資 料

The Development of Nuclear Codes in Japan, (I)

By Tasaburo YAMADA* and Toshio AOKI**

The application of the digital computer in nuclear engineering has been increasing rapidly, and many scientists and engineers are engaged in this field. In order to co-ordinate their activities, the Japan Nuclear Codes Group (JNCG) and the Shielding Codes Group (SCG) were organized in the middle of 1959. The following paper describing the historical and present status was prepared by these groups and presented at Seminar on Codes for Reactor Computation at Vienna, Austria (April 25~29, 1960), sponsored by International Atomic Energy Agency (IAEA).

For the editorial convenience, the Lists of the Registered Codes will be presented in the next number of this Journal

The editorial staffs of this compilation were:

K. Arai	(HITACHI)	K. Ono	(CRIEPI)
Y. Arai	(JAPCO)	M. Takada	(TOKYO UNIV.)
M. Hachiya	(MITSUI)	T. Takeshita	(IBMJ)
T. Kawai	(HITACHI)	S. Terasawa	(HITACHI)
T. Morita	(ETL)	M. Tokizawa	(NAIG)
T. Nakayama	(JAERI)	A. Tsuruo	(KAJIMA)

I. INTRODUCTORY PERIOD OF COMPUTER APPLICATION TO NUCLEAR ENGINEERING

The peaceful uses of atomic energy in Japan were started in 1954, when the related committees were organized in the Government. After the first Geneva Conference, this trend became more remarkable.

At that time, the automatic digital computer, which is now considered a very important tool for the research of nuclear energy, was not ready for practical uses. Although scientists and engineers were devoting great efforts for developing computers, only small pilot models were completed. Furthermore, until that time foreign medium-scale computers had not been imported. Under these circumstances, only a few people understood the significance of the digital computer in the field of nuclear engineering.

The first application of digital computer

was made in 1955, "15-Group Critical Calculation of a Reflected Water Boiler Reactor" (HITACHI)** using IBM-602A. In 1956 the ETL-Mark II, the first domestic relay type computer for scientific purposes in Japan, was used in "10-Group Critical Calculation of Fast Reactor" (ETL). After a while, a computing center of FACOM-128, which is a modified and commercial model of ETL-Mark II, was opened, and made much contribution to the reactor calculation.

A small punched card machine (CPC) was also used for the "Critical Calculation of Homogeneous Heavy Water Reactor" (TOSHIBA). Realizing the limitation of small scale machines and analytical approaches, people began to recognize the necessity of

* 山田太三郎 Chairman JNCG:Electro-Technical Lab. (電気試験所)

** 青木敏男 Chairman SCG:Japan Atomic Energy Res. Inst. (日本原子力研究所)

** cf. List of abbreviation of establishments (p. 347)

numerical treatment of the problems by large and high speed computers.

Thus, the installation of high speed computers and the training of the programming engineers gained ground and much attention were paid to them. However, our scientists were continuing to carry out many works with considerable success by relay computers, in spite of their being small and slow. An IBM-602A was also used in design works of JRR-3 (Japan Research Reactor No.3—Japan-made Reactor No.1).

On the other hand, the computer project made much progress. The machines completed in this period were ETL-Mark IV (the first transistor type computer) at Electrotechnical Laboratory, PC-1 at Tokyo University and HIPAC-I at Hitachi Ltd. (the machines with parametron computing components which were developed in Japan a few years ago). Being stimulated by these achievements, several manufacturing companies entered into the production stage of digital computers. Its results appeared in 1958 as the completion of several domestic medium scale computers. A number of data processing systems for business uses were also imported.

At that time, Japan was considering the import of a British-type power reactor. In order to estimate the economical feasibility of that reactor, the relay-type automatic computer (ETL-Mark II)* was used for burn-up calculation, the result of which was presented in the 2nd Geneva Conference (P/1339). "Four-Group Two Dimensional Critical Calculation of Water Moderated Reactor of Cylindrical Geometry" (NAIG) was also performed by the same computer. This is the predominant research in the critical calculation in this period and attracted much attention of reactor physicists.

