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SODIUM-COOLED REACTORS SAFETY ENGINEERING PROGRAM

FIRST QUARTERLY REPORT
AUGUST–OCTOBER 1972

U.S. ATOMIC ENERGY COMMISSION
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SODIUM-COOLED REACTORS SAFETY ENGINEERING PROGRAM FIRST QUARTERLY REPORT AUGUST—OCTOBER 1972

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GENERAL ELECTRIC

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ABSTRACT

The Demonstration Plant will demonstrate the safe economical generation of electric power from a liquid metal cooled fast breeder reactor. Many aspects of the safety of such a plant have been under study for several years.

The purpose of the project for which this document is the first quarterly report is: (1) to bring into sharp focus both the requirements or needs for specific technical information related to safety, and the results of previous studies, wherever performed, (2) to recommend to AEC/RDT a course of action which will provide the information found to be still required.

The existing LMFBR activity concerning safety includes both analytical and experimental programs. A major requirement is the establishment of mechanisms for the guidance of the National Safety Program in the integration of these analytical and experimental programs. This guidance must establish specific objectives, priorities, and schedules for the programs, and it must provide a mechanism for identifying and correcting whatever problems that arise before they interfere with the schedule for the design and construction of the Demonstration Plant.

This project began on July 1, 1972, as a separate activity. However, it is in part an extension of previous work under Tasks C-1, C-2, G-10 and G-12 of Project Agreement 10. In addition to these areas which focused primarily on core safety, the current program will be broadened to encompass all phases of reactor and plant safety.

This report covers the activity during August, September, and October 1972.

1. SUMMARY

1.1 PROGRAM INTEGRATION

A proposed procedure for integrating LMFBR safety development needs and priorities into the national safety program has been submitted to AEC/RDT.

Liaison activities have been established with ANL through an in-residence liaison engineer supported by the Safety Engineering Program.

A letter report has been issued assessing the proposed HEDL program of Cladding High Temperature Behavior.[1]

The PA-XX work plan was submitted to and reviewed by RDT. A revised work plan is in preparation.

1.2 SAFETY NEEDS

A partial review of safety needs in the HCDA* area was performed in conjunction with PA-67 analyses. Results of the review were employed to provide RDT requested input on analysis needs for the FEFPL experiments, and to comment on the objectives and applicability of the ANL/TREAT S series experiments (S-11 and -12).[2]

The ANL accident analysis codes, SAS-2A, VENUS II, and REXCO-H were obtained from ANL/RAS and have been installed on local computers. Current efforts are being directed at bringing these codes to full operational status on the local machines.

- The VENUS II disassembly code has been functionally checked out at University of California-Lawrence Berkeley Laboratory (UC-LBL).
- A version of the SAS-2A predisassembly code is operational on the UC-LBL computer facility. Several numeric instabilities and modeling problems have been identified and are in the process of being resolved with ANL/RAS.
- Programming difficulties have yet to be overcome in making the MFCI code operational on a local computer facility; this will be pursued in the coming quarter.
- The REXCO-H structural dynamics code has been exercised utilizing a GE LMFBR design.

1.3 EVALUATION OF PROGRAMS

Round-robin analyses of the H-3 experiment (post-test) and the L-3 experiment (pre-test) have been initiated at GE in preparation for a fuel modeling meeting to be held in December.

Letter reports were issued concerning the ANL FEFPL P-2 test program[3] and the feasibility and applicability of the ANL TREAT tests, S-11 and S-12.[2]

Meetings were organized and attended concerning general information on FEFPL program and the P-2 test in particular (August 14 and 15 at ANL and September 26 at GE). General review of the ANL FCI program and a detailed review of the S-11 and S-12 TREAT tests were also performed.

1.4 DOCUMENTATION OF GE CODES

FREADM code development work performed during FY-72 was assembled and is being prepared for documentation under this program. A description of the input required for running FREADM-MARS or FREADM-VENUS in the coupled mode has been written.

A first draft of a full description of the TOFF (Transient Overpower Fuel Failure) code has been written.

* Acronyms are listed in Appendix A.

