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IAEA/UNDP-ROM/87/002
Technical Report 4

NUCLEAR SAFETY

ROMANIA

NUCLEAR FUEL PERFORMANCE, MODELING AND EVALUATION

UNITED NATIONS DEVELOPMENT PROGRAMME

INTERNATIONAL ATOMIC ENERGY AGENCY

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NUCLEAR FUEL PERFORMANCE, MODELING AND EVALUATION

Report prepared for
the Government of Romania

by

the International Atomic Energy Agency
acting as Executing Agency for
the United Nations Development Programme

UNITED NATIONS DEVELOPMENT PROGRAMME
INTERNATIONAL ATOMIC ENERGY AGENCY

VIENNA 1993

Report on an IAEA Field Mission

on

NUCLEAR FUEL PERFORMANCE MODELING AND EVALUATION

for

Institute for Nuclear Power Research

at

Pitesti, Romania

Submitted by

Tai-Ran Hsu, Ph.D.

IAEA Project Code:
ROM/9/004(ROM/87/002)

August, 1992

Project Title: Nuclear Safety
Special Task Title: Fuel Performance Evaluation-Power Cycling Behavior of Fuels
Duty Station: Institute for Nuclear Power Research, Pitesti, Romania

<u>Terms of Reference:</u>

(1) To assist the counterpart in understanding the physical processes during fuel power cycling;
(2) To assist the counterpart in the development of a computer code for power cycling behavior of fuel elements (preferably for CANDU-type fuel);
(3) To advise the counterpart in the design of irradiation tests aiming at the evaluation of fuel behavior during power cycling.

Upon arrival at the site, the author was asked by his counterpart to take on the following three additional duties:

(4) To extend the duty listed in Item(2) to include the modeling of fuel behavior under both normal operating and power transient (LOCA) conditions;
(5) To advise the counterpart on the application of Computer-aided design (CAD) for fuel bundles;
(6) To advise the senior administrators on the direction of future research activities of the Institute.

Status of Project Implementation

The Fuel Performance Evaluation Section at which the author performed most of his duties consisted of ten members. The Head of the Section, Dr. Grigore Horhoianu is a physicist and so are most of the members in the Section. Dr. Horhoianu succeeded Dr. Constantin Gheorghiu as the Head of the Section in April this year. Dr. Gheorghiu became the Scientific Director of the Institute at the same time. Mr. Radu Moscalu, an Engineering Physicist and an active member of fuel modeling was assigned to the author as the technical contact person, although the author was also frequently consulted by Mr. Gabriel Papodopol on "Fuel modeling for LOCA conditions and CAD"; Mr. Marius Paraschiv and his wife, Adriana on "Fission gas release", and Mrs. Elena Gheorghiu on "Defective fuels". The other members either attended the four special lectures delivered by the author, or were involved in various discussion sessions.

At the time of author's arrival, several members in the Section expressed their feeling about the uncertain future of the Institute and also about the proper directions for their works in: (1) Development of computer code for fuel modeling; (2) Power ramp experiments; (3) Fission gas release models; (4) CAD for fuel bundle design; (5) Modeling of fuel behavior under LOCA. Status of research activities in these five areas and also the associated technical problems have been presented in Appendix I of this report.

Work Programme

The author carried out his field mission by performing the following tasks:

(1) Formal lectures on the following topics:
"Nuclear Fuel Modeling" on June 23
"TEPSAC Code for Fuel Modeling" on June 25
"Power Cycling on CANDU Fuels" on June 26
"Cyclic Creep Fracture of Engineering Materials" on July 2

(2) Group consultations on:
- Fission gas release on June 25
- Finite element method in thermomechanical analysis on June 26
- Heat transfer analysis by the TEPSAC code on July 1
- Boundary conditions for heat transfer and diffusion of fission gas analyses on July 6
- LOCA modeling on July 6

(3) Individual consultations on:

- Interpretation of in-reactor power ramp experiments,
- Interpretation of fatigue strength of Zircaloy from experiments,
- Application of analytical fission gas release model,
- Out-reactor experiments, e.g. by the SIMFEX concept,
- LOCA modeling and phase transformation & oxidation models of Zircaloy sheaths for LOCA analyses,
- Input to the TEPSAC code,
- CAD for fuel bundle design.

(4) Evaluation of existing computer codes for fuel modeling and the specification of essential configurations for new computer code (see Appendix III and IV)

(5) Identified a "theme" role for the Institute, as well as recommending its future research activities, at the request of the Scientific Director, Dr. Gheorghiu (Appendix V).

