No. 19934

UNITED STATES OF AMERICA
and
NETHERLANDS

Agreement on research participation and technical exchange in the USNRC Heavy Section Steel Technology/Elastic Plastic Fracture Mechanics and Aerosol Release and Transport Research Programs and the Dutch BROS I-II/EPOSS and Aerosol Research Programs (with appendices). Signed at Washington on 21 April 1980 and at The Hague on 6 June 1980

Authentic text: English.

Registered by the United States of America on 10 June 1981.

ÉTATS-UNIS D'AMÉRIQUE
et
PAYS-BAS

Accord de participation à la recherche et d'échanges techniques portant sur les programmes de recherche de l'USNRC sur la technologie des aciers à profil épais et la mécanique de rupture élastoplastique et sur l'émission et le transport des aérosols et sur les programmes néerlandais de recherche BROS I-II/EPOSS et en matière d'aérosols (avec appendices). Signé à Washington le 21 avril 1980 et à La Haye le 6 juin 1980

Texte authentique : anglais.

Enregistré par les États-Unis d'Amérique le 10 juin 1981.

AGREEMENT[1] ON RESEARCH PARTICIPATION AND TECHNICAL EXCHANGE BETWEEN THE UNITED STATES NUCLEAR REGULATORY COMMISSION (USNRC) AND THE NETHERLANDS ENERGY RESEARCH FOUNDATION (ECN) IN THE USNRC HEAVY SECTION STEEL TECHNOLOGY (HSST)/ ELASTIC PLASTIC FRACTURE MECHANICS (EPFM) AND AEROSOL RELEASE AND TRANSPORT (ART) RESEARCH PROGRAMS AND THE DUTCH BROS I-II/EPOSS AND AEROSOL RESEARCH PROGRAMS

The Contracting Parties

Considering that the United States Nuclear Regulatory Commission (USNRC) and the Netherlands Energy Research Foundation (ECN)

(*a*) Have a mutual interest in cooperation in the field of reactor safety research, and

(*b*) Have as a mutual objective improving and thus ensuring the safety of reactors on an international basis, and

(*c*) Have as a mutual objective the achievement of full reciprocity in the exchange of technical information in the field of reactor safety research, and

(*d*) Recognize that their respective Countries are member nations of the International Energy Agency which encourages cooperative programs on reactor safety research, and

(*e*) Have expressed their intention to provide for technical exchange in the USNRC-funded Heavy Section Steel Technology/Elastic Plastic Fracture Mechanics programs (HSST/EPFM) and Aerosol Release and Transport (ART) programs and in the Dutch-funded BROS I-II programs being conducted under contractual arrangement with Government funding by Rijn-Schelde-Verolme Machinefabrieken en Scheepswerven N.V. (RSV), the Nederlandse Organisatie voor toegepastnatuurwetenschappelijk onderzoek ten behoeve van Nijverheid, Handel en Verkeer (NO-TNO), the Technische Hogeschool Delft (THD), the Naamloze Vennootschap tot Keuring van Electrotechnische Materialen (KEMA) and the EPOSS program conducted by the THD (the foregoing Dutch Parties conducting the BROS I-II and EPOSS programs being referred to hereinafter as the BROS/EPOSS Parties) and in the Fast Reactor Aerosol Research (Aerosol) Program being conducted by the Energie Onderzoek Centrum Nederland (ECN),

Have agreed as follows:

Article I. PROGRAM COOPERATION

A. The USNRC and the ECN, in accordance with the provisions of this Agreement and subject to applicable laws and regulations in force in their respective Countries, will provide for technical exchange in the HSST/EPFM Program

[1] Came into force on 6 June 1980 by signature, in accordance with article V (A).

(Appendix A), the ART Program (Appendix B), the BROS I-II/EPOSS Programs (Appendix C), and the Fast Reactor Aerosol Research (Aerosol) Program (Appendix D).

B. The term "assignee" as used herein shall mean the BROS/EPOSS Parties or any other organization designated by the signatory parties in their respective countries.

Article II. SCOPE OF AGREEMENT

A. *Scope of Responsibility—USNRC*

1. The USNRC, in consideration of the technical benefits received by its participation in the Dutch BROS I-II/EPOSS and Aerosol programs, and by its receipt of information under this Agreement, agrees to permit the ECN and BROS/EPOSS parties to participate in the HSST/EPFM and ART programs, which the USNRC will carry out, as described in Appendices A and B, or as amended, subject to the availability of funds.

