FAKIR

A user-friendly standard for decay heat and activity calculation of LWR fuel

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INTRODUCTION

About 3000 irradiated Light Water Reactor (LWR) fuel assemblies are received yearly by COGEMA from their customers throughout the world in the reprocessing plant at LA HAGUE. The fuel assemblies are transported by COGEMA from the French power plants, by Nuclear Transport Limited (NTL) from the other European power plants and by Pacific Nuclear Transport Limited (PNTL) from Japan.

Due to the decay heat and activity inherent to the spent fuel content, the shipping casks owned by the transporters are subjected to extensive thermal and containment analysis from the designers for both normal and accident conditions. Thermal analysis aims to demonstrate the compliance of the packages with regard to the transport regulations by fuel decay heat and heat transfer calculations, and by full scale thermal testing. Calculated decay heat and activity limits define the "working area" of the cask and are quoted in both design safety report and package approval. Staying within these limits ensures the consignor of the compliance with the transport regulations i.e. that accessible surface temperature will not exceed the limit, that fuel cladding damage during transport or unloading, and thus radioactive leakage into the containment systems, will not occur... Cask over-heating may also affect the life of the seals and the behaviour of temperature-sensitive components such as resin neutron shielding. Apart from just transport considerations, the cask unloading and fuel storage facilities have undergone identical thermal analysis and are designed with their own limits.

The philosophy of the IAEA recommendations makes the consignor responsible for checking and demonstrating to the safety authorities, the compliance of the fuel assemblies to be shipped with regard to the limiting safety parameters for transport. On the other hand, the consignee is responsible for checking that the limiting safety parameters for unloading and storage are not exceeded. Fuel decay heat and residual activity not being accessible by direct measurements, these values must be calculated before transport according to a qualified and agreed standard method.

THE FAKIR STANDARD

It is possible, for a one off study, to run a large and well-known calculation code such as ORIGEN, FISPIN, CINDER or PEPIN/APOLLO. However it would not be justified for a consignor to do so on a routine basis, mainly for time and cost reasons. Advantages of running large codes lie in their extensive validations and qualifications giving the results accuracy and limited conservatism. Their drawbacks are that they require expert code users or at least highly qualified staff, large and costly dedicated computers and long running time. They also calculate results such as isotopic concentrations which are not necessary for the consignor requirements. Large codes are therefore not suitable for the routine LWR fuel decay heat and activity calculations of consignors or consignee such as COGEMA or NTL which need to process between 1500 and 3000 fuel assemblies per year and for several dates of transport.

The alternative approach to routine decay heat and activity calculations for transport applications is to use, as in the early days, simple but crude formulas with the drawback of over-estimating the results and therefore limitating the use of the transport casks. Furthermore these formulas are no longer applicable to the various irradiation patterns now adopted by the reactors for the fuel management.

Considering the number and the diversity of the parties involved in the transport, storage and reprocessing cycle, there was therefore the need for an alternative standardized method for the calculation of decay heat and activity of LWR spent fuel lying between the simple but crude formula and the large costly code. The design specification of this standardized method was set as:

- To cover all types of LWR fuel received as yet by COGEMA and modular to be extended to future deliveries.
- To be computerizable and to run on basic and non-dedicated hardware;
- To accept as input the contractual data required by COGEMA for transport and reprocessing;
- To be flexible enough to accomodate the changes in transport scheduling;
- To be as simple as possible to use (no scientific background required);
- To be reliable and to give in output an as low as possible over-estimation of the decay heat and activity of the spent fuel assemblies;
- To be documented and qualified.

Solutions to this specification are given by several standards like the ORNL curves (L.B. Shappert 1970), ANSI/ANS 5.1 (1979), USNRC regulatory guide 3.54 (1984) or ISO (1992). However,a common limitation of these standards lies in their general conservatism and their field of application which cannot be extended to various types of fuel. For instance, they are not suitable for Mixed Oxyde (MOX) fuel and reprocessed uranium decay heat calculations and do not account for parameters such as the type of array. Furthermore, they do not give any indication of the residual activity resulting from the fuel irradiation. Finally, in addition to the fuel irradiation history, the user must provide and justify part of the input data , which are not contained in these standards (ANS 5.1 and ISO) such as the contributions of the fissile nucleides to the thermal power during irradiation.