A calendar which summarizes daily activities is presented in Table 1.

The author left behind copies of his lecture notes of the first three topics, and also the duplicated copies of all AECL reports listed in Appendix VI.

Conclusion

Major accomplishments of this field mission can be outlined as follows:

(1) A consensus was reached among all parties involved in the project to develop a multi-dimensional analysis code based on the TEPSAC code. Major effort will be made to develop the necessary modules as listed in Appendix III.
(2) More in-reactor power cycling experiements will be performed on fuel elements. In view of the lack of in-reactor diametral measuring device at the Institute, measurements of diametral changes of fuel sheaths will be made after each and subsequent cycles.
(3) Out-reactor experiments similar to the SIMFEX arrangement will be developed to assess fatigue strength of Zircaloy, and also for environmentally-assisted sheath defects, e.g. stress corrosion cracking (SCC).
(4) Current effort on the development of fission gas release models should continue, but whatever the model, it should be in the form that can be readily adapted in the new fuel modeling code.

The **major impact** of this mission can thus be viewed as to have assisted the host institution to focus its effort in developing a realistic fuel modeling code which can effectively assess the physical behavior of CANDU fuel elements for normal operating conditions, power cycling and the hypothetical LOCA situations. The mission also provided the host institution with ways and means for bench-mark verifications of the code by low-cost in- and out-reactor experiements.

Recommendations

(1) To the Fuel Performance Evaluation Section:

Recommended solutions to most of the technical problems encountered by the Section have been presented in Appendix I of this report. Following are additional recommendations on research and development activities which the Section may undertake in the immediate future:

a)Immediately establish the development of a fuel performance modeling code as a goal. It is imperative that realistic time frames be established for accomplishing such a goal,
b)Once such goal and realistic time schedules are established, each member in the Section should be assigned a contributing role. Dr. Horhoianu or his designate should act as the coordinator of this task,
c)The fuel modeling team should include membership from other sections, such as Material testing and Thermal hydraulic groups. Additional members may be acquired on a "loan" basis from other groups in the Institute. New staff should be hired in these areas if necessary.
d)Attention should also be paid to the thermomechanical behavior of fuel bundles and sub-channel effects such as uneven coolant flow and fluid-induced vibrations.
e)To independently develop analytical and experimental programs in fuel performance evaluation. Avoid duplication or "re-inventing wheels" by following similar activities of other organizations such as AECL, without justifiable causes,
f)Design and perform all future in- and out-reactor experiments for one and only one purpose, i.e. to serve the needs of fuel performance modeling code development.

(2) To the Institute:

a)The Institute should place "Fuel Perfomance Modeling" as the top priority development project, if the goal of "Using Romanian made fuels for Canadian made reactors" by the country is to be realized. Full support should thus be given to this development,

b)The Institute should do all it can to encourage and facilitate the access of updated AECL reports and literatures on fuel performance modeling and evaluation,

c)Establish close working relationships with the Fuel fabrication plant and the owner and operator of all CANDU power stations in the country.

d)The Institute should strongly encourage, as well as facilitate the publications of its research and development activities in the forms of reports and technical papers. Effort should be made to have its publications reaching the institutions which it desires to have exchange of information, e.g. AECL and IAEA.

(3) To RENEL (Romanian Electricity Authority):

a)The Authority and the Government of Romania are reminded that no country in the world, large or small, can have viable nuclear power generation without strong supports from a viable research institute (Appendix V). The government thus should do its best not only to maintain, but also should strengthen the capabilities of the Institute,

b)Funds should be made available for sponsoring research and management personnel and engineers to be trained abroad, in particular at AECL establishments in Canada,

c)Interaction and communication with other countries having nuclear experiences are essential to sustain a viable nuclear industry in Romania. RENEL should thus secure funds for the personnel at the Institute to attend international conferences and symposia as well as short courses on special topics in technical and management areas. Moreover, it should invite international experts to disseminate new and update technology and management experiences to its employees.