2. The USNRC agrees to permit the ECN to assign one mutually agreed upon technical expert to each of the HSST/EPFM and ART programs for participation in the analysis of program experiments.

3. In addition, the USNRC agrees to permit the ECN to assign one technical expert as a consultant to each of the HSST/EPFM and ART program review groups, which periodically review the status of the current programs and of future program plans.

4. The USNRC agrees to grant the ECN and its assignees access to all experimental data and results of analyses generated by the HSST/EPFM and ART programs during the period of this Agreement.

5. The USNRC agrees to provide the ECN and its assignees access to USNRC computer codes developed to analyze experimental data generated by the HSST/EPFM and ART programs. Access to proprietary codes and data will not be provided except by written authorization of the owner.

6. The USNRC agrees to bear the total costs of transportation, living expenses and any other costs arising from its participation in the BROS I-II/EPOSS and Aerosol programs, and for the transport and related costs for apparatuses and other equipment furnished by the USNRC.

7. The USNRC agrees to provide the ECN and BROS/EPOSS parties access to all results obtained from USNRC's and its contractors' analyses of information and experimentation developed for the BROS I-II/EPOSS and Aerosol programs during the period of this Agreement.

B. *Scope of Responsibility—ECN*

1. The ECN in consideration of the technical benefits received by its participation in the HSST/EPFM and ART programs and by its receipt of information under this Agreement, agrees to permit the USNRC and its contractors to participate in the BROS I-II/EPOSS and Aerosol programs which the BROS/EPOSS Parties will carry out, as described in Appendix C, or as amended, subject to the availability of funds, and in the Aerosol Program which the ECN will carry out, as described in Appendix D, or as amended, subject to the availability of funds.

2. The ECN agrees to permit the USNRC to assign one mutually agreed upon technical expert to each of the BROS I-II/EPOSS and Aerosol programs for participation in the analysis of program experiments.

3. In addition, ECN agrees to permit the USNRC to assign one technical expert as a consultant to appropriate ECN program review or planning groups, which periodically review the status of the BROS I-II/EPOSS and Aerosol programs and of future program plans.

4. The ECN agrees to grant the USNRC and its assignees access to all experimental data and results of the analyses generated by the BROS I-II/EPOSS and Aerosol programs during the period of this Agreement.

5. The ECN agrees to provide the USNRC and its assignees access to Dutch computer codes developed to analyze experimental data generated by the BROS I-II/EPOSS and Aerosol programs. Access to proprietary codes and data will not be provided except by written authorization of the owner.

6. The ECN agrees to bear the total costs of transportation, living expenses and any other costs arising from its participation in the HSST/EPFM and ART programs under this Agreement, and for the transport and related costs for apparatus and other equipment furnished by the ECN.

7. The ECN agrees to provide the USNRC and its contractors access to all results obtained from ECN's and the BROS/EPOSS Parties' analyses of information and experimentation developed for the HSST/EPFM and ART programs during the period of this Agreement.

Article III. PATENTS

A. With respect to any invention or discovery made or conceived during the period of, or in the course of or under, this Agreement for ECN participation in the HSST/EPFM and ART programs, the USNRC on behalf of the United States Government, as the receipient party, and the ECN as assigning party, and for USNRC participation in the BROS I-II/EPOSS and Aerosol programs, the ECN on behalf of the Netherlands Government, as the recipient party, and the USNRC as assigning party, hereby agree that:

1. If made or conceived by personnel of one party (the assigning party) or its assignees while assigned to the other party (recipient party) or its assignees:
   (*a*) The recipient party shall acquire all right, title, and interest in and to any such invention, discovery, patent application or patent in its own Country and in third countries, subject to a nonexclusive, irrevocable, royalty-free license to the assigning party, with the right to grant sublicenses, under any such invention, discovery, patent application or patent for use in the production or utilization of special nuclear material or atomic energy; and
   (*b*) The assigning party shall acquire all right, title, and interest in and to any such invention, discovery, patent application, or patent in its own country, subject to a nonexclusive, irrevocable, royalty-free license to the recipient party, with the right to grant sublicenses, under any such invention, discovery, patent application or patent, for use in the production or utilization of special nuclear material or atomic energy.

2. If made or conceived other than by personnel in paragraph 1 above and while in attendance at meetings or when employing information which has been communicated under this exchange agreement by one party or its contractors or BROS/EPOSS Parties to the other party or its contractors or BROS/EPOSS Parties, the party making the invention shall acquire all right, title, and interest in and to any such invention, discovery, patent application or patent in all countries, subject to the grant to the other party of a royalty-free non-exclusive, irrevocable license, with the right to grant sublicenses, in and to any such invention, discovery, patent application, or patent in all countries, for use in the production or utilization of special nuclear material or atomic energy.

