Whiteshell Nuclear Research Establishment Pinawa, Manitoba ROE 1LO	Pensior Suzanne I., Walfischgasse 4 Tel. 52 74 16	"

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Mr. S. Vuori	Research Centre of Finland Nuclear Energy Laboratory P.O. Box 169 SF-00181 Helsinki 18		
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Mr. C. Devillers	Service d'analyse et d'évaluation des risques Departement de sûreté nucléaire B.P. 6 92260 Fontenay-aux-Roses		12 - 16 October
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Mr. W. Schock	(Same address as above)	as above	12 - 16 October

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Mr. S. Chakraborty	Division pour la sécurité des installations nucléaires CH-5303 Würenlingen		12 - 16 October
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Mr. A. Hedgran	Department of Reactor Technology Royal Institute of Technology 1044 Stockholm		12 - 16 October
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Mr. E. Gilby (CHAIRMAN)	Nuclear Safety Technology & Overseas Collaboration Safety & Reliability Directorate of the UKAEA Wigshaw Lane Culcheth, Warrington WA34NE		12 - 16 October

Mr. S. Harbison	Nuclear Installations Inspectorate Thames House North Millbank, London SW1	Pension Lerner I., Wipplingerstrasse 23 Tel. 63 52 19	12 - 16 October

UNITED STATES OF AMERICA

Mr. R. Denning	Battelle Columbus Laboratories 505 King Avenue Columbus, Ohio 43201	Hotel Tigra I., Tiefer Graben 14 63 96 41	12 - 16 October
Mr. A.P. Malinauskas	Chemical Technology Division, ORNL PO Box X, Oak Ridge, Tennessee 37830	Pension Wiener I., Seilergasse 16	12 - 16 October
Mr. W. Pasedag	U.S. Nuclear Regulatory Commission Washington, D.C. 20555	Hotel Tigra I., Tiefer Graben 14	12 - 16 October
Mr. W. Stratton	Los Alamos National Laboratory PO Box 1663 Los Alamos, New Mexico 87545	Pension Wiener I., Seilerg. 16 Tel. 52 48 16	12 - 16 October

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Mr. Schwerenkaemper	C.E.C. Joint Research Centre 21020 Ispra (Varese) Italy	Pension Dr. Geissler I., Postgasse 14 Tel. 63 28 03	12 - 16 October

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