A REPORT ON THE STATUS AND FUNCTIONS OF THE TSING-HUA OPEN-POOL REACTOR

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ABSTRACT

This is a report on the various functions and applications of the Tsing Hua Open-pool Reactor which has been in use in Taiwan since 1961. The report is divided into three sections discussing the three main functions of the reactor:

(1) education and training purposes,

(2) research and development,

(3) practical applications, especially radioisotope production and irradiation services.

Details are given under each of these headings and a list of thesis work based on use of the reactor is given in an appendix.

At the National Tsing Hua University in Taiwan, for the past ten years we have been utilizing the nuclear reactor bothfor educational and practical purposes. The Tsing Hua Open-pool Reactor (THOR) reached its initial criticality in April 1961. Its first core used 20% enriched uranium, and the present core enrichment is 90%. Since its initial operation THOR has been used for training and education, research and development, radioisotope production and irradiation services. A brief account of these three functions is given below:

(I) Education and Training:

The Institute of Nuclear Science at the National Tsing Hua University was established in 1956. It began by offering M.S. courses in Nuclear Physics, Nuclear Chemistry and Nuclear Engineering. THOR has been used extensively after its completion for their laboratory work and research for theses in connection with these courses. As the faculty grew larger, the burden of teaching courses was transfered to newly established branches of the Tsing Hua University and the Institute was able to concentrate on more special programs. The new branches of the university were the Institute of Physics, the Institute of Chemistry and the Institute of Nuclear Engineering. They were established in 1966, 1968 and 1970 respectively. In addition, the undergraduate Department of Nuclear Engineering was established in 1964. Reactor Laboratory is a required course both for senior students majoring in nuclear engineering and for graduate students who did not specialize in nuclear engineering as undergraduates. As prerequisites for this course in Reactor Laboratory, students must pass courses in principles of Nuclear Engineering and Reactor Physics. The course itself consists of the following:

1) Reactor operation and control,
2) Reactor Engineering and Technology,
3) Reactor Physics,
4) Neutron Moderation and Diffusion, and
5) Neutron Physics.

There are twenty experiments included within these categories, however only twelve of them are offered to all students. The rest are only carried out as special projects (for details see Appendix A).

The Institute of Nuclear Science continued to offer training courses of special kinds to other branches of the university responsible for the formal academic program. These were in fields not covered by the academic courses of the university and were designed to meet various practical needs. To give you an idea about what sort of courses there were I have listed some of them.

1.) Health Physics Training Course, 2.) Radio-isotope Basic Technique Course, 3.) Radiation Instrument Maintenance Training Course, 4.) College Students Summer Seminar on Atomic Energy and 5.) Nuclear Power Technology Training Course. All these training courses need a reactor for the experiments. The Nuclear Power Technology Training course is especially worth mentioning. Its contents include: Elementary Reactor Physics, Energy Removal in Reactor, Reactor Kinetics, Reactor Control and Instrumentation, Reactor fuel, Reactor Safety and Reactor Laboratory besides Nuclear science fundamentals, applied mathematics and electronics, (for details see appendix B). The duration of the course is six months, however, each session varies according to its special requirement.

Number of Students Trained at THOR

	Number of classes or Sessions	Number of Students or Trainees
Nuclear Engineering Undergraduate Students	4	152
Nuclear Engineering Graduate Students	11	174
Radiation Instrument Basic Technique Training Course	14	144
Radiation Instrument Maintenance Training Course	3	67
Nuclear Power Technology Training Course	5	139
College Students Summer Seminar on Atomic Energy	5	260
Health Physics Training Course	2	58

II. Research and Development

Besides using the reactor in the ordinary course work for the training of our students, we have also applied it to experiments and programs aimed at research and development. From the beginning we had two aims in mind for the reactor. The first was the general upgrading of our science education. This included the use of the reactor for the training of students in the ways I have just discussed and also included use for research and development which will be the next topic.

Following are some of the activities which have been or are carried out at THOR:

1.) Reactor Operation and Control

- a. Feasibility study using the N^{16} power meter as a power control channel.
- b. A quick and precise technique to determine control rod worth.
- c. Reactor loading effect.
- d. Transfer-function study.
- e. Optimal control for a nuclear reactor in a distributed parameter model.

2.) Fuel Management

a. Neutron flux measurement and fuel burn up calculation.

b. Spent fuel burn-up study.

(i) by measuring the fission neutrons in the thermal column

(ii) by measuring delayed neutrons

(iii) by measuring the change of reactivity

(iv) by mass spectrometer

c. Spent fuel handling technique and transportation.