B. Neither party shall discriminate against citizens of the country of the other party with respect to granting any license or sublicense under any invention pursuant to subparagraphs A(1) and A(2) above.

C. Each party will assume the responsibility to pay awards or compensation required to be paid to its nationals according to the laws of its country.

Article IV. EXCHANGE OF SCIENTIFIC INFORMATION AND USE OF RESULTS OF PROGRAM

A. Both parties agree that, pending the grant by the transmitting party of approval to publish, information developed or transmitted under this Agreement will be freely available to governmental authorities and organizations cooperating with the parties. Such information, except as noted below in paragraphs B and C, may, as required by the administrative procedure in its own country, also be made available to the public by either party through customary channels and in accordance with the normal procedures of the parties.

B. It is recognized by both parties that in the process of exchanging information, or in the process of other cooperation, the parties may provide to each other "industrial property of a proprietary nature." Such property, including trade secrets, inventions, patent information, and know-how, made available hereunder and which bears a restrictive designation, shall be respected by the receiving party and shall not be used for commercial purposes or made public without the consent of the transmitting party. Such property is defined as:

(*a*) Of a type customarily held in confidence by commercial firms;

(*b*) Not generally known or publicly available from other sources;

(*c*) Not having been made available previously by the transmitting party or others without an agreement concerning its confidentiality; and

(*d*) Not already in possession of the receiving party or its contractors or BROS/EPOSS Parties.

C. Recognizing that "industrial property of a proprietary nature," as defined above, may be necessary for the conduct of a specific cooperative project or may be included in an exchange of information, such property shall be used only in the furtherance of nuclear safety programs in the receiving country. Its dissemination will, unless otherwise mutually agreed, be limited as follows:

(*a*) To persons within or employed by the receiving party, and to other concerned government agencies of the receiving party, and (*b*) To USNRC prime or subcontractors or to the Dutch BROS/EPOSS Parties for use only within the country of the receiving party and within the framework of its contract(s) with the respective party engaged in work relating to the subject matter of the information so disseminated, and

(*c*) On an as-needed, case-by-case basis, to organizations licensed by the responsible governmental authority in the country of the receiving party to construct or operate nuclear production or utilization facilities, provided that such information is used only within the terms of the license and in work relating to the subject matter of the information so disseminated, and

(*d*) To contractors of licensed organizations in subparagraph (*c*) receiving such information, for use only in work within the scope of the license,

provided that the information disseminated to any person under subparagraphs (*b*), (*c*) and (*d*) above shall be pursuant to an agreement of confidentiality.

D. The application or use of any information exchanged or transferred between the signatory parties under this Agreement shall be the responsibility of the party receiving the information, and the transmitting party does not make any warranty, expressed or implied, nor assume any legal liability or responsibility for any third party's use of any information so exchanged or transferred. Moreover, the receiving party shall hold the transmitting party harmless from all damages of any third party in connection with the use or application of any information exchanged or transferred between the signatory parties to this Agreement.

Article V. FINAL PROVISIONS

A. This Agreement shall enter into force upon signature of the parties and shall remain in force for a period of 3 years.

B. Either party may withdraw from the present Agreement after providing the other party written notice 6 months prior to its intended date of withdrawal.

C. The USNRC may at its option participate in a continuation of the ECN BROS I-II/EPOSS and Aerosol programs beyond the 3-year period of this Agreement under mutually acceptable terms and conditions.

D. The ECN may at its option participate in a continuation of the USNRC HSST/EPFM and ART programs beyond the 3-year period of this Agreement under mutually acceptable terms and conditions.

E. If any of the technical programs described in Appendices A, B, C and D are substantially increased in scope, the parties shall consider ways in which the equitable balance of the exchange may be maintained.

F. If any of the technical programs described in Appendices A, B, C and D are substantially reduced or eliminated, work mutually agreed to be of equivalent interest may be substituted by mutual agreement.

G. In recognition that the research on neutron surveillance dosimetry and radiation embrittlement sponsored by the parties is closely related to the safety research on steel technology covered under this Agreement, the USNRC and the ECN may, as mutually agreed upon, include such research for technical exchange and cooperation under this Agreement.