In order to compensate for the lack of self-contained code for decay heat and activity calculations, this stringent design specification has been achieved by the Fuel After Heat Keyboard Instant Result (FAKIR) calculation code. Development of FAKIR started in 1984 in collaboration between COGEMA, the CEA-SERMA Laboratory and NTL. It is now used as the standard method for decay heat and activity calculation of LWR spent fuel for both transport and storage applications. Using a similar basic formalism as for the ANS 5.1 or ISO standards, FAKIR is made more flexible by its modular conception which allows the use of tabulated values stored in libraries. Libraries are defined for a number of standard cases. Intermediate cases are processed by interpolations between several libraries. In the event of a new type of fuel out of the range of the current field of application, it is possible and fairly simple to build the adequate libraries and thus to extend the FAKIR field of application.

DESCRIPTION OF THE FAKIR CODE

Decay heat is calculated from:

$P = P_{FP} + P_A$ where:

$$P_{FP} = \{ \sum_{L} \frac{P_L}{\sum_{i} f_{iL}\, Q_i + Q_{0,L}} \sum_{i} f_{iL} \left[F_i\,(t_j\,,\mathrm{oo}) - F_i\,(T_L + t_j\,,\mathrm{oo}) \right] \}\, G\,(\tau\,, t_j) \text{ and:}$$

P : total thermal decay heat;
P_{FP} : thermal decay heat due to fission products;
P_A : thermal decay heat due to heavy actinides;
L : subscript for the irradiation steps;
i : subscript for the fissile isotopes;
j : subscript for the cooling times;
P_L : thermal power of the irradiation step L;
f_{iL} : fractional fission of isotope i during irradiation step L;
Q_i : recoverable thermal energy from one fission of isotope i;
$Q_{0,L}$: recoverable energy from exceeding neutron capture in structural material for one fission during irradiaton step L;
t_j : cooling time after final irradiation shutdown;
T_L : duration of irradiation step L;
$F_i(t_j,\mathrm{oo})$: decay heat power of fission products of the fissile isotope i at time t_j after the end of an infinite irradiation time referred to one fission per second without capture (infinite time assumed to be 1E13 s);
τ : final burnup after L irradiation steps;
$G(\tau,t_j)$: corrective factor which accounts for neutron capture in fission products as a function of τ and t_j.

P_A is calculated from $P_A = P_{U239} + P_{Np239} + P_{OA}$ where P_{U239} and P_{Np239} are the contribution to the decay heat of U239 and Np239, and P_{OA} is the contribution of the other actinides. P_{U239} and P_{Np239} are calculated with the ISO proposed formulas and P_{OA} is tabulated as a function of τ and t_j fo several initial enrichments.

In the FAKIR code, $F_i(t_j,\mathrm{oo})$, f_{iL}, $P_{OA}(\tau,t_j)$, and $G(\tau,t_j)$ are tabulated in libraries built from numerous runs of the combination of PEPIN/APOLLO codes. APOLLO (Kavenoky and Sanchez,1987) is a general purpose 2D assembly spectrum code which solves the Boltzmann integral transport equation. Using, as input, the neutron related data given by APOLLO, PEPIN (Duchemin et al. 1982) solves the Bateman equations by the analytical method. PEPIN calculates the build up and depletion of 699 main fission products under and after irradiation. The APOLLO/PEPIN combination is largely used throughout the French nuclear industry and has been approved by the French safety authorities. Benchmarking has shown a good agreement with the other codes internationaly available (Duchemin and Nordborg,1990). Libraries are available in FAKIR as functions of the type of fuel, type of array, initial enrichment in fissile material and burnup. For PWR fuel, the libraries are available for initial enrichments of 1.8 w/o to 4.5 w/o and a burnup range of 1 to 70,000 MWd/TeU.

Residual activities are derived by multiplying P_{PF} and P_A contributions to the decay heat by factors $Q_{FP}(\tau,t_j)$ and $Q_A(\tau,t_j)$ which are also tabulated for several initial enrichments and burnup.

For calculations with intermediate initial enrichments and burnup, $F_i(t_j,\mathrm{oo})$, f_{iL}, $Q_{FP}(\tau,t_j)$, $Q_A(\tau,t_j)$, $P_{OA}(\tau,t_j)$ and $G(\tau,t_j)$ are interpolated between the pre-established libraries by the Spline interpolation method. Thanks to this modular conception and tabulated data, FAKIR is a self-contained code. A basic and non-dedicated 286 Personal Computer hardware is sufficient to run calculations with FAKIR.