TABLE 1 SUMMARY OF DAILY ACTIVITIES
(JUNE, 1992)

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
21 Preparation for the mission	22 (1) Briefing by Dr Gheorghiu, Scientific Director on: Organization and activities of the Institute. (2) Began the review of FEMAXI-3 code.	23 (1) Lecture on: Nuclear Fuel Modeling. (2) Established the schedule and agenda for the mission.	24 (1) Visited the Triga reactor and the Hot Cell facility. (2) Also visited the In-reactor power ramp experiments. (3) Consultation on Results on in-reactor power ramp exp. Fatigue strength exp. for Zircaloy sheaths.	25 (1) Lecture on: TEPSAC Code for Fuel Modeling. (2) Consultation on Fission gas release Input to TEPSAC code for a test case.	26 (1) Lecture on: Power Cycling on CANDU Fuels. (2) Consultation on Finite element methods in thermo-mechanical analysis of fuel element	27 Documentation of week's activities
28 Preparation for the next week's activities	29 Consultation on: -Input to TEPSAC code. -Application of an analytical model on fission gas release. -Stress waves in fuel sheath in LOCA situations. -Review of FEMAXI3 code.	30 (1) Completed the review of FEMAXI code. (2) Prepared a comparasion and evaluation of: ELESIM2, FEMAXI3 and TEPSAC codes				

TABLE 1 SUMMARY OF DAILY ACTIVITIES - CONT'D
(JULY, 1992)

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
			1 Consultation on: -Evaluation of 3 computer codes. -Configuration of code for fuel modeling purpose. -Heat transfer analysis used in the TEPSAC code.	2 Lecture on: Cyclic Creep Fracture of Engineering Mate-rials. Consultation on: CAD for fuel bundle and end-plate design. Out-reactor experi-ments using SIMFEX set-up.	3 Documentation of week's activities.	4 Traveling
5 Preparation for the next week's activities	6 Consultation on: -LOCA modeling. -Boundary condi-tions used in the FE formulations in heat transfer and fission gas diffusion analyses	7 -Meeting with Drs. Gherghiu and Hohoi-nu on the direc-tion and future role of the Insti-tute. -Meeting with Mr. Valeca, Managing Director, on similar topics.	8 -Consultation to Dr Gheorghiu on the management of research institute -Preparing written statements on the research direction and future roles of the Institute on Dr. Gheorghiu's request.	9 -Participated in a wrap-up meeting with members of the Fuel Performance Evaluation Section -Consultation on: Fluid induced vibration on fuel bundles; Separation of fati-gue from cyclic creep; Finite strain theory.	10 -Consultation on: In-reactor power cycling; Extrapolation of fission gas re-lease from enrich-ed fuels irradia-ted in Triga reac-tor to those irra-diated in CANDU reactor. -Meeting in Bucharest (see * below)	11 Documentation of week's activities. Initiated the draft of the final report to IAEA.

* The meeting took place at the RENEL building in Bucharest. Presented in the meeting were: Messrs. Iosif Bilegan, Director, Technical Direction, Florian Glodeau, Head, Strategy & Development Department, and Dr. Gheorghiu. Topics for discussion were similar to those discussed with Mr. Valeca, and those presented in Appendix V.

APPENDICES

Appendix I: Status and Associated Problems of Current Research Activities (with Recommended Solutions)

Appendix II: Evaluation of Fuel Modeling Codes

Appendix III: Additional Works Required for Building a Fuel Modeling Code on TEPSAC Code.

Appendix IV: Overview of Nuclear Fuel Modeling

Appendix V: Proposed Theme Role for the Institute.

Appendix VI: References on CANDU Nuclear Fuel Modeling

APPENDIX I

STATUS AND ASSOCIATED PROBLEMS OF CURRENT RESEARCH ACTIVITIES - WITH RECOMMENDED SOLUTIONS

1. Overall Impression:

This group consists of 10 members under the leadership of Dr. Grigore Horhoianu. Most members are young and are enthusiastic to learn. They work hard to strive for due recognition by outside world under a difficult situation. My overall impression on this group is thus quite positive.

2. Current Acitivites:

2.1 Code development

At the present time, major effort is being made in developing reliable fuel modeling codes. This involves the development of operating conditions fuel modeling by R. Moscalu and the development of accident condition fuel model is assigned to G. Papadopol.

Two codes, ELESIM2 code purchased from AECL and FEMAXI-3 code obtained from the Nuclear Data Bank from Paris are being used for the modeling of fuel behavior under operating conditions. Since the ELESIM2 code is for 1-dimensional analysis for both the pellet and the sheath, and the FEMAXI-3 code is also for 1-demensional thermal, but 2-dimensional mechanical analysis, both codes have serious limitations in describing the complex thermomechanical behavior of fuel elements in critical areas near the fuel pellet to pellet interface and near the end-cap weld zones.

Effort in developing a computer code for modeling fuel behavior under accident (LOCA) condition follows the direction of the ELOCA code which is the first generation such code developed by the AECL.

Problems:

There is a definite need for a multi-dimensional analysis code for the purpose of design and the correlation of experimental results. There is also lack of reliable input data and physical models to the codes. Additionally, there is a need for a proper case(s) which can be used to verify the cods(s).