H. Any dispute between the parties concerning the interpretation or application of this Agreement which is not settled by negotiation or other agreed mode of settlement shall be referred to a tribunal of three arbitrators to be chosen by the parties, and who shall also choose the chairman of tribunal. Should the parties fail to agree upon the composition of the tribunal or the selection of the chairman, the President of the International Court of Justice shall, at the request of the parties, exercise those responsibilities. The tribunal shall decide any such dispute by reference to the terms of this Agreement and any applicable laws and regulations, and its decision on all questions of facts shall be final and binding on the parties.

I. A copy of this Agreement shall be deposited with the Executive Director of the International Energy Agency in recognition of the Agency's interest in international cooperation in energy research and development.

For the United States Nuclear Regulatory Commission:

By: [*Signed — Signé*][1]

Title: Acting Executive Director for Operations

Date: April 21, 1980

For the Netherlands Energy Research Foundation:

[*Signed*]

By: Prof. Dr. J. A. GOEDKOOP

Title: Managing Director of Research

Date: June 6, 1980

APPENDIX A-1

USNRC HEAVY SECTION STEEL TECHNOLOGY (HSST) PROGRAM

I. *Objectives*

The Heavy-Section Steel Technology (HSST) Program is a major Nuclear Regulatory Commission (NRC) sponsored safety engineering research activity devoted to development of a quantitative basis for assuring adequate margins of safety against fracture of the primary coolant pressure boundaries of water-cooled nuclear power reactors. The principal objects of study are the thick-walled pressure vessels of these reactor systems. All relevant aspects of the technology of the steels and weldments commonly used in reactor pressure vessels are being investigated. Another important part of the program is to establish quantitative relationships between the characteristics of materials and loading conditions under which fracture would occur in a flawed structure.

The specific objectives of the program are to provide a thorough quantitative assessment of heavy-section reactor vessel steel fracture characteristics including a realistic assessment of fracture potential and development of fracture prevention criteria. The program will include the effects of irradiation, flaw growth mechanisms, and the effects of thermal shock, with crack propagation and arrest characteristics under both stress and toughness gradients.

Table 1 describes the general test program capabilities.

The program has been underway since 1967 and over 70 technical reports or progress reports have been produced. The program is extending into studies of thermal shock, weld heat affected zones and failure under pneumatic loads.

[1] Signed by William J. Dircks — Signé par William J. Dircks.

II. *Research Areas*

The HSST program is comprised of the major research areas listed below:

1. *Elastic Plastic Fracture Analysis Development and Evaluation.* This part of the program has been set up to develop new methods of elastic-plastic fracture analysis and to evaluate existing methods. J-R curve test development for upper shelf toughness characterization is an important task in FY 77-78. Photoelastic measurements, an analysis of nozzle corner cracks, is conducted in model vessels. The required fracture toughness testing is performed in this area. Also this research area provides the analytical support for the thermal shock and the intermediate test vessel (ITV) programs.

2. *Cyclic Crack Growth and LWR Crack Growth Analyses.* In this research area, the investigators are to continue to develop cyclic crack growth rate data including the effects of material, LWR water chemistry, temperature, R-ratio, cyclic rate, hold time, loading rate, etc., and to determine a realistic upper bound relationship between da/dN and delta K. From these data, the investigator will update the crack growth analyses for LWR pressure vessels.

3. *Irradiation Effects.* The purpose of this research area is to determine the static and dynamic toughness of the ductile upper shelf of irradiated reactor vessel materials. Included among the FY 1977 tasks are completion of a 4T-CT program on low shelf weld metals and initiation of a third irradiation of this material.

4. *Intermediate Vessel Testing.* Tests are planned to evaluate structural integrity of repair welds both on the upper shelf and in the transition region. A crack arrest test is also planned.

5. *Thermal Shock.* The aim of this research area is to verify the method of analysis that is used to predict crack propagation in a reactor vessel subjected to emergency core cooling system (ECCS) operation following a postulated loss-of-coolant accident (LOCA). Thermal shock tests on 21-inch OD test cylinders have been completed, and studies are underway to design a "warm prestressing" test using liquid N.