Following these studies, the "MERCURY-0 Code" (HITACHI ; FACOM-128) for the parametric study of the reactor core and

"SPECTRUM-Series Codes" (HITACHI ; FACOM-128) were developed, and they were much used for the reactor design study, especially, for the analysis of positive temperature coefficient on the British-type reactor. "BWR Preliminary Calculation" (NAIG ; UNIVAC-120) was made by a small punched card machine in the early of 1958.

II. DEVELOPMENT PERIOD

In the middle of 1958, we entered into the second stage of computer applications to the nuclear field. IBM-650s were installed at JAERI and MAPI, a Bendix-G15D at MELCO and a USSC at TOSHIBA. The IBM computing center was also opened with an IBM-650 and its full auxiliary equipments.

Some domestic computers were also made available for practical uses. The typical computers used for reactor calculation, are ETL-Mark IV (transistor) at Electrotechnical Laboratory, HIPAC-101 (parametron) at HITACHI, Ltd. and JEIDACs at JEIDA. The computing center (JEIDA) of the domestic machines was opened with the help of the Japanese Government, where the training projects of programmers were started.

In March 1959, the Meteorological Agency of the Japanese Government installed an IBM-704 (8K-8K) for weather forecast. It is the only large scale computer in Japan.

The relay computers, which made much contribution in the early period, are still playing a supplementary role. With the increase of availability of computers, the branches to which computers are applied, have correspondingly increased — the problems of group diffusion, burn-up, Xe-oscillation, reactor kinetics, physics, Monte Carlo, transport theory, fusion, reactor safety, shielding and so on. The number of scientists associated with computers has also been increasing rapidly.

In the course of nuclear code develop-

* The first word in parentheses is the name of the organization and the second is that of the computer.

ment, emphasis has been placed on the problems of group diffusion, burn-up and boiling water reactors. At JAERI, the extensive applications of computers have been considered in connection with the problem of a semi-homogeneous reactor project.

A few typical codes of each category will be described in the following sections:

1. Group diffusion

"Two-Group Two Region Code" (JAERI; IBM-650) is the first registered code in the IBM Library. It deals with the analytical solution of spherical reactors, and is used for preliminary survey calculation. "SUNRISE-2B" (HITACHI; HIPAC-1) is a two-dimension, two-group, critical calculation code, for boiling water reactors. In this code, backward method and Peaceman-Rachford acceleration method were first employed in Japan; their usefulness greatly impressed our nuclear physicists. Several codes of the similar kind have been developed at various organizations. "CUBE" (NAIG-IBM-650) is a code for three-dimensional critical calculation by synthesizing the one-dimensional analytical solution. This code is applied for the survey study of a small-size reactor. "ZEUS-1" (HITACHI; IBM-650) is a code which deals with two-dimension, few-group, multi-region diffusion equation for BWR, for which a medium scale computer is utilized to the limit of its capability.

2. Burn-up

In 1958, the extensive research was made for the purpose of studying the economical feasibility of power reactors and of planning a long-term power reactor development schedule. "Fuel Cycle" (CRIEPI; FACOM-128) was designed to clarify the possibility of plutonium recycling. The significance of digital computers in reactor physics was again proved by this calculation. "MARS Series" (HITACHI; IBM-650) is a one-dimension, burn-up code for BWR. It has

been extensively applied for the burn-up problems. One of its characteristics is the flexibility to handle intricate radial shuffling.

3. Kinetics

"VULCAN Series" (HITACHI; IBM-650) is for IBM-650 and deals with the transient phenomena of a water moderated reactor, especially with temperature distribution in fuel rods, heat flux through fuel surfaces and delayed neutron density during power transient. This is considered to be useful for the kinetics and safety analysis of power reactors. "Dynamic and Safety Calculation of British-Type Reactor" (JAPCO; FACOM-128, NEAC-2203) was designed to solve the problem associated with the operation of the reactor, such as start-up, accidents, Xe spatial oscillation and so on.

"DIANA" (HITACHI; HIPAC-101) deals with the transient hydrodynamic equation of two phase flow and void reactivity response in BWR. Elaborate efforts were made for the treatment of transient behavior and the solution of hyperbolic-type partial differential equations.

