

Characterization of KANUPP Irradiated Fuel Bundles

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Pakistan Atomic Energy Commission (PAEC)**

Introduction to KANUPP

- CANDU Reactor
- First Fuel Loading in 1971
- Full power operation started in 1972
- 6180 FPDs / ~17 FPYs of operation since commissioning
- Completed 30 years design life in the year 2002
- By refurbishment & safety upgrades, KANUPP operational life has been extended up to 2021
- Under water storage of spent fuel bundles in spent fuel storage bay



KANUPP Reactor Data

Reactor Power:	433 MWth at 100% RP; 137 MWe
Licensing Power:	98 MWe (77% RP)
Allowable Bundle Power:	453 kW
Outer Fuel Element Power Rating:	52 kW/m
No. of Fuel Channels	208; 206 in Operation & 2 are Defueled
No. of Fuel Bundles / Fuel Channel	11
Fueling Regime	Single Bundle Push in 52 Channels; Double Bundle Push in 156 Channels
Current Moderator Operating Band:	173 – 176 inch
Design Average Discharge Burnup:	7400 MWD/TeU (177.6 MWh/KgU)

Design Layout of KANUPP Spent Fuel Storage Bay (SFSB)

- 11 spent fuel bundles stored in one storage tray
- Storage layout (Original Design): 120 stacks of trays each consisting of 18 tiers of trays
- Design Storage capacity: 23,760 spent fuel bundles
- Total Water Depth : 5.94 m
- Water Shield thickness: 3.96 m
- $8.7E-3$ mSv/hr is maintained at 30.5 cm (1 foot) above the water surface



KANUPP Spent Fuel Dry Storage

- KANUPP spent fuel dry storage (KSFDS) was planned to serve
 - ❖ As an ultimate solution of storage problem to enable the plant to operate safely up to 2021
 - ❖ To store the spent fuel safely in a dry storage facility for approx. 50 years till the availability of the National Repository
- KSFDS has started its full swing operation in August 2019
- Four casks each consisting of 108 spent fuel bundles have been transferred to dry fuel storage facility



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Enhancement in SFSB (October 2019)