TABLE 1

Heavy Section Steel Test Program capabilities

Test Phase	*Capabilities*
1. Intermediate Test Vessel (ITV) Testing	Temperature from ambient to ~200°F (~93°F)
	Pressures from ambient to ~35 ksi (~241 MPa)
2. Pneumatic Load Testing of Vessels	Vessel sizes up to ~39 in. (99 cm) OD by 54 in. (137 cm) high
3. Thermal Shock Testing	Temperatures from −10°F (−23°C) to 550°F (288°C)
	Ambient pressure
	Specimen sizes: Straight cylinders 21 in. (53 cm) OD and 39 in. (99 cm) OD
4. Irradiation Effects	Hot cells for studying highly irradiated Charpy, tensile and 1T CT specimens
	Irradiation facilities: temperature control up to 550°F; fluences up to ~2× 10^{19} n/cm^2; specimen up to 4 in. CS

APPENDIX A-2

USNRC ELASTIC PLASTIC FRACTURE MECHANICS PROGRAM

I. *Objective*

(1) To develop the methodology required to perform safety analyses under conditions in which stable crack growth occurs; specifically involved are the determination of the J-R curve from a single specimen, the analysis methods to be applied, and the development of the tearing instability concept.

(2) To develop J-R curve data base for reactor and piping steels, and piping weldments; validate tearing instability predictions with compact specimen tests; explore limits of J-controlled crack growth with respect to cross slip phenomena and total crack extension.

II. *Scope of Program*

1. Load-displacement analysis for J-R curve.
2. Verification of tearing instability analysis.
3. Limits of J-integral analysis (deformation theory).
4. J-R curve data base.
5. Validity criteria.

APPENDIX B

USNRC AEROSOL RELEASE AND TRANSPORT PROGRAM*

I. *Mixed Aerosols in Containment Volumes (NSPP/CRI-II Program) (ORNL)*

1. *Background*

An LMFBR HCDA is postulated to result in the suspension of airborne fuel particulates (mixed oxide aerosols) and products of sodium combustion (Na_2O; Na_2O_2 aerosols) within the containment building. The assessment of any subsequent release to the atmosphere requires calculations of how the mixture aerosol concentrations change in time as affected by the natural aerosol processes (agglomeration, plateout, and gravitational settling). Computer models have been developed to calculate the nuclear-aerosol transients in containment buildings. These codes require inputs that include aerosol material properties and must be experimentally validated at appropriate concentration levels and, especially, for appropriate mixtures of the fuel aerosols and the sodium oxide aerosols.

2. *Objectives*

a. NSPP: The overall objective of the NSPP program is to provide experimental validation of HAARM-3 for mixture aerosols under appropriate containment building conditions.

b. CRI-II:

—Develop and calibrate the aerosol generating, sampling, and measurement techniques.

—Qualify the use of UO_2 and U_3O_8 as appropriate fuel aerosol simulants.

—Investigate fuel aerosol behavior at very high concentrations.

* The USNRC program in fast reactor safety research covers the full range of applicable fuel cycles of fast reactor concepts.

—Conduct mixed aerosol experiments to provide scaling data relative to NSPP and to provide aerosol property and morphology information.

—Investigate how fission products associate and travel with the fuel aerosols.

—Investigate effects of a high radiation field on aerosol behavior.

3. *Scope*

The NSPP/CRI-II portion of the ART Program is to provide the experimental validation of the HAARM-3 aerosol behavioral code (developed by USNRC) under appropriate containment conditions, to provide some of the nuclear aerosol properties, and to investigate the behavior under special circumstances (such as presence of moisture, high concentrations, and presence of a radiation field). The experiments use two separate facilities, the Nuclear Safety Pilot Plant (NSPP) and the Containment Research Installation (CRI-II). The NSPP vessel is of intermediate size (volume = 38.8 M^3; height = 3 M) and the CRI-II vessel is ~5 M^3 in volume. Mixture aerosols are produced in these facilities by the simultaneous burning of sodium and uranium, and the vessels are equipped to measure the transient concentrations, plateout rates, fallout rates, and aerosol size distributions. Other system parameters are measured which include vessel temperatures, pressures, convection currents, and aerosol morphology (TEM and SEM photomicrographs).

Tests in NSPP include single component tests with sodium oxide aerosols at various concentration levels as produced by spray and pool fires, single component tests at various concentrations levels with U_3O_8 aerosols as produced by burning uranium, and tests using mixtures of the two varying total mass concentration, mass ratios, and agglomerate size differentials (different times for mixing the two species).

Special additional tests in CRI-II include the addition of traced fission product simulants and the addition of a high radiation field.

II. *HCDA Bubble Source Term (FAST/CRI-III Program) (ORNL)*

1. *Background*

The assessment of the consequences of an LMFBR HCDA requires estimating how much fuel and fission products escape from the primary containment. One postulated path for such release is via a bubble of fuel vapor (and/or sodium vapor) containing noncondensable fission gases that rises through the sodium pool to be released out leakage paths in the (presumed) damaged head.