4. Physics

"Calculation of Thermal Neutron Spectrum" (MAPI; IBM-650) gives the thermal group constants by calculating the Wigner-Wilkins spectrum. Several similar works are now being planned by various organizations. "SONNE" (NAIG; USSC) calculates the inelastic scattering cross section and the directional distribution of elastically scattered neutron by using the optical model. This code has come out as a result of deep interest of our scientists in this theme.

Two codes have been developed for BWR design, which include the calculation of void dependent nuclear constants. One of them, "MERCURY Series" (HITACHI; IBM-650), is a code for criticality calculation, and the other, "HERMES Series" (HITACHI; IBM-650) obtains three-group constants. They

supply nuclear constants for the following calculations.

The codes related to experimental results have not been developed yet, because of the delay of reactor experiment projects.

5. Transport

" S_n Code" (JAERI; IBM-650) has been developed for IBM-650. It is noted that a medium scale machine is used for S_n solution.

6. Monte Carlo

Some of our scientists are interested in Monte Carlo method. "PACIFIC Series" (KAJIMA, ISM; FACOM-128) is the first Monte Carlo code programmed in Japan and treats the scattering of gamma-ray in various shaped media by the collision density method. More refined approaches are in progress for the leakage calculation in complicated geometry. "FUSION-1" (HITACHI; HIPAC-101) gives the history of ions trapped in a mirror type magnetic bottle. It is an application of ion cyclotron resonance for fusion projects.

Applications of Monte Carlo method to various branches of nuclear physics are being considered.

7. Shielding

The major works in this category are "Shadow Shield Calculation at Reactor Accident" (TEPCO; NEAC-2203) and "Calculation of Radioactivity in Coolant" (MAPI; Bendix-G15D). The Shielding Codes Group (SCG) has many projects in this branch.

Summarizing the above, the development after the middle of 1959 is outstanding. Remarkable is the fact that great efforts have been made to solve large problems by small and medium-scale computers. As an inevitable result, many of the above-mentioned codes have less generality.

As a whole, the limitation of medium scale computers has been widely recognized among the nuclear scientists. To meet this

situation, several organizations are considering the installation of large scale digital computers. Many a scientist has started programming for the IBM-704. Among these projects is "Burn-up Calculation Code for BWR" (ETL; IBM-704) by two-dimension treatment, which is approaching completion.

III. ORGANIZATIONS OF RESEARCHERS

Due to the rapid advancement of nuclear code works and the increase of the programming engineers in 1959, the following groups have been organized to coordinate their activities:

The Japan Nuclear Codes Group (JNCG)

The Shielding Codes Group (SCG)

The purpose of the JNCG includes the discussion of new ideas, the exchange of information, the registration of new codes and the study of foreign codes. The group consists of the some fifty scientists and engineers who represent nearly twenty organizations. About sixty computer programs have been so far registered, the list of which will be presented in Part (II).

The group covers almost all programming engineers in nuclear field and is playing an important role in Japan. In the years to come, we attempt to ensure the availability of large scale computers and to develop nuclear codes for them.

Thirty scientists belong to the SCG. Japanese people are much concerned about the radiation hazard due to their historical background. To build nuclear facilities, the precise estimation of radiation and safety is greatly required. We also should solve the problem of minimizing the weight of shielding material for nuclear propulsion ships.

This group is making joint efforts for the development and use of the general codes for these problems. The whole projects of the group are shown in Appendix C.

List of abbreviation of establishments

CRIEPI	Central Research Institute of Electric Power Industry	IBMJ	IBM Japan, Ltd.
ECL	Electrical Communication Laboratory	KAJIMA	Kajima Construction Co., Ltd.
ETL	Electrotechnical Laboratory	MAPI	Mitsubishi Atomic Power Industries Inc.
FUJI	Fuji Electric Manufacturing Co., Ltd.	MELCO	Mitsubishi Electric Manufacturing Co., Ltd.
FUJICM	Fuji Communication Apparatus Manufacturing Co., Ltd.	MITSUI	Mitsui Shipbuilding and Engineering Co., Ltd.
HITACHI	Hitachi, Ltd.	NAIG	Nippon Atomic Industry Group Co., Ltd.
HOKUSHIN	Hokushin Electric Works, Ltd.	NEC	Nippon Electric Co., Ltd.
ISM	Institute of Statistical Mathematics	OKI	Oki Electric Industry Co., Ltd.
JAERI	Japan Atomic Energy Research Institute	TEPCO	Tokyo Electric Power Co., Ltd.
JAPCO	Japan Atomic Power Co., Ltd.	TOSHIBA	Tokyo Shibaura Electric Co., Ltd.
JEIDA	Japan Electronic Industry Development Association		