2.2 Power ramp experiments

One fuel element instrumented with thermocouples is being irradiated in the Trigar reactor. The fuel element is subjected to programmed power cycles. The irradiated fuels will be examined in the Hot Cell after all power cycles are applied. The purpose of these experiments is to: (1) assess the damage, e.g. distortion of the geometry, on the fuel element, (2) to correlating the neutron flux depression to the heat generation in the fuel pellets.

Out-reactor experiments involving fatigue strength of Zircaloy sheath were carried out. Fatigue loadings in the form of repeated profile deformations were applied to the Zircaloy specimens. Stress (S) vs. Cycles to failure (N) curves have been established for the sheath material.

Problems:

(1) There is a lack of clear definition on: Power ramp rates, cycling patterns for fuels with different burnups.
(2) There is no sophisticated in-reactor experimental test rig that allows in-situ deformation measurements.
(3) There has been difficulties in interpreting the test results.
(4) There is a need for a set of comprehensive damage criteria for fuels subject to power cyclings.

2.3 Fission gas release

Analytical models have been developed by some members, e.g. Marius and Adriana Paraschiv, to predict the diffusion of fission gas into "spherical" bubbles and the escape of the same gas to the pellet/sheath gap through the intergranular tunnels. Unfortunately their work has not been well received by their colleagues, as the work is the result of complex mathematical drivations.

Problems:

(1) How to apply the work of the Paraschives to fuel modeling.
(2) What model to use to predict fission gas release, especially during. the LOCA and by the extended burnup fuels.

2.4 Out-reactor loop tests

Test facility is available to measure the flow conditions of hot water over 12-bunddle assemblies. The measurements included primarily the pressure drops of water flow.

Problem:

Interpolation of results

2.5 Computer-aided design of fuel bundles

Current effort involves the use of the CDC-2000 program for the design of end plates. This program has solid modeling capability. It, however, requires excessive memory of the existing CDC-Cyber computer.

Problem:

Lack of better software and hardware, especially microcomputers for interactive operations between the designer and the machine.

2.6 LOCA analysis

An attempt has been made to develop a computer code for LOCA analyses. The concept involved in this development is similar to that of ELOCA code used by the AECL.

Problems:

(1) What theory to use for the model?
(2) Information on issues such as: phase transformation of Zircaloy sheathg material, formation of Zirc-oxide layers, cracking behavior and fission gas release during and after the LOCA.

3. Possible Solution to the Problems

3.1 Code development

An evaluation of the two existing codes, ELESIM2 and FEMAXI-3, was made (see Appendix II). There is a clear indication of the need for a multi-dimensional analysis code. The author offered a code of his own, TEPSAC* for their consideration. (* an abbreviation of : Thermo Elastic-Plastic Stress Analysis) It is a 2-dimensional plane and 3-dimensional axisymmetric analysis code. Theories and the finite element formulations for the thermal and mechanical analysis are well documented in one of his books ("The Finite Element Method in Thermomechanics" Unwin & Allen, London, 1986). Two copies of this book were donated to the Institute by the author, along with a computer diskette which contains the listing of the program. The reason for offering the TEPSAC code is that this code was used as the base code for the development of two fuel modeling codes for the AECL - the FULMOD code for operating conditions and the FAXMOD code for accident (LOCA) conditions. The author also advised the group on what additional works are required to convert TEPSAC code into an effective fuel modeling code. Major additional effort is itemized in Appendix III.

3.2 Power ramp experiments

The Institute does not have any facility to measure real-time in-reactor deformation of fuel sheaths during and after power ramps. Facilities such as IRDMR (In-reactor diameter measuring rig) developed by AECL can be used for this purpose. The Institute does not have the resource to build such rig and the reactor loop for using such rig. It, however, has adequate hot cell facility to measure the profile of fuel elements after the irradiation. A feasible way is to develop a credible computer code, such as proposed in the foregoing section, to predict the deformation of the fuel sheath and verify the predicted results by post-radiation profile measurements after the fuel elements being power-ramped in the Triga reactor after each ramp. Since published literatures by AECL have indicated that most damage to the fuel elements occur at the first few power cycles, such practice need not to be extended beyond, let us say, the first five cycles.

3.3 Fission gas release

An analytical model has been developed to predict the diffusion of fission gas into the "spherical" bubbles at the boundaries of "spherical" grains. The model in its present form is far from being of direct use to the fuel modellers. The proposed solution to this problem is to examine the cross-sections of irradiated fuel elements at a given burnup and establish statistical databases for the shapes and sizes, as well as numbers of Uranium oxide grains and bubbles. The established model can then be applied to assess more accurately the portion of the total fission gas released that is stored in the bubbles. The balance of the released gas, of course, can be assumed to have escaped into the pellet/sheath gap.