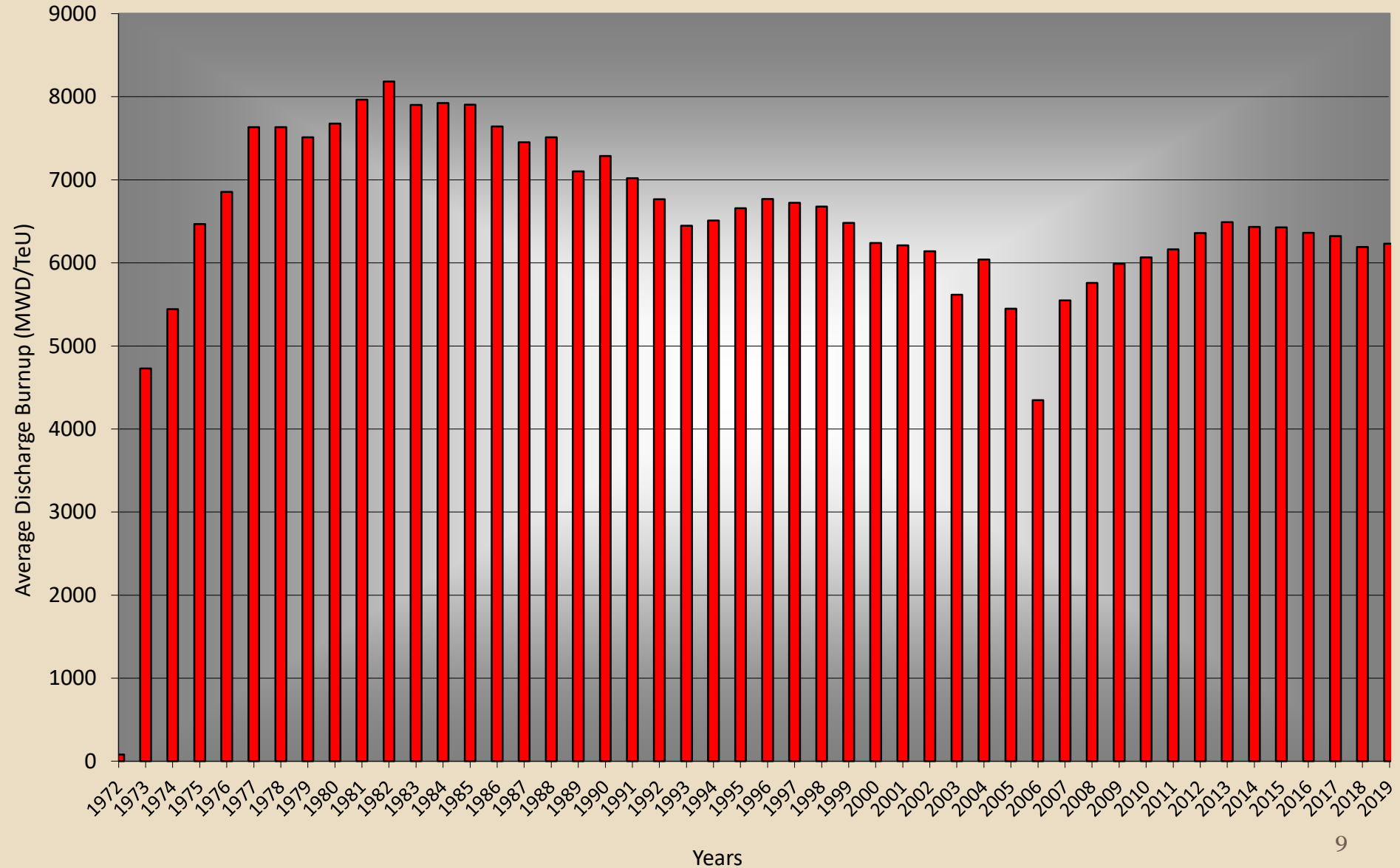
Description	Quantity (Nos.)
Design bundle capacity of spent fuel storage bay	23760
Enhanced bundle capacity by implementation of HDTR System	31680
Total number of HDTRs to be placed in storage bay (Planned)	60
Number of HDTRs loaded in bay	57
No. of Casks filled and transferred to KSFDS facility	04
Total spent fuel bundles in 4 casks	432
Total No. of Spent Fuel Bundles Currently Stored in SFSB	30871