〔Appendix A〕 History of Nuclear Code Developments in Japan

1952		(Completion of ETL-Mark I (ETL), the first digital automatic computer in Japan)	
1955		(Completion of ETL-Mark II (ETL)) (Completion of FACOM-100 (FUJI); Opening of the first computing center (FUJI Computing Center) in Japan) Multi-group Critical Calculation (HITACHI ; IBM-602A)	
1956		(Completion of FACOM-128 (FUJI)) Critical calculation of fast reactor (ETL; ETL-Mark II) Critical calculation of homogeneous heavy water moderated reactor (TOSHIBA;CPC)	
1957		Burn-up calculation of graphite moderated reactor (ETL; ETL-Mark II) B-1 Design Calculations of JRR-3 (JAERI; IBM-602A) Critical calculation of water reflected cylindrical reactor (ETL; TOSHIBA; ETL-Mark II) (Completion of HIPAC-I (HITACHI))	
1958	Apr.	MERCURY-0; Infinite multiplication factor (HITACHI; FACOM-128)	P-1
	Jun.	One-dimensional critical calculation of BWR (NAIG; UNIVAC-120)	
	Aug.	JUPITER-1; Criticality (HITACHI; HIPAC-1) G1-2 Two-group two-region code; Criticality (JAERI; IBM-650)	
	Sep.	(Opening of IBM Computing center (IBM-650)) (Installation of IBM-650 (JAERI)) (Installation of Bendix G1D (MELCO)) Calculation of fuel cycle (CRIEPI; FACOM-128) Calculation of control rod effect (MELCO; Bendix G15D)	
	Dec.	SUNRISE-2B; Two-dimensional critical calculation of BWR (HITACHI; HIPAC-1) G2-1	
1959	Jun.	Completion of PACIFIC-series; Monte Carlo calculation of gamma-ray scattering (KAJIMA, IMS; FACOM-128) S-2, 3, 4, 5	
	Feb.	Design calculation of fast reactor by PROD-II (CRIEPI; IBM-650) IBM Library	
	Mar.	Calculation of temperature coefficient (MAPI; Bendix G15D) (Installation of IBM-704 (The Meteorological Agency))	
	Apr.	Calculation of Xe-oscillation of British-type power reactor (JAPCO; FACOM-128)	
	May	(Series of calculations on a semi-homogeneous reactor (JAERI; IBM-650))	
	Jun.	(Opening of Bendix Computing Center (Bendix G15D)) (Opening of JEIDA Computing Center (NEAC-2203, HITAC-301 etc.))	

		Research calculation of coupled reactor by DMM (CRIEPI; IBM-650) IBM Library	
Jul.		VULCAN-1; Kinetics (HITACHI; IBM-650)	K-2
Aug.		Burn-up calculation series (ETL; ETL-Mark II)	
Sep.		(Installation of IBM-650 (MAPI))	
		MARS-I, II; Burn-up (HITACHI; IBM-650)	
		CUBE; Three dimensional critical calculation (NAIG; IBM-650)	G1-9
		FUSION-I; Monte Carlo calculation on thermonuclear research (HITACHI; HIPAC-101)	M-2
		DIANA; Calculation of hydrodynamic problem (HITACHI; HIPAC-101)	K-5
Oct.		Application of computer to meteorological observation's data (JAERI; IBM-650)	
		Spectrum calculation of BWR (NAIG; IBM-650)	
		Calculation of dynamic and safety characteristics of British-type reactor (JAPCO; NEAC-2203, FACOM-128)	K-3
Nov.		Calculation of neutron flux distribution by P_3 Approximation (FUJI; FACOM-128)	B-6
		VESTA; Two-dimensional burn-up calculation (HITACHI; IBM-650)	
		Evaluation of power cost generated from nuclear power station (TEPCO; NEAC-2203)	
1960.	Jan.	Calculation of fast neutron spectrum and energy-group constants (MAPI; IBM-650)	
		SPACE ANALYZER; Two-dimensional critical calculation (NAIG; IBM-704)	G2-5
		Theoretical neutron inelastic scattering cross section of ^{238}U (NAIG; USSC)	
		Two-dimensional burn-up calculation (ETL; IBM-704)	B-8
		ZEUS-I; Two-dimensional critical calculation (HITACHI; IBM-650)	G2-2
		Cell calculation of HTR by P_3 (HITACHI; IBM-650)	IBM Library
Feb.		Shadow shield calculation at reactor accident (TEPCO; NEAC-2203)	
		Calculation of thermal neutron spectrum and thermal-group constants (MAPI; IBM-650)	
		IBM-704 coding of MARS-I, II, HERMES-I, ZEUS-II (HITACHI; IBM-704)	
		S_n -Code; Solution of transport equation by S_n -method (JAERI; IBM-650)	T-3