The author realizes that the above recommended approach will take substantial amount of time, and it may be too time consuming to be practical. An interim solution for the fuel modellers is to continue their practice of using the ELESIM2 code for predicting fission gas release for the CANDU fuels.

3.4 Out-reactor loop tests

Information on these tests was sketchy. It is important that such tests provide loading and thermal boundary conditions such as local heat transfer coefficients between the fuel sheath and the coolant, which are necessary for fuel modeling. The author cannot be certain as how the present arrangement of using hot water flowing over inactive and "cold" fuel elements could lead to the required information.

3.5 Computer-aided design of fuel bundles

The author recommends an immediate acquisition of at least one microcomputer with Intel 80486 type of CPU and multi-color ink-pen plottor. Softwares such as ANSYS, SDRC-IDEAS and AutoCad should be considered for such purpose.

3.6 LOCA analysis

The author recommends the modellers at the Institute to adopt the same base code i.e. TEPSAC code for the LOCA analysis. However, appropriate modules such as (1) phase transformation from α to β phase Zircaloy, (2) the oxidation of Zircaloy at elevated temperature, (3) the effect of braze of Berylleum bearing pads (4) fission gas release during rapid expansion of sheath, (5) tertiary creep of sheath materials; should be established and be incorporated in the code. The author left the Institute with a few AECL reports in which empirical expressions for items (1),(2),(3) and (5) are available.

The issues of predicting sheath ballooning by using the finite strain theory in the model is secondary in the author's view. The configuration of CANDU fuel channel is such that it can produce a blockage of coolant flow with a moderate sheath expansion. Large sheath strain above 15% level is thus not physically possible. The benefit from the finite strain theory in the code would thus be marginal.

Appendix II

EVALUATION OF FUEL MODELING CODES

	ELESIM2	FEMAXI-3	TEPSAC*
PURPOSE	For CANDU fuel only	For LWR fuels	Developed for the base code for CANI fuel modeling cod(
COMPUTATION METHODS	1-D finite difference thermal analysis of fuel. 1-D stress analysis of sheath using 1-D creep law.	1-D thermal analysis of fuel using heat conduction equation. 2-D stress analysis of sheath using finite element method.	2-D plane or 3-D axisymmetric finit element analysis for both fuel pel] and sheath.
TYPES OF FUEL MODELS	Operating conditions only.	Operating conditions only.	for both operatin{ and power transie
MODELING GEOMETRIES	One slice of fuel element.	Half a pellet and sheath.	Stack of pellets, entire fuel elemer
DISCRETE MODELS	100 ring elements in fuel pellet. One segment along the length.	10 ring elements in pellet, 1 layer of isoparametric elements across sheath. Up to 12-segment along the length	Unlimited use of simplex elements i the entire fuel e] ment.
CAPABILITIES:			
Circumferential Ridging	By empirical formula	By imposed axial constriants.	By computations.
Longitudinal Ridging	No	No	Can be done by usi the plane model.
End-cap/Sheath welding	No	No	Yes
Prediction of SCC	No	No	No*
Fission Gas Release as Function of Burnups	Yes	By empirical model	No*
Power Cycling	Yes	No	No*
LOCA Analysis	No	No	No*
FUNCTIONS:			
Pellet/Sheath Interaction	Open gap & full bonding	Open gap, full bonding & sliding	Open gap & slidin (CANLUB)
Irradiated Material Properties	No	Only on yield strength.	No*
Pellet/Pellet Interaction	No	Simulated	Yes
ACCESSIBILITY TO CODE LISTINGS	Yes	Yes	Yes
MICROCOMPUTER VERSION	No	No	Yes

* See Appendix III

Appendix III

ADDITIONAL WORK REQUIRED FOR CONSTRUCTING A FUEL MODELING CODE ON THE BASIS OF TEPSAC CODE

REQUIRED MODULAR DEVELOPMENT	POSSIBLE SOURCES FOR INFORMATION
Gap Element Module for thermal and mechanical pellet/sheath interactions	Formula and subroutines available[1]
Fission Gas Release Module	Elesim2 code
Fuel Swelling Module	Elesim2 code
Heat Generation from: Neutron flux and Burnup-dependent flux depression	Elesim2 code
Irradiated Material Properties Databases	Available references, or in-house generated.
Sliding Pellet/Sheath Interface	Formula and subroutines available[1]
Stress Corrosion Cracking Module	Available in reference[2]
Fuel Sheath Creep for LOCA Analysis	Available in reference[3]
Oxidation of Fuel Sheath during LOCA	Available in reference[4]
Cyclic Creep-Fatigue-Fracture Module	Formulation Available[1] with material constants to be determined by in-house experimentations.