2. SAFETY ENGINEERING

2.1 GENERAL

The purpose of this program is to establish procedures, determine requirements, and implement action to resolve safety-related questions pertinent to LMFBR development. Action will be implemented through recommendations to AEC/RDT on technical direction and utilization of national laboratory safety programs. In order to provide recommendations for such direction, a priority listing of plant safety needs will be established and continually updated. To satisfy these needs, (1) detailed experimental and analytical requirements will be defined to permit focusing of the safety test and analysis programs conducted at the national laboratories; (2) personnel will be assigned to national laboratories as liaison to provide a vehicle for timely exchange of pertinent information between GE and the laboratories. (This program is limited in FY-73 to one liaison engineer at the Argonne National Laboratory.)

Increased utilization of the capabilities of the national laboratories will also be attained through acquisition and use of non-GE safety analysis codes and the evaluation of the applicability of these codes to LMFBR and expected Demonstration Plant conditions, e.g., the analysis of non-prototypic effects. Finally, the development of experiments and the formulation of analytical models at the national laboratories will be critically monitored for technical responsiveness to the identified LMFBR safety-development needs.

2.2 PROGRAM INTEGRATION

The activities in this section include the preparation and implementation of procedures for integrating with national LMFBR programs as well as providing the advanced planning and design information to relate the safety development program to the LMFBR. Additional activities include QA, planning and schedule support, and on-site liaison at the national laboratories (initially limited to ANL).

2.2.1 Integration

Work was initiated on the preparation of a procedure for coordinating national laboratory work in support of the Demonstration Plant Safety Program. The initial effort was focused on proposing a mechanism for providing technical guidance to RDT for programs at the national laboratories. The resulting format of a proposed procedure for integrating the LMFBR safety development needs and priorities into national laboratory work programs has been submitted to RDT for review and comment.

2.2.2 Liaison

A General Electric liaison engineer has been assigned under this project to the Argonne National Laboratory (ANL) and a reporting procedure on liaison activities initiated. This liaison engineer who had been performing that function for a year under PA-10, has also arranged for the transmittal to GE-BRD of specific design, test, or code data and ANL documents which pertain to the LMFBR safety development programs and test facilities. Control of the documents is maintained through the office of the Safety Engineering (PA-XX) Technical Project Engineer.

A standard part of the liaison engineer's activities involves regular participation in or attendance at many ANL meetings dealing with the safety development testing program. For example, he has been involved in meetings on the Fuel Element Failure Propagation Loop (FEFPL) test objectives, the R-Loop (TREAT* reactor test loop) final design review, and the review of the current and future direction of ANL's Fuel-Coolant Interaction (FCI) Program.

A portion of the liaison engineer's workload also involves direct participation in ANL safety development activities as a method of attaining intimate, in-depth knowledge and understanding of the ANL safety development program. Currently the liaison engineer is participating in the safety and test design analysis of the planned TREAT R-Loop test series.

* Acronyms are listed in Appendix A.

2.2.3 Administration

ANL and HEDL have requested complete design/fabrication data packages on the details of the stagnant-sodium TREAT capsules C4B* (High-Burnup Fuel Experiments) and the C6* (Comparative Tests) capsule assemblies for possible future use in the FFTF safety testing programs. These packages are in preparation and will be delivered in November.

Reviews of LMFBR Safety Development Program documents are underway. These reviews are being used to maintain cognizance of and to provide background for input to safety development programs.

The PA-XX work plan was submitted to and reviewed by RDT. A revised work plan based on RDT's comments is in preparation.

2.3 SAFETY NEEDS

The technical activities in this section include the development and maintenance of a priority list of demonstration plant safety needs and adaptation and installation of safety analysis codes on local computation facilities. These activities are intended to provide proper focus and integration of fast reactor safety development programs.

2.3.1 Plant Safety Needs

Safety needs will be evaluated based on total plant considerations. Relative priorities will be defined for establishing consequences resulting from events ranging from fuel rod failures or coolant flow disturbances to malfunctions in the auxiliary or heat transfer systems.

An initial assessment of critical safety areas appropriate to HCD analyses was performed in conjunction with PA-67. Fuel-coolant interactions (FCI) are important factors in this safety area since they are related to mechanical loading on the containment and post accident heat removal (PAHR) requirements. The results of this assessment were applied to a review of the ANL/TREAT S series FCI experiments (S-11 and -12). Formal comments were given to RDT/HEDL/ANL[2] and discussed at the October 4 and 5 FCI meetings at ANL. The highlights of these comments and a summary of the results of the meeting are presented in Section 2.4.3 of this report.