[Note : The right-most column shows the corresponding code number which appears in Part (II)]

Appendix B. Brief Survey of Digital Computers in Japan

The demand for the digital computer in this country has greatly increased with the progress of industry in the last few years. After the several years of fundamental research, domestic computers entered into the stage of commercial production. The Table B-I shows the characteristics of the domestic computers which are used for scientific purposes, including the nuclear reactor design calculation and the other related problems.

Since the capacity of these computers is not sufficient for the large scale problems which are often encountered in reactor calculation, several foreign machines have been imported, the list of which is shown in Table B-II. (The computers for scientific purposes only are described here.)

Table B-II List of non-domestic machines installed in Japan

	In use	On order
Bendix G15D	3	—
LGP 30	2	—
DATATRON 205	1	2
IBM 650	10	5
704	1	—
705	—	1
7070	—	6
UNIVAC II	—	1
UFC	3	4
USSC (UCT)	3	9

Table B-1 Characteristics of the domestic digital computers (1)

Name	ETL-Mark. II	ETL-Mark. III	ETL-Mark. IVA	ETL-Mark. V	M-1	TAC
Manufacturer Date	ETL 1955	ETL 1957	ETL April, 1959	ETL (late 1960)	ECL 1957	Tokyo Univ. Feb. 1959
Major elements	Relay	Transistor Ge-diode	Transistor Ge-diode	Transistor Ge-diode	Parametron	Tube Ge-diode
Mode of operation	Asynchro.	Serial decimal fixed pt. 180kc	Serial decimal fixed pt. 220kc	Serial decimal fixed pt. 230kc	Parallel binary fixed pt. 6-30 kc	Binary fixed, floating 330 kc
Clock frequency						
Word size		5 digits + sign	7 digits + sign	11 digits + sign	39 bits + sign	35 bits or 10 digits
Instructions	1 address external	1 address 29 operations	1.1/2 address 70 operations 2 index registers	1.1/2 address 130 operations 3 index registers	1 address 130 operations	1 address 38 operations 1 index register
Memory	Relay 200 wds. Constant 180 wds.	Mag. drum 1000 wds. 1.67 ms access time	Mag. core 1000 wds. 0.08 ms acces time Mag. drum 1000 wds. 2 ms access time	Mag. drum 4000 wds. (200 wds. quick ac- cess memories)	Mag. core 256 wds.	CRT 17920 bits 0.003 ms access time
Operating speeds	add. sub. 0.2 sec mult. 0.14-1.1 sec div. 0.16-1.4 sec	3.4 ms 4.5 ms 6.4 ms	0.2 ms 2.9 ms 2.9 ms	2.1 ms 7.7 ms 8.0 ms	5 ms 22 ms 87 ms	0.48 ms 5.04 ms 9.84 ms
Input/Output	60 channel tape read punch 400 wds./min Line printer 150 lines/min	PTR 200ch./sec Tape punch 30 ch/sec Typewriter	PTR 200ch./sec Tape punch 30 ch./sec 2 units Typewriter	PTR 200ch./sec 2 units Type punch 30 ch./sec Typewriter 10 ch./sec	PTR 200ch./sec Tape punch 12 ch./sec Typewriter	Tape reader 8 ch./sec Typewriter
External memory						
Remarks						