Source Term Evaluation of KANUPP Spent Fuel Bundle

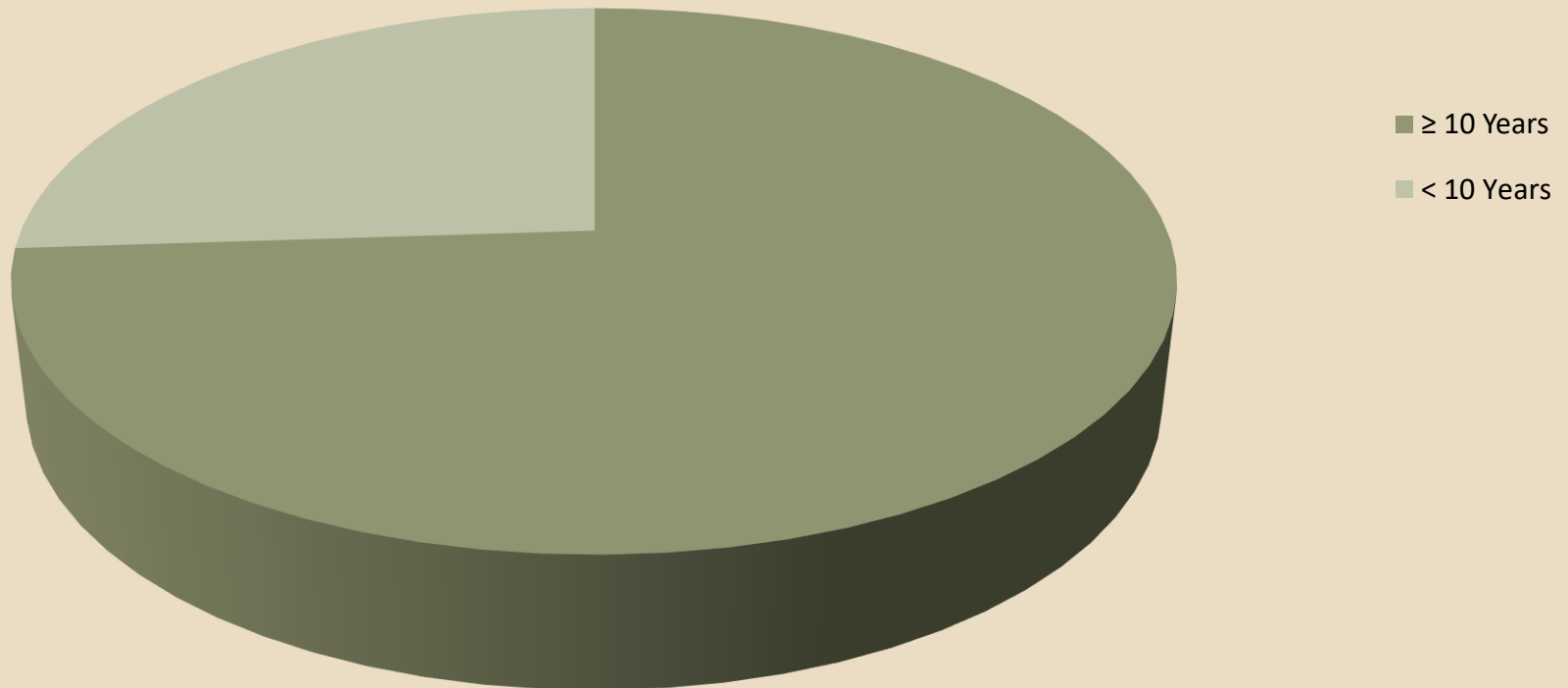
Objectives

- Spent fuel bundles had to be shifted from wet storage to dry fuel storage (KSFDS) to create space in the SFB as well as for interim storage during KANUPP Decommissioning
- The spent fuel characterization was performed as a prime requirement for the design of spent fuel basket and storage cask.
- Shielding requirement and dose rate estimation
- Development of model to be used in evaluating the ability of spent fuel to meet specific waste acceptance criteria