3.) In Pile Dosimetry

a. Neutron energy spectrum study using

(i) Activation detectors

(ii) Li^6 semi-conductor

(iii) He^3 spectrometer

(iv) Fission track detectors

b. Neutron Temperature Measurement Using

(i) Activation detectors

(ii) Danger coefficient method

(iii) Mass spectrometer

(iv) Fission track detectors

4.) Reactor Physics

a. Noise analysis

b. Rossi-Alpha Method

5.) Neutron Moderation, Diffusion and Absorption.

To measure the age, diffusion coefficient, diffusion length and absorption cross section on some special materials such as deuterium compound.

6.) Reactor Engineering and Technology

a. Heat Transfer Study

b. Neutron Irradiation Facilities Study

(i) Under water irradiation container design

(ii) Cooling system design for irradiation tube.

M.S. theses work carried out by graduate students since 1961 are listed in appendix C.

III. Radio-isotope Production and Irradiation Services:

Ever since its establishment one of the main functions of the Institute of Nuclear Science has been to act as a national laboratory in the field of nuclear science. In this capacity it has applied THOR to many practical uses mainly in the field of radioisotope production and irradiation Services.

Since 1962, one year after the completion of the reactor, the institute has been engaged in the production and supply of short-lived radio-isotopes to domestic users. At present the following nuclei are regularly produced and supplied locally: F-18, Na-24, Mg-28, P-132, S-35, K-42, CA-45, Cr-51, Fe-59, Cu-64, Zn-65, AS-76, Br-82, Rb-86, Tc-99, Mo-99, I-131, RISA, ROSE BENGAL, Hg-197, Au-198 (colloid), and Hg-203.

Neutron Irradiation is also an important service rendered by THOR. The Institute had always been busy answering requests from all over the country to utilize the THOR for irradiation purposes. They include seed irradiation for mutation purposes, rice boar and fruit fly for eradication study, solid state physics-material damage by irradiation. Neutron physics - capture gamma study, Hot atom chemistry - applied to isotope production, Engineering study - engine wear study, electrical wire characteristic change stude, In-pile dosimetry study.

Activation analysis is also a very important application of THOR. At present, the following tasks are being carried out through the use of THOR:

1.) Ancient bronze analysis - in cooperation with the National Palace Museum,
2.) Tunna fish mercury content analysis - in cooperation with the Food Processing Research Institute,
3.) Mercury content in rice to determine its origin - in cooperation with the Agriculture College, National Taiwan University,
4.) Analyzing Cu, Zn, Cr, As contents in human tissue - in cooperation with Naval Medical Research Unit No. 2
5.) Surface water and air pollution study - in cooperation with the Taiwan Institute of Environmental Sanitation
6.) Fissile mineral determination by using the delayed neutron countering method.

From the work described above it is quite clear that experiments utilizing the reactor are indispensible in our nuclear program. Because of the multi-function nature of THOR, its operation schedule is quite busy. The regular scheme is as follows:

Monday - student reactor laboratory,

Tuesday through Wednesday - continuous full power operation for radioisotope production, irradiation services and experiments requiring high power level.

Thursday and Friday - Research and theses work, the operation procedure is determined by experimenter's requirements.

Saturday - Preventive maintenance.

Sunday - Cooling period for low power reactor laboratory .

Four weeks are allocated for overhaul annually, usually two weeks each time during both summer and winter vacations. This operation schedule proved to be satisfactory. However, the present overloaded situation could be improved if some of the students reactor laboratory and training courses laboratory were shifted to use a sub-critical assembly. Reactor power upgrading is also under study. The main idea is to increase the available flux and machine time for research work to cope with future needs.

APPENDIX A

REACTOR LABORATORY

A. Reactor operation and control

1.#* Approach to critical experiment of THOR

2. Determination of the exact critical mass

3.#* Calibration of the regulating blade worth

4. * Negative reactivity measurement by the blade drop method

5.#* The Measurement of in-core neutron flux by the induced activity method and power level calibration

6. Measurement of the transfer function of THOR by means of a pile oscillator.

B. Reactor engineering and technology

7. * Measurement of the reactor importance function

8. * Measurement of the absorption cross section by the danger coefficient method.

C. Reactor physics

9. Uranium-235 delayed neutron parameters

10. * Fast fission factor.

D. Neutron moderation and diffusion

11. Measurement of neutron and gamma attenuations in water

12.# *Measurement of thermal neutron diffusion length in water

13.#* Age of Pu-Be neutron source

14. Measurement of the neutron temperature

15. * Removal cross section and fast neutron shielding.