2. *Objectives*

The objectives of these experiments and analyses can be stated as follows:

a. Phenomena identification:

—Is the bubble interface stable?

—Are sodium droplets entrained? How much and rate? Mechanism of entrainment?

—Bubble composition (UO_2 vapor or sodium vapor?)

—What are the sources of sodium vapor? Boiling from the interface? Vaporization of entrained droplets? UO_2 liquid interaction with bulk sodium?

—Do liquid UO_2 fragments penetrate interface and interact with the liquid sodium? Magnitude of FCI under pressure dispersion?

—Does the UO_2 vapor condense? Onto the interface? Within the bubble volume?

—Do condensed UO_2 particles get removed into the sodium or are they transported with the bubble?

b. Quantification of thermal exchange rates:

—Condensation of UO_2 vapor in presence of noncondensable gases onto the bubble interface and onto structures.

—Magnitude of liquid-liquid FCI.

c. Quantification of particle transport rates (how much of the UO_2 gets transported through the sodium?).

d. Characterization of the HCDA source (particle size distribution and properties).

3. *Scope*

The FAST/CRI-III portion of the Aerosol Release and Transport (ART) Program is to experimentally and analytically investigate phenomena associated with this release path. The experiments made use of a unique technique designated Capacitor Discharge Vaporization (CDV) in which electrical energy stored in capacitors is used to place UO_2 samples into energy states in excess of 3.5 KJ/gram. These samples, simulating severe HCDA states, are allowed to disassemble into various environments (vacuum, argon, under water, and under sodium) within two instrumented vessels, FAST and CRI-III. FAST, the major under water and under sodium vessel, is 2 feet in diameter by 6 feet in height. It is instrumented with high speed motion picture cameras (for under water tests) a recording pyrometer, submersible pressure transducers, a network of thermocouples and void detectors, and aerosol sampling equipment in the cover gas space. Acoustic devices are being developed for tracking the bubble movement and size in the under sodium tests.

Tests are firmly scheduled through FY 1981 which consist of several series of CDV disassemblies in vacuum, in argon, under water, and under sodium. All tests will vary energy input to the UO_2 sample, temperature and pressure of the surrounding environment, and depth of the liquid (water and sodium tests). Follow-on tests will use multipin samples and evaluate the effects of structures.

III. *Aerosol Properties Measurements for Mixed Aerosols (BCL)*

1. *Background*

Results of contained aerosol experiments and sensitivity analyses performed with aerosol behavior models have indicated a significant effect on airborne aerosol concentration which results from the actual or assumed properties of agglomerated aerosol particles. The properties of most importance are those related to irregular, fluffy or chain-like structures and concern the mobilities of such agglomerates and their effective dimensions for particle-particle collisions.

2. *Objective*

The objective of this experimental program is to measure the properties of agglomerates formed from aerosols of mixed materials. These results are intended for use in improving analytical models of aerosol behavior and in analyzing the results of large scale aerosol behavior experiments.

3. *Scope*

In the past, measurements have been made of agglomerates of sodium oxide particles to determine effective densities and migration velocities in a thermal gradient as dependent on agglomerate mass. These results were incorporated into the HAARM-3 computer code thereby providing more realistic predictions of aerosol behavior. Similar data are needed for agglomerate formed from mixtures of fuel materials, structural materials, and sodium oxide. Of these, UO_2 aerosols formed by vaporization in inert gas atmospheres have been studied to date and studies of mixtures of the noted materials are underway and scheduled.

APPENDIX C

DUTCH BROS-I, EPOSS AND BROS-II PROGRAMS

C-1. BROS-I program

Summary

The main aim of the "BROS"-program was to contribute to the existing knowledge and its practical applicability regarding the extension behavior of cracks in nozzle corner regions of thick walled LWR pressure vessels.

The main activities were:

A. Theoretical research directed towards development of computation methods to calculate the extension behavior of cracks in nozzle corner regions with regard to the economic use of these procedures.

B. Experimental verification of the developed computation procedures by testing of models (fatigue testing and fracture testing by overload of nozzle-on-flat-plate models).

C. Determination of fatigue- and fracture (linear elastic)-related parameters of the material from which the models are manufactured to interpret the results of the model tests as well as investigations on elastic-plastic fracture toughness parameters of ASTM A 508 Cl. 2 material.

D. Research on the applicability of acoustic emission techniques to detect, localize and characterize crack-extension in ASTM A 508 Cl. 2 material.