A description of the REXCO-HEP version input requirements has been received and is being evaluated for further REXCO calculations at the UC-LBL facility.

2.4 EVALUATION OF ANALYTICAL AND EXPERIMENTAL PROGRAMS

The objective of this subtask is to:

1. Collect and utilize all of the analytical methods necessary to perform required safety analyses and evaluations.

2. Maintain cognizance of on-going experimental programs.

3. Critically evaluate both the analytical methods and the on-going experimental programs with regard to objectives, priorities, and correlations.

This activity provides the general and detailed requirements defining safety development test objectives and analytical methods work based on plant safety needs. Safety related test data will be reviewed and incorporated into models in a cooperative effort with the national laboratories. Available analytical tools will be applied to comparative (round-robin) analysis of the safety tests and to the analysis of non-prototypic effects on safety test results. Planned safety development programs will be critically evaluated for applicability to plant safety needs. All evaluations will be forwarded to the cognizant program personnel.

* Both capsule designs were originated, and fabrication and some testing was performed under Task C-1 of PA-10

2.4.1 Acquisition of Analytical Programs

Plans are to determine what existing codes are applicable to various areas of LMFBR safety analysis. Once such a list is completed, these codes will be acquired and assimilated on available computer systems for future use in LMFBR safety studies.

Versions of the ANL codes which are applied to HCD analyses were acquired from ANL/RAS. Familiarization and verification of code applications have been closely integrated with the requirements of PA-67, HCDA Analyses. In most cases close working relationships have been established and maintained with cognizant ANL/RAS personnel. For all of the codes, numerous problems involving clarification of input requirements and computer software and code formulation were resolved.

Numeric instabilities in the SAS-2A[4] DEFORM (equivalent spring constant) and Coolant Dynamics (vapor phase friction factor) modules were identified and partially resolved. The question of lower time step size limitation for numeric stability is being reviewed by ANL/RAS.

Reasonable agreement between SAS-2A[4] and FREADM[5] was obtained for steady-state temperature predictions. Preliminary results of a HCDA analysis for a GE LMFBR design, initiated by loss of sodium flow in the core, indicate that the inherent SAS-2A sodium dynamics calculation was successfully employed through utilization of a two-phase sodium vapor friction factor.

An initial, single precision version of VENUS was installed on the GE computer facility. This code was found to be unacceptable whenever large single-phase pressures became important. As a result, the VENUS II code was acquired for the UC-LBL facility; most functions of this code have been successfully utilized.

The MFCI code, as modified to run on the GE computer facility, contained numerical instabilities. Some problems have been exercised on the ANL/IBM system but, at present, the code remains in an early state of familiarization. A strong effort will be made to ensure the availability of this code in the coming quarter.

The REXCO-H code obtained from ANL/RAS is an undocumented modification of the code which was described in ANL-7498.[6] The program was made operational on the GE computer facility and checked against a sample problem performed at ANL. Difficulties were encountered with interpretation of the input requirements and code formulation. These difficulties are currently being resolved.

The initial calculations with REXCO-H have yielded questionable results prior to determination of the structural deformations. A likely source of the problem is considered to be excessive distortion of the physical Lagrangian grid. If so, the use of the ANL REZONE program will be investigated to continue the calculations.

2.4.2 Evaluations

2.4.2.1 HEDL Program for Behavior of Cladding at High Temperatures

A report was sent to RDT and HEDL[1] in support of the FTR fuel cladding behavior in a loss-of-flow accident. In effect, this report was GE's assessment of the Cladding High Temperature Behavior Program. The report was in response to a request by HEDL which suggested that cladding ballooning may be a factor in the loss-of-flow accident failure sequence. It was pointed out by GE that in order to effectively evaluate cladding ballooning:

1. Test conditions must be such that a realistic assessment of the consequences will be assured.

2. That once an adequate temperature history is established for bulk coolant and average cladding, it still is necessary to identify and simulate local peaking conditions (e.g., under wire wraps, and circumferential temperature scalloping, etc.). It would be expected that local hot spots would significantly reduce the degree of cladding ballooning.