E. Neutron physics

16. * Total neutron cross section by the transmission method

17.#* Resonance absorption integral

18. Threshold detectors for fast neutrons

19. Neutron time-of-flight spectrometry

20. Neutron diffraction.

APPENDIX B

NUCLEAR POWER TECHNOLOGY TRAINING COURSE

1.	Introductory atomic and nuclear physics	(30 hrs.)
2.	Introduction of radiation with matter	(20 hrs.)
3.	Reactor chemistry	(30 hrs.)
4.	Physics of nuclear detectors	(15 hrs.)
5.	Basic nuclear electronics	(20 hrs.)
6.	Introductory reactor physics	(40 hrs.)
7.	Thermal aspects of reactors	(30 hrs.)
8.	Reactor heat transfer	(20 hrs.)
9.	Reactor kinetics	(40 hrs.)
10.	Reactor control and control instrumentation	(30 hrs.)
11.	Radiation protection and monitoring	(30 hrs.)
12.	Reactor shielding	(20 hrs.)
13.	Reactor safety	(30 hrs.)

\# 6 experiments for nuclear power technology training course.

* 12 experiments offered to all students.

14. Applied mathematics (60 hrs.)

15. Digital computer (30 hrs.)

16. English (100 hrs.)

17. Electronics laboratory *

18. Radiation measurement laboratory **

19. Chemistry laboratory

20. Health physics laboratory ***

21. Reactor laboratory

22. Reactor operation (18 hrs.)

Electronics laboratory *

(1) Oscilloscope operation

(2) Transistor and diode characteristics

(3) Pulse amplifiers

(4) Power supplies

(5) Regulators

(6) Pulse shaping

(7) Rate Meters

(8) Scaler

(9) Discriminators

(10) Coincidence and Anticoincidence circuits.

RADIATION MEASUREMENT LABORATORY **

(1) Characteristics of a G-M counter.

(2) Gas-flow proportional counter.

(3) Beta range determination.

(4) Neutron detection by a long counter.

(5) Gamma-ray spectrum and calibration of a multichannel analyzer.

(6) Single channel analyzer gamma-ray spectrometer.

(7) Absorption of gamma-rays.

(8) Characteristics of scintillation counters.

(9) Semiconductor detectors.

(10) +Neutron flux mapping by foil and wire activation.

(11) +Absolute counting by 2π proportional, G-M, and scintillation counters.

(12) Positron anihilation by 2 scintillation detectors.

(13) +Beta-thickness gauge.

(14) Delayed neutron measurement.

(15) Time to pulse-heigh converter measurement.

Those with + take two afternoons, the rest take one afternoon for each experiment.

HEALTH PHYSICS EXPERIMENTS ***

(1) Environment monitoring for a reactor facility.

(2) Radiation survey and detection for a reactor facility.

(3) Calibration and application of survey meters.

(4) Reading of Tsing Hua film badge.

(5) Urinalysis.

(6) Gamma-ray attenuation experiment.

(7) Fast neutron dose evaluation.

The number of students for each experiment is limited to six.

APPENDIX C

M. S. THESES BY GRADUATE STUDENTS

1961 Class:

1.	Determination of Dysprosium and Samarlium in Rare Earth Minerals by Activation Analysis	Yu-Wen Yu Pei-Hsin Yu
2.	Calorimetric Dosimetry of Gamma Radiation by Thermistors	Hsing-Chi Yu
3.	A Study of thermal Aspect of Tsing Hua Nuclear Reactor	Chang-Ping Wang
4.	Measurements of Neutron Spectra by Threshold Detectors	Chi-Chung Wang Sheh-Chun Chou
5.	Angular Distribution of Fission Fragments from U-238 with Neutrons of Moderate Energy	Shau-Jin Chang Yuan-Li Wang
6.	Ellipsoidal Reactor Analysis	Tien-Chen Liu Chung-Ching Liu

1962 Class:

7.	Measurements of Neutron Spectra of Tsing Hua 1 MW Open-pool Type Research Reactor	Ching Lu-Shiu Hua-Ching Tong
8.	Investigation of Neutron Inelastic Scattering	Ko Ton
9.	Szilard-Chalmers Reactions on Copper Compounds	Yin Moon-Lung Chow-Kin-Lian

10.	Absolute Determination of Neutron Source Strength and the Measurement of the Space Distribution of Thermal-Neutron Flux	Weng Pao-Shan
11.	A Study of Tsing Hua Reactor Operation Characteristics	Lu Yang-Shen
12.	A Study of fuel Element Geometry	Chen-Hu-Hsiu Liu-Yang-Kan
13.	Study of Natural Convection between Parallel Plates for Steady Uniform Wall Heat Flux	Hsu Kuan-Ling Chen-Ka-Wei
14.	Measurement of Transfer Function of the Tsing Hua Reactor	Yang Chio-Min