FAKIR INPUT DATA

For decay heat and residual activity calculations, FAKIR only uses part of the data which are required by COGEMA from their customers and known as transport and reprocessing sheet 1 and 2 (Prétesacque and Corny, 1989). These data are established by the reactors and distributed to the consignors and transporters under a standardized form. FAKIR input data are of two categories:

Data related to the reactor:

. type of reactor: PWR or BWR;
. numbering of cycles;
. length of each cycle expressed in number of Equivalent Days at Full Power (EDFP).

Data related to the fuel assembly:

. identification number;
. type of array;
. weight of heavy metal;
. initial enrichment in fissile material (in weight or percentage);
. type of fuel: uranium oxyde, mixed oxyde fuel or reprocessed uranium;
. irradiation history: cycles of irradiation and specific power or irradiation per cycle;
. dates or cooling times for calculation.

Thanks to the interactivity with the user, FAKIR manual data entry is made as simple as possible and requires no scientific background. Errors on data entry are minimized by cross-checking the information before being accepted or validated for calculation. In order to avoid the tedious task of manual data entry or to speed up the calculation, it is also possible to link FAKIR to an external data base. Any ASCII file such as those used by the reactors to fill in the transport and reprocessing sheets are acceptable through a conversion programme. Contrary to the ISO or the ANS 5.1 standard, FAKIR does not require the user to provide data other than directly available information.

FIELD OF APPLICATION

In its current version, FAKIR applies to the following cases:

- PWR and BWR fuel assemblies;
- Burnup comprised between 1 and 70,000 MWd/TeU;
- Cooling times comprised between 1 second and 100 years;
- All patterns of irradiation history.

QUALIFICATION OF FAKIR

Qualification of the contribution of the fission products (P_{FP}) given by FAKIR has been performed by comparison of results with PEPIN on cooling times ranging from 0.1second to 50 years, for various irradation histories and initial enrichments. The comparison showed an average error of 0.23% for continous cycles to 2.07% in case of irregular irradiation history with jump of cycles. The overall qualification of fakir was carried out by comparison of results with FISPIN 6 , ORIGEN S, KORIGEN and PEPIN calculation codes. Decay heat and activity calculations were performed from the similar input specifications given below:

- Reactor irradiation history represented by a histogram of intervals (cycles) with a constant operating power of 38.25 MW/MTU and irradiation times varying in accordance with the burnup at end of cycles.
- Inter-cycle time of 42 days.
- Cooling times of 15 days; 1, 3, 6, 9, 12, 15, 18 months; 2, 3, 5, 10 years.

Case number 1:

- Initial enrichment in U235: 3.25 w/o.
- Number of cycles: 3.
- Burnup per cycle (MWd/TeU): 11,000/11,000/13,000 (final burnup 35,000).

Case number 2:

- Initial enrichment in U235: 3.70 w/o.
- Number of cycles: 4.
- Burnup per cycle (MWd/TeU): 10,500/10,500/10,500/10,500 (final burnup 42,000).

Case number 3:

- Initial enrichment in U235: 3.70 w/o.
- Number of cycles: 4.
- Burnup per cycle (MWd/TeU): 10,500/10,500/10,500/13,500 (final burnup 45,000).

Case number 4:

- Initial enrichment in U235: 3.70 w/o.
- Number of cycles: 4.
- Burnup per cycle (MWd/TeU): 10,500/10,500/10,500/18,500 (final burnup 50,000).

Case number 5:

- Initial enrichment in U235: 3.70 w/o.
- Number of cycles: 4.
- Burnup per cycle (MWd/TeU): 10,500/10,500/10,500/28,500 (final burnup 60,000).

Tables 1 to 5 compile the results given by the different calculation codes. It appears that FAKIR is in good agreement with the other codes showing a slight over-prediction comprised between 1% at short cooling times and 10% for longer cooling times when comparing to FISPIN or PEPIN.

Qualification of FAKIR is also based on a full scale calorimetric experiment. Extensive temperature measurements were performed by TRANSNUCLEAIRE on a TN 12/2 (100 Te) transport cask loaded with 12 PWR fuel assemblies from the French power plant of TRICASTIN Unit 3 and having very similar irradiation histories. Temperatures were measured on numerous points around the cask in horizontal and vertical positions at thermal equilibrium before unloading in the dry cell of the COGEMA reprocessing plant at La Hague. Temperatures were compared with those measured during the thermal test of the cask for well known heat inputs which concluded to a total decay heat of between 64.5 KW and 69.6 KW. For the same fuel load, FAKIR calculated a decay heat of 71.511 KW giving an over-prediction comprised between 2.7% and 9.8%.