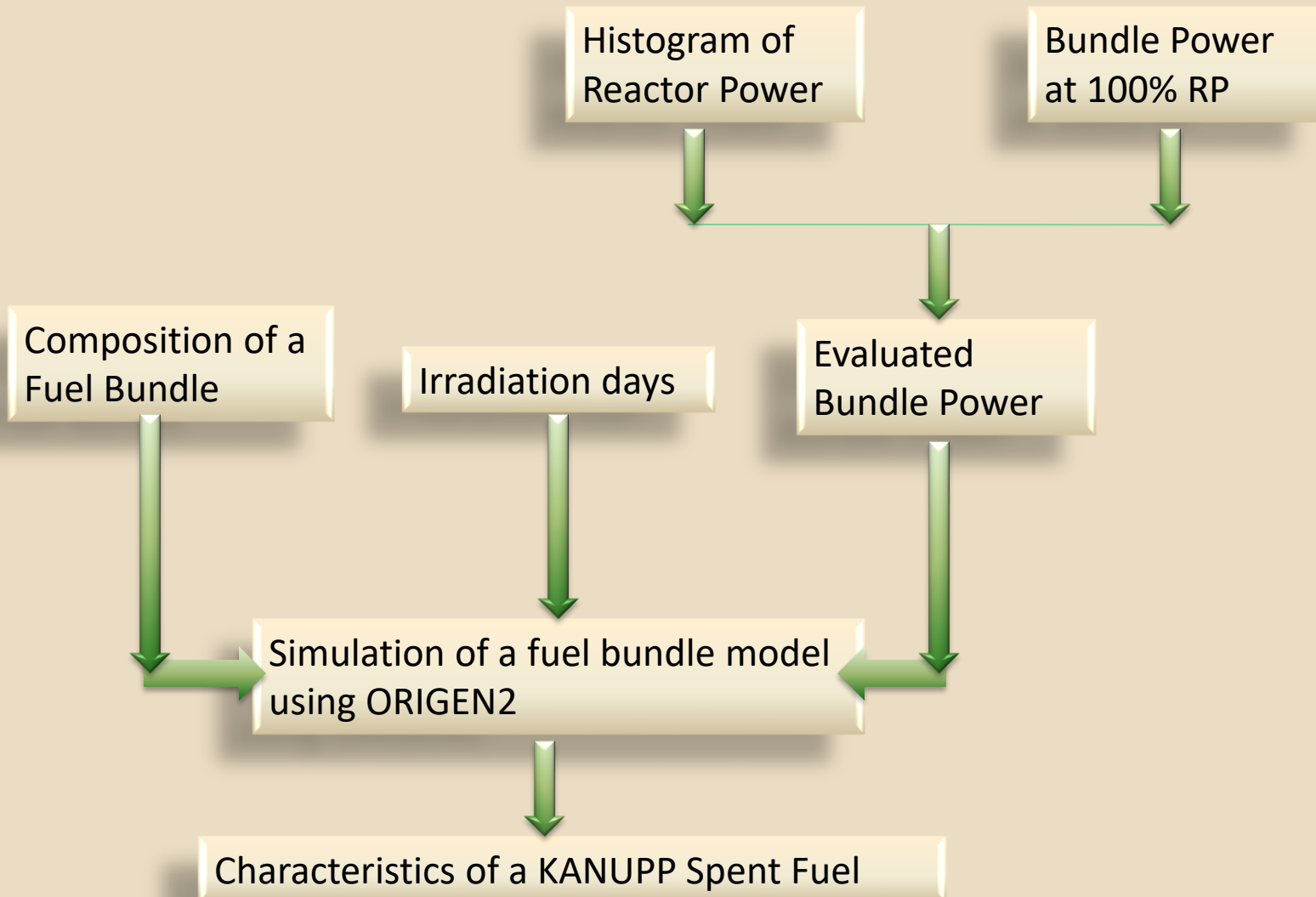
Discharge Burnup Variations During 1972 – 2019