The program is partly financed by the Dutch Ministry of Economic Affairs and will be finished by July 1979.

The budget estimate was $1,700,000 based on the 1975 cost level.

Reports:

Progress and interim technical reports are mainly in Dutch; final technical reports will be published in English.

The first final technical reports are available in July 1979.

For further reference see RenD 79272 dated May 1979.

C-2. EPOSS program

1. *General aim*

Crack extension behavior in heavy section nuclear steel pressure vessels in areas of complicated geometry.

2. *Particular objectives*

Evaluation of the applicability of the J-integral concept (an elastic-plastic fracture mechanics concept) for predicting elastic-plastic crack extension for complex crack configurations in nuclear pressure vessels, notably cracks in nozzle corner regions.

3. *Experimental facilities and program*

Main activities are:

a. Theoretical investigations:

—Computation of J-integral values by the finite element method for 2-dimensional configurations, ranging from simple test specimens to uniaxially loaded plates with cracks emanating from a central hole;

—Computation of J-integral values by the finite element method for some 3-dimensional configurations, viz.

—Bars with a quarter-circular edge crack

—Uniaxially loaded plates with quarter-circular cracks emanating from a hole

—Flat plates with a central nozzle and a crcak at the nozzle corner

—Evaluation of the applicability of simplified approximation procedures to determine J for said configurations.

b. Experimental investigations:

—J_{Ic}-tests on standard specimens for the model material: i.e., Al 2024-T3

—Model-tests on 2-dimensional configurations: i.e., uniaxially loaded plates with cracks emanating from a central hole

—Model-tests on the 3-dimensional configurations mentioned under *a*.

4. *Project-status*

—Procedures for efficient computation of J-values by the finite element method have been established.

—Computations of J-values for simple 2-dimensional configurations have been completed.

—Computations of J-values for more complicated 2-dimensional configurations have been completed.

—J_{Ic}-tests on standard specimens have been completed.

—Experimental investigations on uniaxially loaded plates with cracks emanating from a central hole have been completed.

The program has been finished in 1977, the originally planned 3-dimensional investigations will be carried out within the BROS-II program (Appendix C.3).

5. *Relation with other projects*

The study is an extension of the BROS-project into the elastic-plastic regime (see Appendix C1).

6. *Reference documents*

Rep. MMPP-110, Delft Un. of Technology, Lab. for Thermal Power Engineering.

7. *Budget*

Approx. dfl 750,000.

C.3 BROS II: proposed program for continued research on flaws in thick-walled, steel vessels

Introduction

Recently a Dutch cooperative research program, called BROS, aimed at investigation of the behavior of cracked nozzle-vessel junctions in nuclear pressure vessels has been finished.

In this program LEFM techniques were applied and relatively small attention was paid to elastic-plastic fracture mechanics. As an extension of this work a proposal for further research was done, in which application of EPFM-techniques will be given special attention. Apart from this some additional LEFM work will be carried out.

The proposed program will be organized the same way as the BROS-program: i.e., a cooperation of various companies and institutes sponsored by the Dutch Ministry of

Economical Affairs. The total budget will amount to Hfl 3,000,000 ($1,500,000). The program starts September 1979 and will be finished by the end of 1981.

The total program is divided in seven subprograms, each covering a main topic, that will be investigated mainly at one laboratory. Briefly the topics that will be investigated are summarized below. In the description a rough cost-estimate is presented to indicate the weight of the different parts.

Subprograms

Subprogram 1. In this program LEFM-finite element calculations for a nozzle containing a corner-crack will be performed. The loading in the nozzle region will be deducted from thermal analysis, simulating the emergency cooling procedure of a nuclear reactor.

This program will be executed by Rhine Schelde Verolme.

Cost-estimate: Hfl 155,000 ($77,000).

Subprogram 2. This part is aimed at extending the existing knowledge in the field of elastic-plastic finite-element procedures to determine the onset of stable crack growth. Analysis up to now mainly concerned 2D configurations; this program will be directed towards 3D-geometries, for instance nozzle-vessel intersections. With regard to the large amounts of computing time necessary, also optimizing procedures, like application of crack-tip elements, will be studied.

Except numerical methods also the possibility of applying semianalytical methods will be studied.

This program will be executed at the Delft University of Technology.

Cost-estimate: Hfl 800,000 ($400,000).

Subprogram 3. In the subprograms 4, 5, and 6 different fracture parameters, characterizing initiation and slow stable crack-growth, are reviewed. The applicability of these parameters will be studied by experiments on a few configurations under uniaxial and biaxial loading conditions. These experiments will be conducted on an existing 2 MN biaxial testing system. The geometries will, for a start, consist of plates containing line-cracks and subsequently holes with edge-cracks. At a later stage a 3D-configuration will be considered.