Fuel assemblies' characteristics for the calorimetric test

Element Number	Weight U (Kg)	Init.Enr.U5 (w/o)	BU at End of Cycle (MWd/TeU)/Spec.Power (MW/TeU)			FAKIR Dec.Heat (KW)
			1	2	3	
1	463.974	3.200	8436/28.31	24256/43.58	38693/36.73	6.109
2	463.353	3.189	8189/27.48	24080/43.77	38742/37.31	6.156
3	464.667	3.223	13353/44.81	26346/35.79	38575/31.12	5.450
4	463.448	3.232	8124/27.26	24029/43.81	38465/36.73	6.071
5	464.363	3.202	9974/33.47	24518/40.07	38703/36.09	5.988
6	464.633	3.238	8320/27.92	24100/43.47	38477/36.58	6.057
7	464.122	3.220	8350/28.02	24110/43.42	38573/36.80	6.078
8	464.809	3.214	8396/28.17	24128/43.34	38645/36.94	6.103
9	463.112	3.195	8363/28.06	24190/43.60	38695/36.91	6.086
10	464.568	3.190	9987/33.51	24507/40.00	38790/36.34	6.029
11	463.670	3.248	13493/45.28	26590/36.08	38365/29.96	5.354
12	464.440	3.200	9820/32.95	24364/40.07	38719/36.53	6.031

Cooling time: 304 days

Total : 71.511

FAKIR EXPERIENCE

FAKIR is now used since 1986 for routine calculation of decay heat and activity of all LWR fuel received at the COGEMA reprocessing plant at La Hague which represents more than 25,000 calculations on fuel assemblies originating from 110 power plants throughout the world. Therefore, decay heat and residual activity of each fuel assembly are checked on a standardized basis.

Originally designed for transport planning and compliance checking of decay heat and activity, FAKIR is also used for the preparation of cask loading plans. Indeed, it is possible to limit dramatically the cask's external dose rates by a careful selection of the fuel assemblies to be shipped, and by optimizing their position in the cask basket. Selection of fuel assemblies is based, as first approximation, on decay heat and activity comparison. The outer positions of the cask basket is then filled with the coolest fuel providing shielding to the inner positions which can be filled with hotter fuel assemblies. We have observed significant reduction of dose uptake during cask handling and transport when applying this simple rule of fuel selection in the preparation of transport campaigns.

FUTURE PLANS

In order to enhance FAKIR and to extend the use of its fuel data base, we consider several directions of future development:

. Building the new decay heat and activity calculation libraries to cater for the new types of fuel which are to be transported or received in the coming years.

. A heat transfer calculation module which will estimate the cask's external surface temperature as a function of the decay heat load, ambient temperature and cask characteristics.

. A cask dose rate prediction module which will use the same fuel data base as for the decay heat module.

. A cask loading plan optimization module.

A limitation to the accuracy of FAKIR is the modelling of the fuel irradiation history by histograms of intervals at constant operating power. We are currently developing an input data entry module for detailed fuel irradiation history description available to the more advanced users.

CONCLUSION

Using a similar mathematical formalism to the ISO or the ANSI standards, FAKIR is a self-contained code which does not require scientific background nor powerful and dedicated computers. Tabulated data libraries prepared from runs of large codes allow easy extension to new types of fuel and provide a "built-in" qualification. The flexibility and user-friendliness of FAKIR is a great factor of economy as it can be used by anyone, from secretarial staff up to the physicist, and allows the fuel assemblies to be recalculated very quickly to adjust to the changes in the transport programme. When planning a campaign of several transports, the interpretation of FAKIR calculations allow dose uptake limitation by optimization of the casks loading plans. New applications under development at the CEA-SERMA Laboratory will extend the use of the fuel data base to cask temperature and gamma and neutron dose rate prediction.