Table B-1 Characteristics of the domestic digital computers (2)

Name	PC-1	SENAC	NEAC-2201	NEAC-2203	FACOM-128B	PC-2 (FACOM-202)
Manufacturer	Tokyo Univ.	NEC	NEC	NEC	FUJICM	FUJICM
Date	1958	1958	1958	1959	1958	(June 1960)
Major elements	Parametron	Parametron	Transistor Diode	Transistor Diode	Relay	Parametron
Mode of operation	Parallel	Parallel binary	Serial decimal	Serial decimal	Decimal floating	Parallel binary
Clock frequency	binary fixed pt.	fixed, floating	fixed pt. 200kc	floating	Asynchro.	fixed, floating
Word size	35 bits+sign	48 bits (incl. 8 bits exp.)	9 digits+sign	11 digits+sign	8 digits+sign+exp. (up to 19)	48 bits (36+exp. 12)
Instructions	1 address 44 operations	1 address 128 operations 7 index registers	1.1/2 address 63 operations 2 index registers	1.1/2 address 87 operations 3 index registers	3 address external	1 address 200 operations 7 index registers
Memory	Mag. core 256 wds.	Mag. drum 1024 wds. 1.5 ms access time	Mag. drum 1000 wds. (40 wds. quick access) 2.5 (quick 0.5) ms access time	Mag. drum 2000 wds. (40 wds. quick access) 3 ms access time	Cross bar 180 wds. Constants 80 wds.	Mag. core Up to 4096 wds. 0.02 ms access time
Operating speeds	0.3 ms 3 ms 12 ms	add. sub. fix. 0.3 flo. 1.4 ms mult. fix. 1.6 flo. 1.6 ms div.	add. sub. fix. 1.2 flo. 5.2 ms mult. fix. 5.7 flo. 9.7 ms div.	3.2 ms 5.4 ms 9.6 ms	0.12 sec 0.3 sec 0.1 sec	0.04 ms 0.25 ms 1.5 ms (incl. access time)
Input/Output	PTR 200ch./sec Tape punch 60 ch./sec Typewriter	PTR 200ch./sec Tape read punch 10 ch./sec Typewriter 7 ch./sec	PTR 200ch./sec Tape read punch 8 ch./sec Typewriter 8 ch./sec	PTR 200ch./sec Tape read punch 8 ch./sec Typewriter 9 ch./sec	72channel tape read punch 360wds./min Line printer 120 lines/min Fuji card reader (orders and constants)	PTR 400 ch./sec Tape punch 25 ch./sec Typewriter Line printer 150 lines/min Mag. drum Mag. tape planned
External memory			External drum	External drum		
Remarks			3 models in use 5 models on order	3 models in use 5 models on order	Several models in use	

Table B-1 Characteristics of the domestic digital computers (3)