REFERENCES:

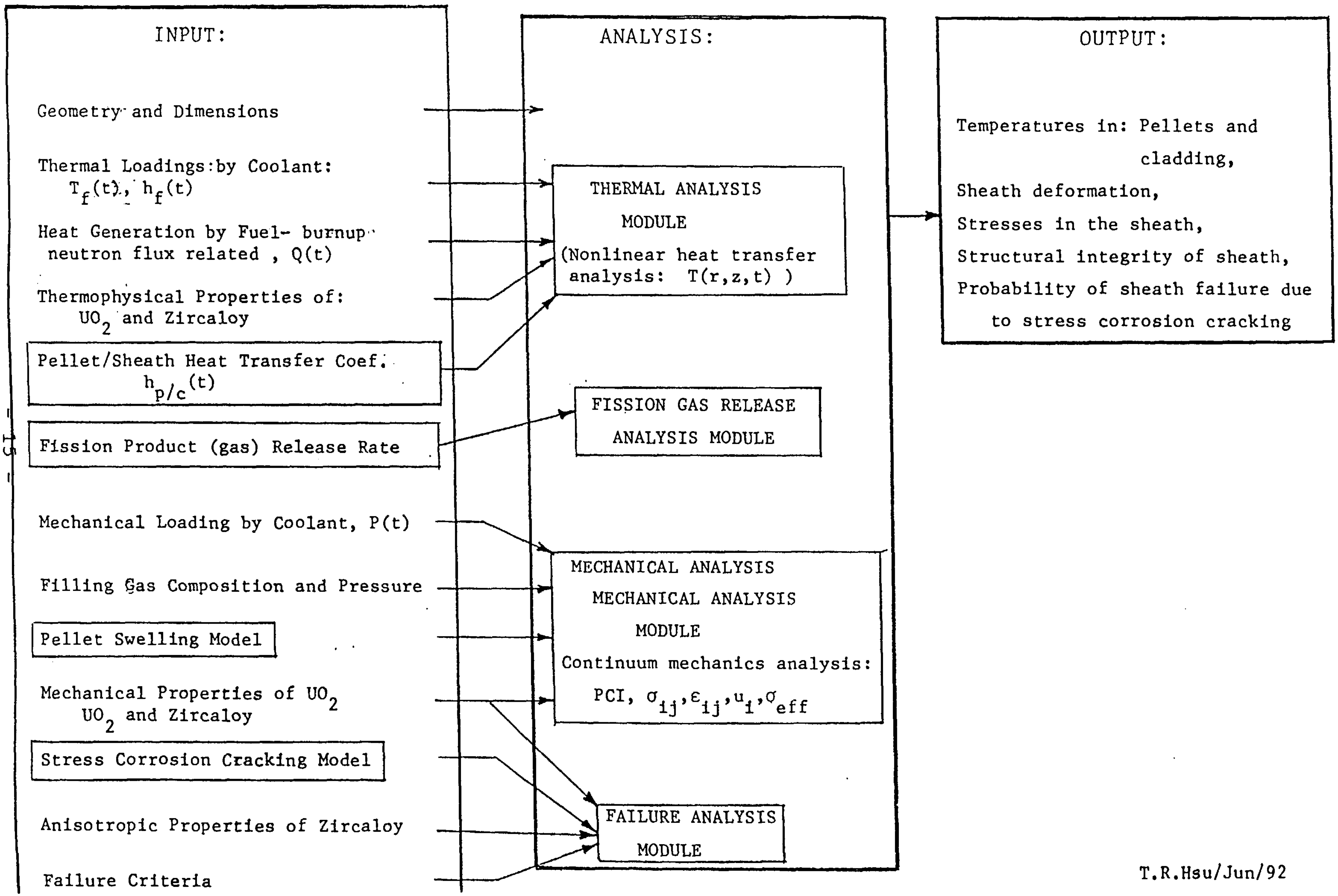
(1) T.R. Hsu - Private communications.

(2) "CANDU Fuel-Power Ramp Performance Criteria", W.J. Penn, R.K. Lo and J.C. Wood, Nuclear Technology, Vol. 34, 1977, pp. 249-268.