These experiments will be performed by Rhine Schelde Verolme.

Cost-estimate: Hfl 780,000 ($390,000).

Subprogram 4. These investigations form a continuation of an experiment part of the BROS-program on elastic-plastic fracture parameters. Important aspects that will be studied are:

—To establish material-scatter and to solve the question how to deal with this when applying the results to actual structures.

—Study of different features at the initiation point like plastic zone size, crack-opening stretch and the applicability of various experimental techniques for determining the onset of crack extension.

—Geometry influences.

The experimental part is accompanied by a finite-element computational part.

This part of the program will be carried out at The Metal Research Institute T.N.O.

Cost-estimate: Hfl 350,000 ($175,000).

Subprogram 5. Subprogram 5 comprises the characterization of stable ductile crack growth. Important factors for the investigation will be energy considerations, development of CTOD or J during crack-extension, crack opening angle, development of plasticity, failure mechanisms of specimens and structures. The program consists of an experimental and a finite element computational part.

This program will be carried out at The Metal Research Institute T.N.O.

Cost-estimate: Hfl 385,000 ($192,000).

Subprogram 6. The aim of this subprogram is, like subprogram 5, the charaterization of slow stable crack growth.

In general, the same methodology as in subprogram 5 will be used. It is felt that in the coming years stable crack growth will become one of the most important topics in EPFM research, which justifies two subprograms dealing with this subject.

Most of the activities will deal with the numerical simulation of stable crack growth, where the experimental results of subprogram 2 and previously obtained results will be used.

The subprogram will be carried out at the Delft University of Technology, in close cooperation with the Metal Research Institute T.N.O., being the executor of subprogram 5.

Cost-estimate: Hfl 200.000 ($100,000).

Subprogram 7. In this subprogram a preliminary study of the possibilities and the usefullness of testing a thick-walled pressure vessel containing different types of cracked nozzles, will be performed. In order to show the applicability of the results of the BROS-program experimentally on a real type structure, requirements and recommendations will be drafted. Close cooperation or participation in a large multiclient project may be considered as a way to realize such an expensive and difficult project.

This study will be performed by N.V. KEMA.

Cost-estimate: Hfl 145.000 ($72,000).

APPENDIX D

Fast reactor aerosol research program

The behavior of aerosols during passage through cracks and penetrations in concrete walls is being studied in order to provide experimental support for the calculation of aerosol deposition within leak paths through containment walls. The important aspects being studied are the gas leak rate, the reduction of mass concentration and the change of particle size distribution due to passage through various leak paths as a function of pressure differences, temperature gradients, and aerosol material. Moreover, chain-like aerosols being used for this work and which are considered to be relevant in an HCDA, will be characterized in terms of aerodynamic diameters. The existing relation between the aerodynamics of such aggregates and their microstructure (Nature *252* (1974), 385) will be further examined.

Basic experimental studies on gas leakage and aerosol deposition in leak paths of various geometries are performed during the first stage of the project. Leak paths are characterized by the dependence of leak rate on the pressure difference over the leak paths. The aerosol deposition rate is studied experimentally for leak path models having various leak characteristics. As a result a model will be developed relating leak path geometry, gas leakage characteristics and aerosol deposition.

The main parameters being studied are:

Aerosol material	Na-oxide, U-oxide
Aerosol mass concentration	0.1 to 1 gm^{-3}
Pressure difference across leak paths	10 to 200 mbar
Temperature gradients over the leak paths	up to 100°C

Based on the experience already obtained the main effort will be concentrated on aerosol behavior in cracks in concrete, whereas an extension to leak paths associated with rubber gaskets, etc. of doors and plugs is considered.

Aerosols are produced by means of exploding wires or by the burning of Na and U.

Mass and number concentrations are determined by means of accepted modern techniques (filter sampling, CNC, OPC and EAA). In particular, particle sizing will be done by means of the Stöber Spiral centrifuge which allows also the assessment of the dynamic shape factors of the mentioned metal oxide aerosol particles.

The results obtained since the start of the project in 1978 were presented in condensed form at the ANS/ENS Fast Reactor Safety Meeting at Seattle (August 1979).

After the expected completion of the present project in early 1981, research at ECN on nuclear aerosols will be continued in a high priority area taking into account the results to be obtained from the ongoing investigations.