FAKIR is a good alternative, for routine calculations, between the large codes and simplified formulas and provides the consignors, the consignees and the safety authorities with a powerful and qualified means of checking the compliance of the casks' contents with the safety parameters. FAKIR has been adopted by COGEMA as the standard method of calculation for both transport and storage of all the LWR fuel assemblies received in the reprocessing plant at La Hague. Thanks to its future developments, FAKIR will become a complete computational system for checking transport and storage safety parameters as well as a design tool for thermal analysis.

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TABLE 1 (3.25% 35,000 MWd/TeU)

	DECAY HEAT (KW/TeU)					ACTIVITY (MCi/TeU)				
Cooling	FISPIN	ORIGEN	KORIGEN	PEPIN	FAKIR	FISPIN	ORIGEN	KORIGEN	PEPIN	FAKIR
15 days	74.08	71.57	72.20	74.15	74.62	17.62	17.32	17.10	17.49	17.66
1 month	53.66	51.15	52.00	53.74	54.27	13.10	12.77	12.60	13.04	13.20
3 months	30.04	28.34	29.20	30.31	30.60	7.32	7.13	7.08	7.35	7.45
6 months	18.94	17.82	18.40	19.16	19.31	4.46	4.34	4.32	4.49	4.55
9 months	13.76	12.96	13.40	13.93	14.05	3.24	3.16	3.15	3.28	3.33
12 months	10.84	10.26	10.50	10.97	11.11	2.60	2.52	2.53	2.62	2.68
15 months	8.90	8.50	8.69	9.02	9.19	2.18	2.12	2.13	2.20	2.25
18 months	7.50	7.22	7.35	7.61	7.80	1.88	1.82	1.83	1.89	1.94
2 years	5.58	5.42	5.50	5.65	5.80	1.44	1.41	1.43	1.46	1.50
3 years	3.46	3.40	3.45	3.48	3.46	0.96	0.95	0.97	0.98	0.99
5 years	1.90	1.90	1.95	1.90	1.90	0.62	0.60	0.62	0.61	0.61
10 years	1.18	1.19	1.24	1.18	1.19	0.42	0.41	0.43	0.415	0.42

TABLE 2 (3.7% 42,000 MWd/TeU)

	DECAY HEAT (KW/TeU)					ACTIVITY (MCi/TeU)				
Cooling	FISPIN	ORIGEN	KORIGEN	PEPIN	FAKIR	FISPIN	ORIGEN	KORIGEN	PEPIN	FAKIR
15 days	76.11	72.86	74.86	76.74	76.49	17.87	17.55	17.50	17.87	17.84
1 month	55.49	52.25	54.10	56.11	56.10	13.33	12.96	12.90	13.40	13.38
3 months	31.64	29.39	20.80	32.34	32.28	7.55	7.33	7.32	7.68	7.65
6 months	20.41	18.89	19.80	20.93	20.88	4.68	4.55	4.53	4.79	4.77
9 months	15.06	13.99	14.60	15.46	15.46	3.46	3.36	3.35	3.55	3.55
12 months	12.00	11.22	11.60	12.31	12.38	2.80	2.71	2.71	2.87	2.89
15 months	9.95	9.09	9.68	10.21	10.34	2.36	2.22	2.30	2.43	2.46
18 months	8.45	8.04	8.25	8.67	8.84	2.05	1.99	2.00	2.10	2.14
2 years	6.37	6.14	6.26	6.52	6.69	1.60	1.55	1.57	1.64	1.68
3 years	4.05	3.97	4.04	4.11	4.15	1.10	1.07	1.09	1.11	1.14
5 years	2.31	2.30	2.37	2.33	2.41	0.71	0.69	0.71	0.71	0.74
10 years	1.47	1.47	1.53	1.47	1.56	0.49	0.48	0.50	0.49	0.52

TABLE 3 (3.7% 45,000 MWd/TeU)