KANUPP Spent Fuel Inventory vs Cooling Time



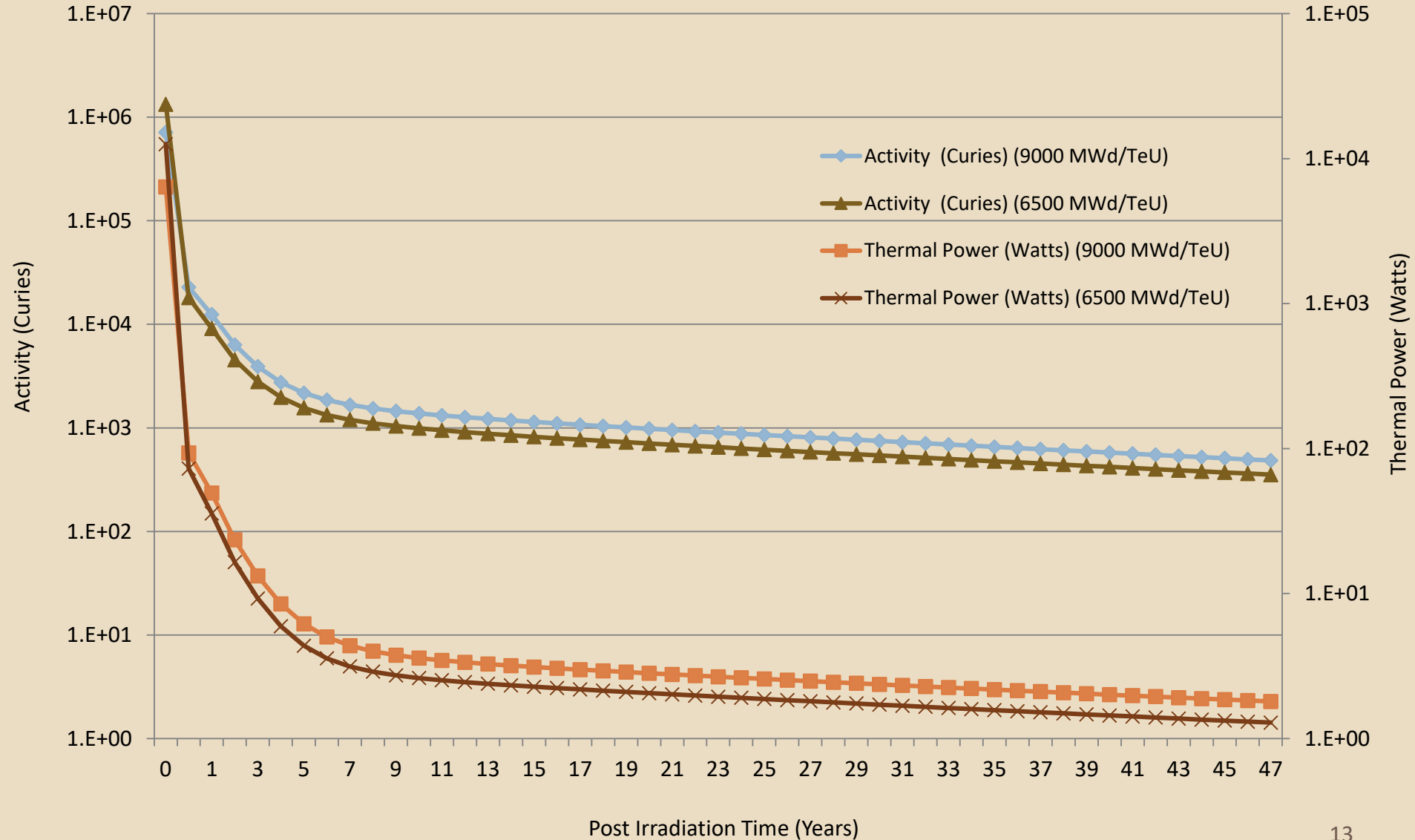
Preparation of Input Data



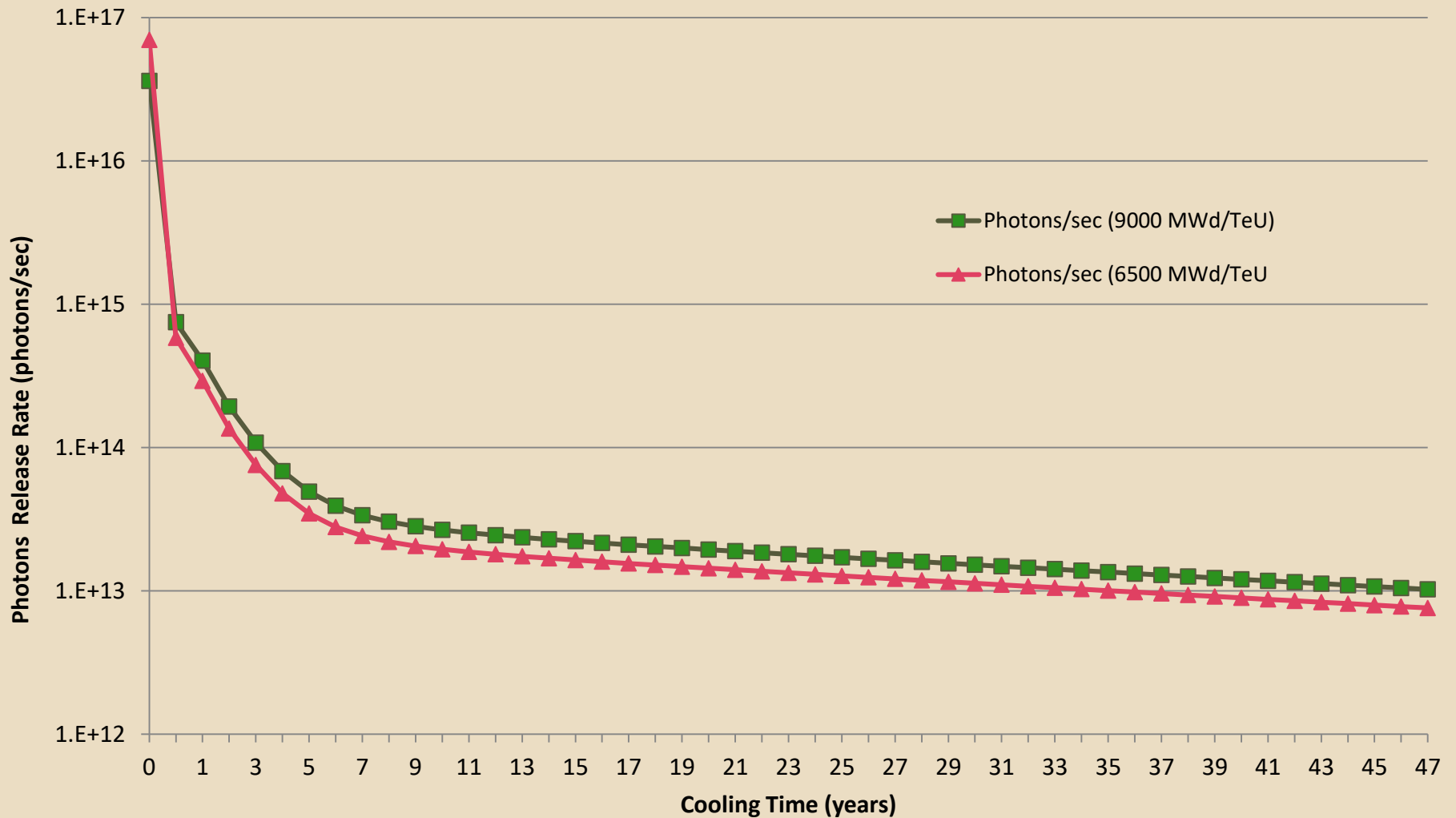
Results

- ORIGEN code processed irradiation histories using decay, cross-section and photon libraries of CANDU reactor model to generate information for FP, Actinides & AP
 - ❖ Isotopic composition (grams)
 - ❖ Activity (Curies)
 - ❖ Decay Heat (Watts)
 - ❖ Gamma Spectrum
 - ❖ Neutron Production data

Source term Variation of a KANUPP Spent Fuel Bundle with Time



Gamma Photons Release Rate



Inventory of Radio-nuclides in a 10 Years Cooled Spent Fuel Bundle

Actinides	Mass (grams)
U235	2.3E+01
U236	1.1E+01
U238	1.32E+04
Np237	4.7E-01
Pu238	6.8e-02
Pu239	3.9E+01
Pu240	1.7E+01
Pu241	2.3E+00
Pu242	1.2E+00
Am241	1.5E+00

Fission Products	Mass (grams)
Kr 85	4.5E-02
Sr 90	1.5E+00
Y 90	3.6E-04
Ru106	1.0E-03
Rh106	4.8E+00
Sb125	4.7E-03
Cs134	9.4E-03
Cs137	3.6E+00
Pm147	6.3E-02
Eu154	4.2E-02
Eu155	8.6E-03