3. Internal cladding attack from fission products could be effective in limiting the amount of ballooning prior to cladding rupture.

4. Consideration must be given to the mobility of the fission gas within the fuel rod. If the gas is not highly mobile (cannot readily diffuse through the fuel), ballooning may not be significant at locations other than the very top of the fuel column.

The above considerations should be evaluated from the standpoint of establishing how many rods in a bundle would be expected to balloon. It has been noted[7] that a 50% planar blockage is required to produce a 5 to 10% reduction in flow through a single channel. This being true, it will require an extraordinarily coherent ballooning to significantly affect the total flow rate. For these reasons it is the present opinion of GE that ballooning will not be a significant factor in the loss-of-flow/failure sequence.

2.4.2.2 The ANL FEFPL Program P-2 Test

An information meeting on the P-2 test in FEFPL was attended at ANL and comments on the P-2 test were completed and distributed.[3] These comments were based upon a review of the test requirements for experiment P-2, as well as the material presented at the August 15 meeting on the same subject. The August 15 meeting served to highlight critical areas as well as answer many of the questions formulated from the review of the P-2 experimental plan. It was felt that the meeting format provided a useful forum for effectively disseminating information on the FEFPL program and for generating comments and evaluations from the ultimate users of the information generated by the FEFPL program.

Comments on the P-2 experiment are summarized as follows:

- There appears to be a need for strongly integrated planning between the P series (FEFPL tests) and other ongoing ANL experimental programs, such as "L" and "R" series, to assure effective planning of tests addressing specific safety questions. An integrated program should evaluate data requirements and, based upon these requirements, select test vehicles for their ability to produce the required data at a minimum cost.

- The FEFPL capability of including relatively large bundles of rods as well as flow transients initiated from steady-state operating conditions should be exploited wherever possible. This can be accomplished by performing phenomenological tests in less prototypic and less expensive facilities such as the "L" and "R" loops with the "proof tests" of resulting models performed in the FEFPL. It should also seem prudent to qualify the TREAT tests with regard to the effect of steady-state operation by performing an early phenomenological test in the FEFPL.

- Operation of the P-2 experiment has been selected to provide for extensive if not complete meltdown of the test fuel. Operation of the test to destruction places a very heavy emphasis upon the ability of the instrumentation to detect interesting phenomena, and that if detected, the ability of the experimenter to interpret these outputs. An alternate which should be evaluated is an earlier termination of the test to provide improved post mortem morphology for use as a reference point to support instrumentation observations as well as provide basic data in areas not covered by instrumentation (fuel and cladding movement, fragmentation), etc. Limiting the amount of fuel taken to melt by initiating an early scram may also possibly permit operation of the P-2 experiment with a full 19-rod test section.

- Operation of the bypass flow control valve appears to be critical to the successful performance of the P-2 experiment. Controlling the opening of this valve, based upon test section inlet flow, could cause the valve to respond abnormally since flow reversals are expected to follow boiling.

- Fallback positions have been established to counter a malfunction of the bypass flow control valve. It is recommended that the operation of this valve be monitored and that the initiation of the "fallback" tests be automated because of the confusion usually associated with a malfunction during a transient test.

- It is intended to determine the failure time of individual fuel rods through the use of pressure transducers attached to the plenum of each fuel rod This may be a reasonably accurate method if the failure occurs in or near the plenum However, if failure occurs in the fuel region, the failure time may be difficult to determine accurately because of the restriction to gas flow past the restructured fuel

- The post mortem examination should be a very important part of test output Neutron radiographs provide a very strong tool for determining the post-test condition of the test section prior to possible disruption resulting from the destructive portion of the examination It is suggested that neutron radiography be performed prior to both the test and the post mortem examination of the P-2 experiment

- Important, yet difficult information to acquire in the FEFP program, is data on the motion of fuel and cladding during the transient This includes data on the occurrence of melting, slumping or ejection, and fragmentation, and their relation to transient heat transfer A task force effort is suggested to study the potential for adapting other sensors or techniques for acquisition of these data