(3) "NIRVANA, A High-Temperature Creep Model for Zircaloy Fuel Sheathing", H.E. Sills, R.A. Holt, AECL-6412, 1979.

(4) "Deformation and Failure of Zircaloy Sheaths Under LOCA Conditions", S. Sagat, H. E. Sills, J. Walsworth, D.E. Foote and D.F. Shields, AECL-7754, 1982.

Appendix IV Overview of Nuclear Fuel Modeling



APPENDIX V

PROPOSED THEME ROLE FOR THE INSTITUTE

1. Justification for Nuclear Power in Romania

Romania has significant reserve in uranium ore. Nuclear power that utilizes natural uranium fuels will give the nation with: (1) independent supply of electric power and thus national security and (2) clean, inexpensive and reliable energy supply.

The adoption of nuclear power and the CANDU reactor system by the National Energy Board is therefore an excellent choice. The decision to import CANDU reactors from Canada, but to produce fuels in this country with its own uranium resource is a sensible one. This arrangement will not only ensure the independence of future supply of fuel from foreign countries, but will also help to develop advanced technologies in other related fields such as "advanced manufacturing", "instrumentation","isotope productions" for medicine and food industry.

2. Justification for Further Investment in Nuclear Power Development

The author was made aware of a current situation of under-utilization of full electric power generating capacity in this country. This situation is probably attributed to the following factors:

(1) Malfunctioning or break-downs of a number of out-dated equipment in fossil fuel generating plants,

(2) The demand for electricity has been declining in recent years.

It is the author's opinion that the demand for electrical power will inevitably revive soon as the country is out of its current recession. ***Energy*** and ***transportation*** are the two most important pillars on which modern economy is built. It will be unthinkable for any government not to invest in reliable and secure sources of energy supply and enjoys an econmomic growth.

The government will thus be facing with a tough decision as to what energy source should it invest. One option is to rejuvenate the defuncted fossil fuel plants. This will mean to replace most of the out-dated equipment. A huge investment will be required in this action. The end result will be a number of virtually new power plants consuming imported fuels. These power stations will seriously pollute the air and water and pose serious threat to the environment. To maintain a clean and healthy environment is a battle which many developed countries in today's world are combating but with limited success.

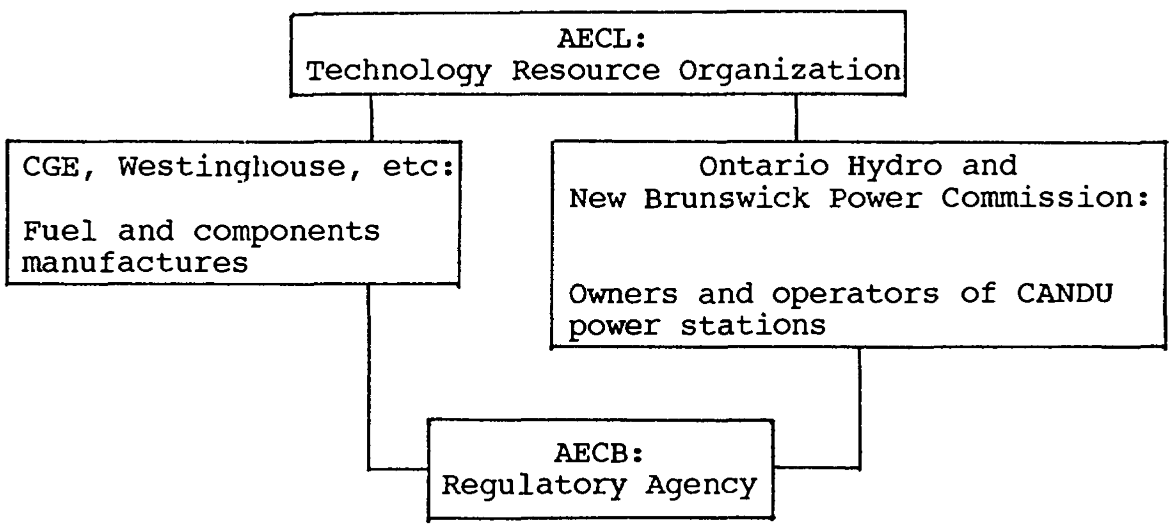
The other option is to complete the commitments made to the CANDU nuclear power stations. There will be substantial investment too. However, the potential benefits can easily out-weigh the heavy investment for the following reasons:

- Independence of foreign energy supply,
- Clean and inexpensive supply of energy,
- Technology spin-off to other related technologies,
- Potential to export excessive energy to the neighboring countries on demand.