1963 Class:

15.	Experimental Studies of Energy Responses of a Boron-compound Neutron Scintillator	Che-Wen Mao
16.	Measuring of the Effect of Void on the Thermal Diffusion Length	Hsing-Shou Cheng
17.	Calculation of the Thermal Flux and Importance Function of the Tsing Hua Reactor	Chian-Yeh Ho
18.	Determination of the Tsing Hua Reactor Neutron Temperature	Su-Tien Hsu
19.	Investigation of Neutron Inelastic Scattering	Ma Ta-Tao

1964 Class:

20.	Neutron Inelastic Scattering up to 10 Mev by the Ellipsoidal Rotator	Chhi-Chong Wu
21.	Fast Neutron Spectrometer	Hsin-Yü Wang
22.	The Measurement of the Energy Spectrum of Neutron Beam from the Reactor Beam Port	Chin-Kuei Wen
23.	The measurement of Neutron Temperature in Tsing Hua Reactor Core and the Study of Its Deviation due to Neutron Leakage	Jium-Kuen Koo
24.	A Study of Resonance Escape Probability in Various System	Chei-Chung Ho
25.	A General Investigation of Nuclear Properties of Fuel-moderator Mixture	Kueng Yeh
26.	A Study of Natural Convection in Thin Channel with known Heat Flux Input	Nai-Chen Ho

1965 Class:

27.	Thermal Neutron Absorption Cross Sections by Modified Two Group Danger Coefficient Method	Chi-Kang Cheng
28.	Determination of Tsing Hua Nuclear Reactor Transfer Function and Transient Analysis by Analog Computer	Yeh-Chin Ko

29.	Study of Thermal Neutron Energy Spectrum in the Reactor Core	Kuo-Hung Chang
30.	The Analysis of Gamma Rays Spectra	Sy-Ming Shy
31.	Flux Monitoring Fuel Element	Tsu-Chung Wu

1966 Class:

32.	Gamma Ray Penetration Through & Backscattering from Concrete Slabs	K. C. Wu
33.	Convective Heat Transfer in Parallel Plate Channel with Sinusoidal Heat Flux Distribution	Shing-Tai Chen
34.	Shielding Design for a 300 Mw Thermal Pressurized Water Reactor	Cheng-Min Tseng
35.	A Study of γ -Ray Dosimetry by Polarographic Method	Sung-Tsuen Liu

1967 Class:

36.	The Effects of Fast Neutron Irradiation on Transistors	Yung-Chau Yen
37.	Studies of Reactor Transients Using an Electronic Simulator	Lung-Rui Huang
38.	Measurement of Thermal Neutron Spectrum by Using a Slow Neutron Chopper	Wei-Hsiang Teng
39.	The Effects of Gamma Radiation on Transistors	J. B. Shao

1968 Class:

40.	Chemical Behavior of Iron-59 Recoil Atoms	Yih-Hsiung Chen
41.	Chemical Behavior of Chromium -51 Recoil Atoms	Ting Gann

1969 Class:

42.	Feasibility Study of Fuel Burn-up Measurement in the THOR Thermal Column	Hwei-Yen Yang
43.	Optimal Control for a Nuclear Reactor in Distributed Parameter Model	Baw-Lin Liu

1970 Class:

44.	Effects of Irradiation Damage by Gamma-rays in Silicon Surface-barrier Detector	Shin-Shyong Wu
45.	The Measurements of THOR Fast Neutron Spectrum at E-1 Beamport by Li^6 Semi-conductor Spectrometer	Chen-Shyong Yeh
46.	The Feasibility Study of Fast Neutron Conversion	Si-Jzei Yang

47.	Reactor Noise Analysis	Tzun-Ren Chang
48.	A Study of the Intermediate Neutron Energy Spectrum	Ming-Huei Lee
49.	Measurements of Thermal and Fast Neutron Fluxes in Reactor with Nuclear Track Detector	Tzer-Fu Huang
50.	Determination of Fuel Burn-up by Using Flux Variation Method	Hsien-Mo Lee
51.	A Statistical Feature of Nuclear Reactor Transfer Function	Kuo-Ting Tao
52.	Fuel Burn-up Measurement by Perturbation Theory	Ta-Ming Lai

1971 Class:

53.	Neutron Activation Analysis on Some Chinese Antique Pieces	Hai-Yung Huang
54.	The Effects of Gamma-rays on the Function Field Effect Transistors	Jen-Shien Chung
55.	Rassi- α Experiment	Yang-Ho Sun
56.	Investigation of Thermal Neutron Energy Spectrum of THOR	Hung-Jen Yang