	DECAY HEAT (KW/TeU)					ACTIVITY (MCi/TeU)				
Cooling	FISPIN	ORIGEN	KORIGEN	PEPIN	FAKIR	FISPIN	ORIGEN	KORIGEN	PEPIN	FAKIR
15 days	77.82	74.05	76.00	77.91	78.27	18.16	17.78	17.60	18.02	18.14
1 month	57.01	53.35	55.30	57.16	57.70	13.58	13.17	13.10	13.53	13.65
3 months	32.88	30.35	31.80	33.28	33.59	7.75	7.52	7.48	7.81	7.87
6 months	21.46	19.76	20.70	21.79	21.96	4.85	4.71	4.69	4.92	4.95
9 months	15.97	14.78	15.40	16.23	16.40	3.61	3.50	3.49	3.67	3.71
12 months	12.79	11.92	12.40	13.00	13.20	2.93	2.84	2.84	2.98	3.03
15 months	10.64	9.71	10.30	10.82	11.07	2.49	2.34	2.41	2.53	2.58
18 months	9.06	8.62	8.83	9.22	9.49	2.16	2.09	2.10	2.19	2.25
2 years	6.86	6.61	6.74	6.97	7.22	1.69	1.64	1.66	1.72	1.77
3 years	4.40	4.31	4.39	4.44	4.53	1.16	1.13	1.15	1.17	1.21
5 years	2.54	2.53	2.60	2.55	2.66	0.75	0.74	0.76	0.76	0.79
10 years	1.60	1.62	1.67	1.61	1.72	0.52	0.51	0.53	0.52	0.55

TABLE 4 (3.7% 50,000 MWd/TeU)

	DECAY HEAT (KW/TeU)					ACTIVITY (MCi/TeU)				
Cooling	FISPIN	ORIGEN	KORIGEN	PEPIN	FAKIR	FISPIN	ORIGEN	KORIGEN	PEPIN	FAKIR
15 days	80.26	75.68	77.70	79.71	80.81	18.51	18.06	17.80	18.23	18.52
1 month	59.16	54.84	56.90	58.80	59.99	13.88	13.42	13.30	13.73	14.00
3 months	34.71	31.76	33.40	34.76	35.52	8.02	7.76	7.69	8.00	8.16
6 months	23.09	21.12	22.20	23.16	23.65	5.10	4.95	4.91	5.11	5.21
9 months	17.41	16.04	16.70	17.47	17.89	3.84	3.72	3.70	3.85	3.94
12 months	14.06	13.07	13.50	14.10	14.53	3.14	3.04	3.03	3.15	3.24
15 months	11.77	10.74	11.40	11.82	12.26	2.67	2.52	2.59	2.68	2.77
18 months	10.07	9.57	9.79	10.12	10.56	2.32	2.26	2.26	2.33	2.43
2 years	7.68	7.41	7.54	7.71	8.11	1.83	1.78	1.79	1.84	1.92
3 years	4.99	4.91	4.98	5.00	5.18	1.26	1.23	1.26	1.27	1.32
5 years	2.92	2.93	3.00	2.93	3.10	0.82	0.81	0.84	0.82	0.86
10 years	1.85	1.88	1.93	1.87	2.03	0.57	0.56	0.59	0.57	0.60

TABLE 5 (3.7% 60,000 MWd/TeU)

	DECAY HEAT (KW/TeU)					ACTIVITY (MCi/TeU)				
Cooling	FISPIN	ORIGEN	KORIGEN	PEPIN	FAKIR	FISPIN	ORIGEN	KORIGEN	PEPIN	FAKIR
15 days	84.48	79.47	80.40	83.50	85.25	19.05	18.66	18.00	18.65	19.10
1 month	62.90	58.03	59.50	62.14	63.96	14.36	13.92	13.50	14.10	14.52
3 months	37.99	34.54	36.00	37.70	38.95	8.46	8.21	7.99	8.35	8.63
6 months	26.09	23.78	24.80	25.88	26.76	5.51	5.37	5.25	5.46	5.64
9 months	20.13	18.52	19.20	19.95	20.70	4.22	4.11	4.05	4.18	4.34
12 months	16.50	15.36	15.80	16.35	17.08	3.49	3.40	3.36	3.46	3.60
15 months	13.96	12.80	13.50	13.86	14.57	2.99	2.83	2.89	2.97	3.11
18 months	12.06	11.50	11.70	11.98	12.68	2.62	2.55	2.54	2.60	2.73
2 years	9.35	9.07	9.15	9.30	9.92	2.08	2.03	2.03	2.06	2.18
3 years	6.24	6.18	6.23	6.23	6.56	1.46	1.42	1.45	1.44	1.51
5 years	3.78	3.83	3.89	3.81	4.10	0.95	0.94	0.98	0.95	1.00
10 years	2.41	2.49	2.54	2.46	2.71	0.66	0.66	0.69	0.66	0.70

Session 2:

RADIATION PROTECTION-I

Chairman : K. Ueki
Co-Chairman : G. E. Whitesides
Coordinator : N. Watabe