3. The Necessity of a Research Institute for Nuclear Power

A research institue such as The Institute for Nuclear Research in Pitesti will remain essential even after all the five CANDU reactors are constructed, and all nuclear power stations are in operation. This fact has been demonstrated by all countries that already have nuclear power stations in operation. Countries, large or small, such as United Kingdom, U.S.A., Japan, China(Taiwan), Korea and Canada, all have strong and active research institutions. These institutions play vital roles in sustaining nuclear power generations in their respective countries.

A familiar model of the Canadian nuclear power industry will illustrate how the research institute, AECL, fits into the overall structure:



There, we see that each party has a useful role to play to make the Canadian nuclear power industry working.

The situation in Romania is very similar. There is a separate fuel fabrication plant, a regulatory body CNCAN, the RENEL (Romania Electricity Board) - the owner and also the operator of CANDU power stations, and the Institute for Nuclear Power Reactors - the technology resource organization.

The linkage system of the four distinct parties works well for the Canadian nuclear industry, and it should work well for this country too. It is thus the author's strong belief that the Institute for Nuclear Power Reactors is not only necessary for now but it will play an even more vital role in the future after all the nuclear power stations are put in service in this country.

4. Recommended Roles for the Institute

The mandate and primary functions of the Institute should be to provide necessary technical support to its fuel fabrication plant and to the future power stations. The Institute is in a unique situation to provide such services. An obvious example is that it has the necessary personnel and facilitiers, e.g. Hot Cell, to deal with the problems associated with irradiated fuels. This kind of problems arise either for the performance evaluation of new fuels produced by the fuel fabrication plant, or for post-irradiation inspections of spent fuels from power plants. Thus, the Institute is expected to develop multifacet technologies and provide a variety of services to its "customers".

A major role which the author believes the Institute can play at the present time and also in the near future is "to ensure the COMPATIBILITY of Romania-made fuels with the Canada-made CANDU reactors". Such compatibility is of vital importance for: (1) the safe and reliable operations of CANDU reactors, and (2) to comply with the terms of performance guarantee of the CANDU reactors as established by the supplier (AECL).

The importance of the issue of compatibility could be illustrated by a simple fact that an engine that is designed to burn gasoline can function properly only with gosoline fuel, but not Diesel or other fuels.

The work for achieving compatibility of Romanian fuel with CANDU reactors should include both the new fuels produced under a Canadian license, and also the fuels already produced in the past. In the latter category of fuels, effort will be focused in the "worthiness" evaluation process.

Major tasks involve in the "Compatibility" activities can be outlined as follows:

(1) Design activities:
Development of improved design methodologies for fuel elements and bundles, design for experimentations and evaluations, etc.;

(2) Evaluation activities:
Development of evaluation techniques and criteria, etc.;

(3) Testing activities:
Development of test facilities for performance evaluation, testing procedures and interpretation of results;

(4) Inspections:
Effective methods and procedures for inspecting new and spent fuels in materials, welding, geometries, tolerances, etc.;

(5) Quality assurance:
Effective methods and procedures for quality assurance in fuel production.

All the above activities should have a goal to satisfy the specifications and standards established by the AECL. A closer liaison and open communication with AECL officials are thus necessary.

Close interactions and collaborations must be maintained between the Institute, the fuel fabrication plant and the Electricity Board at all times.

Fuel modeling involving reliable computer-assisted analysis and simulation can handle many of these tasks as listed above. Development of micro computer based fuel modeling codes should be encouraged, as such approach can save millions of dollars which would otherwise be spent in conducting experiments and derivation of empirical relations.

Being the only resource organization for the Romanian nuclear power industry, the Institute should initiate the following related research issues without much delay:

(1) Treatment and storage management of spent fuels;
(2) Transportation of spent fuels and other radioactive materials;
(3) Development of extended burnup fuels for CANDU reactors.

The first two research topics appear to be far-fetching at the prsent time. However, in view of the eventuality of spent fuels from the power stations, and by judging the geological situation, as well as the road conditions of this country, unique solutions to the safe handling of spent fuels must be initiated now. The last research topic on extended burnup fuels is identified for the benefit of maximising the usage of fuels - a feature that is highly desirable for this country.

5. Summary

The country needs nuclear power for its independence of energy supply. The decision on adopting CANDU reactors using Romania-made fuels is a sensible one. Compatibility between the Romania-made fuels and the Canada-made reactors has thus become a crucial factor for the success of such arrangement. The Institute for Nuclear Power Reactors in Pitesti, Romania has the necessary personnel and facilities to fulfill this objective. Every possible effort should be made to ensure the success of this mission.

Appendix VI

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