2.4.2.3 The ANL S-11 and S-12 Tests

A letter report on the feasibility and applicability of the ANL TREAT tests S-11 and S-12 (sodium autoclave tests investigating high-energy FCI) was distributed to AEC/RDT, ANL, and HEDL [2] In addition, PA-XX personnel participated with RDT, ANL and HEDL in a general review of the ANL FCI program and a detailed review of the TREAT S-11 and S-12 tests (at ANL, October 4 and 5, 1972) The exchange of ideas and information among ANL, HEDL and GE was considered significant and beneficial

The GE review of the ANL S-11 and S-12 TREAT tests was based upon information available in the "Approval-in-Principle' (AIP) and indicated that

1 There is reason to believe that cladding failure may occur earlier than predicted in the AIP

2 It will be extremely difficult to separate the effects of the vapor driven component of the FCI from other forces anticipated during the test

3 The atypical fuel temperature profiles at failure could result in a significant overestimate of the FCI expected for the FTR and Demonstration Plant This results from excessively high average fuel temperature and molten/vaporized fuel fraction following S-11 and S-12 failures

In addition to the formal role associated with the S-11 and S-12 tests critique, additional significant objectives were accomplished by GE's attendance at this meeting These were

1 Commencement of new lines of communication within ANL to allow GE to become more closely involved in the planning of ANL/RAS safety development programs (at this stage, as an advisor in FFTF supportive programs)

2 Assertion that additional detailed pre-test analysis/documentation is required to allow realistic, independent judgement of the ultimate usefulness of upcoming tests

2.4.2.4 Analysis Requirements for the ANL FEFPL Program

Input for the PA-XX response on analysis requirements for the FEFPL program have been distributed in preparation for the planned November meeting [8]

2.4.2.5 Round-Robin Analyses—ANL H-3 (Post-Test) and ANL L-3 (Pre-Test)

Analyses for both post-test H-3 (transient-overpower test in a flowing sodium Mark-II loop) and pre-test L-3 (loss-of-flow test in a similar Mark-II loop) experiments are proceeding as part of a round-robin analysis. The results will be presented and compared with similar analyses from ANL and HEDL during a fuel-modeling meeting scheduled for early December.

2.5 DOCUMENTATION

The purpose of this activity is to document the safety analysis codes developed by GE under Task G-10 of PA-10.

A first draft version of the TOFF (Transient Overpower Fuel Failure) code has been written. The TOFF code predicts the response of a fuel rod to an overpower transient condition.[9] The documentation will include:

- Physical description of the problem
- Assumptions and idealizations
- Input requirements/optional inputs
- Description of subroutines (including flow chart)
- Derivation of equations
- FORTRAN listing

FREADM code development performed during FY-72 was assembled to provide a record of the code status to be documented under this task. FY-72 efforts centered on the coupling of FREADM with the VENUS and MARS codes and with the TOFF/BUBBLE subroutines. Coupling of the latter two modules was not completed. Documentation of the status by end of FY-72 will include identification, but no correction, of problems in the code discovered since the end of FY-72.

A description of input required for running FREADM-MARS or FREADM-VENUS in the coupled mode has been written. This will be included in the user's manual for FREADM to be prepared under this task.

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APPENDIX A
LIST OF ACRONYMS

ANL/RAS	Argonne National Laboratory/Reactor Analysis and Safety Division
DEFORM	Fuel Element Deformation Model (Subroutine in SAS-2A)
FCI	Fuel-Coolant Interaction
FEFPL	Fuel Element Failure Propagation Loop
FREADM	Fast Reactor Excursion Accident Dynamics Model—a computer code
HCD	Hypothetical Core Disassembly
HCDA	Hypothetical Core Disassembly Accident
MFCI	Molten Fuel-Coolant Interaction—a computer code
PAHR	Post-Accident Heat Removal
SAS-2A	A pre-disassembly computer code
REXCO-H	2D hydrodynamics code for primary containment
REXCO-HEP	2D hydrodynamics elastic-plastic code for primary containment
REZONE	Reformulates Lagrangian mesh (to use with REXCO)
TREAT	Transient Reactor Test Facility
UC-LBL	University of California-Lawrence Berkeley Laboratory
VENUS	Computer code for core disassembly
MARS	Computer code for core disassembly

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