Name	FACOM-222	HIPAC-1	HIPAC-101B	HITAC-301	OPC-1	H-1
Manufacturer	FUJICM	HITACHI	HITACHI	HITACHI	OKI	HOKUSHIN
Date	(1960)	1957	1960	1959	1958	1958
Major element	Transistor Diode	Parametron Tube	Parametron Transistor Diode	Transistor Diode	Parametron Tube	Transistor
Mode of operation	Serial-parallel binary-decimal	Parallel binary fixed pt.	Parallel fixed binary, decimal	Serial decimal fixed pt.	Parallel decimal fixed, floating	Serial decimal fixed pt.
Clock frequency	200 kc	1 kc	10 kc	230 kc	10 kc	200 kc
Word size	12 digits + sign	38 bits	39 bits + sign 19 digits + sign	12 digits + sign	8 digits	8 digits
Instructions	1 address 100 operations 9 index registers	1 address 40 operations 2 index registers	1.1/2 address 48 operations 2 index registers	1.1/2 address 74 operations 2 index registers	2 address 22 operations	1 address 39 operations 2 index registers
Memory	Mag. core 250 wds. 0.07 ms access time Mag. drum 9750 wds. 9 ms access time	Mag. drum 1024 wds. 5.5 ms access time	Mag. drum 2048 wds. 3.0 ms access time	Mag. drum 1960 wds. 3.0 ms access time	Mag. drum 8000 wds. 10 ms access time	Mag. drum 1000 wds. (40 wds. quick access) 2.5 (0.5 quick) ms access time
Operating speeds	add. sub. fx. 0.14 flo. 0.38 ms mult. fx. 1 flo. 0.8 ms div. fx. 4.0 flo. 3.5 ms	15 ms 19 ms 170 ms	4 ms 8 ms 35 ms	3.0 ms 10 ms 11 ms	2 ms 20 ms 40 ms	4.2 ms 7.2 ms 11.0 ms
Input/Output	PTR 400 ch./sec Tape punch 30 ch./sec Typewriter Line printer Card unit read 300/min punch 200/min Mag. tape units external drum	Tape reader 8 ch./sec Typewriter 10 ch./sec	PTR 200 ch./sec Tape punch 9 ch./sec Card read punch	PTR 200 ch./sec Tape read punch 10 ch./sec	PTR 200 ch./sec Tape punch 30 ch./sec Line printer 240 lines/min Card read punch 100 cards/min	Tape read punch 8 ch./sec Typewriter
External memory						
Remarks			Revised model of HIPAC 101		Mag. tape	

[Appendix C]

Shielding Codes Group's Shielding Computer Program†

Program No.	Description	No. of dimensions	Geometry	No. of energy-groups	Calculation procedure
††					
SC 1011	γ ray dose rates	1	Slab, cylinder and sphere	8	Build-up method by analytical treatment
SC 1012	γ ray dose rates	3	Slab, cylinder and sphere	8	Build-up method by numerical treatment
SC 1021	Neutron dose rates	1	Slab, cylinder and sphere	3	Diffusion theory and fast neutron removal theory
SC 1022	Neutron dose rates	3	Slab, cylinder and sphere	3	Diffusion theory and fast neutron removal theory by numerical treatment
SC 1031	Capture γ ray dose rates	1	Slab, cylinder and sphere	8	Build-up method by numerical treatment
SC 1041	Reactor shield design Shield weight analysis (unification of 1011, 1021, 1031)	3	Cylinder and sphere	n, 3 γ, 8	Same as SC 1031 (Parametric study for the minimum weight)
SC 1051	Coolant activity	1	Cylinder	5	Build-up method
SC 1061	Temperature and thermal stress distribution in the shield	1	Slab, cylinder and sphere	8	Temperature distribution due to radiation
SC 2011	Growth and decay characteristics of fission products in a fuel rod				Gross total ²³⁵ U fission product production as a function of thermal neutron flux, irradiation time and decay time
SC 2012	Growth and decay characteristics of fission products in a fuel rod				Atomic concentrations as a function of thermal neutron flux, irradiation time and decay time
SC 2021	γ dose rates from fission products in a containment				Dose rates of fission products released in a containment
SC 2031	Fission product release from a containment				Factors influencing initiation, propagation and rate of release and dispersion of fission product in the field
SC 3011	Monte Carlo neutron penetration	1	Multiple layer		Monte Carlo method A uniform infinite beam of monoenergetic neutron source
SC 3021	Monte Carlo γ ray penetration	1	Multiple layer		Monte Carlo method A uniform infinite beam of monoenergetic γ source
SC 3031	Neutron scattering analysis	3	Infinite homogeneous medium (air, water)		Exponential attenuation Distribution of scattered neutron from an anisotropic point source
SC 3041	γ ray scattering analysis	3	Infinite homogeneous medium (air, water)		Build-up method Distribution of scattered γ ray from an anisotropic monoenergetic source
SC 3051	γ ray penetration Effect of irregularities in the shield	3	(a) Cylindrical ducts (b) Edge (c) Small void		Monte Carlo method Isotropic point source

† Computer ; IBM-650, IBM-704, NEAC-2203, Bendix-G15D, FACOM-128B

†† For the left-most digit of Program No., 1, 2 and 3 indicate shielding design code, shielding safety code and shielding research codes respectively.