Activity of a 10 Years Cooled Spent Fuel

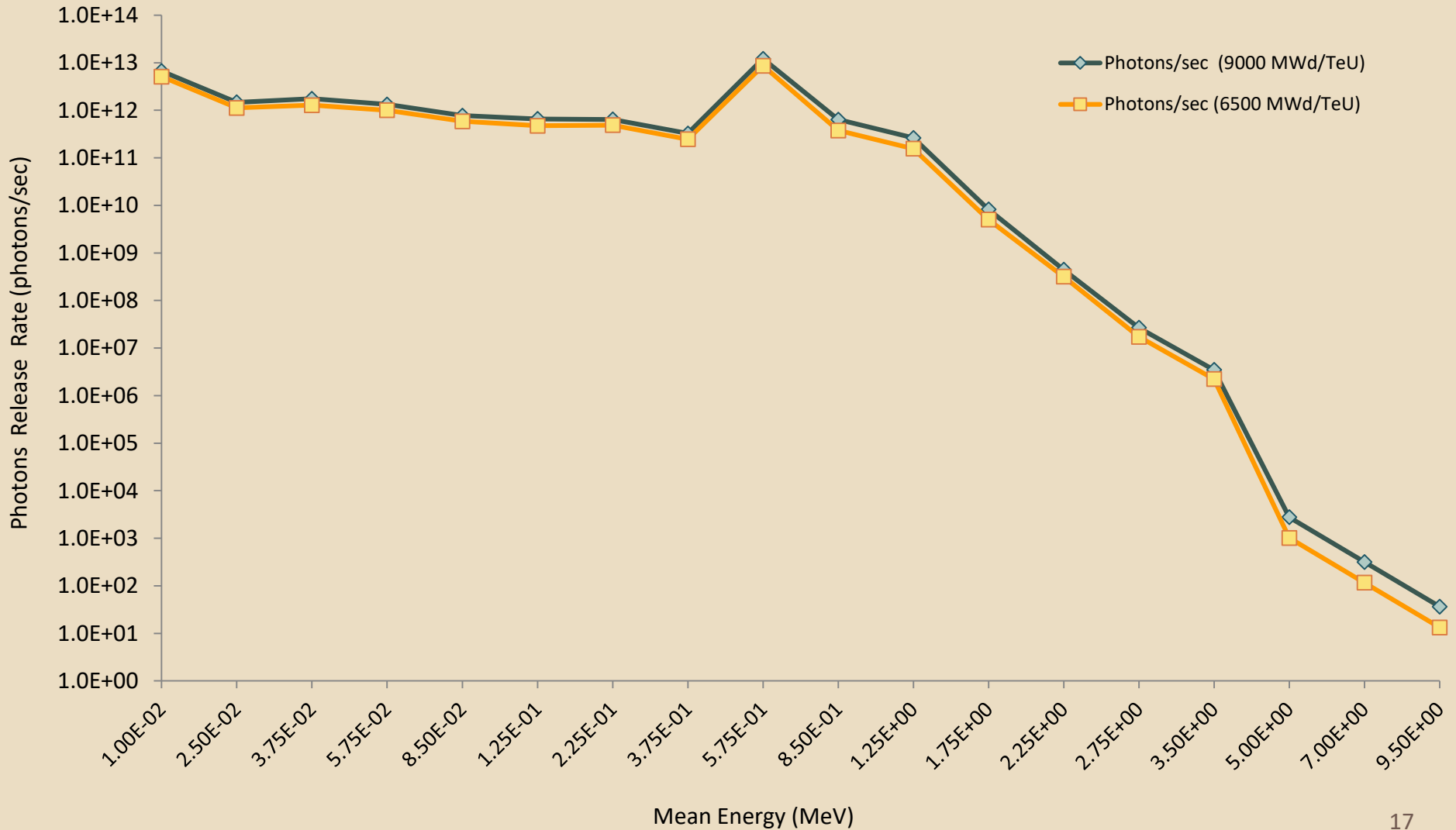
Bundle

Actinides	Activity (Curies)
U235	4.9E-05
U236	7.0E-04
U238	4.4E-03
Np237	3.3E-04
Pu238	1.2E-01
Pu239	2.4E+00
Pu240	3.9E+00
Pu241	2.4E+02
Pu242	4.5E-03
Am241	5.1E+00

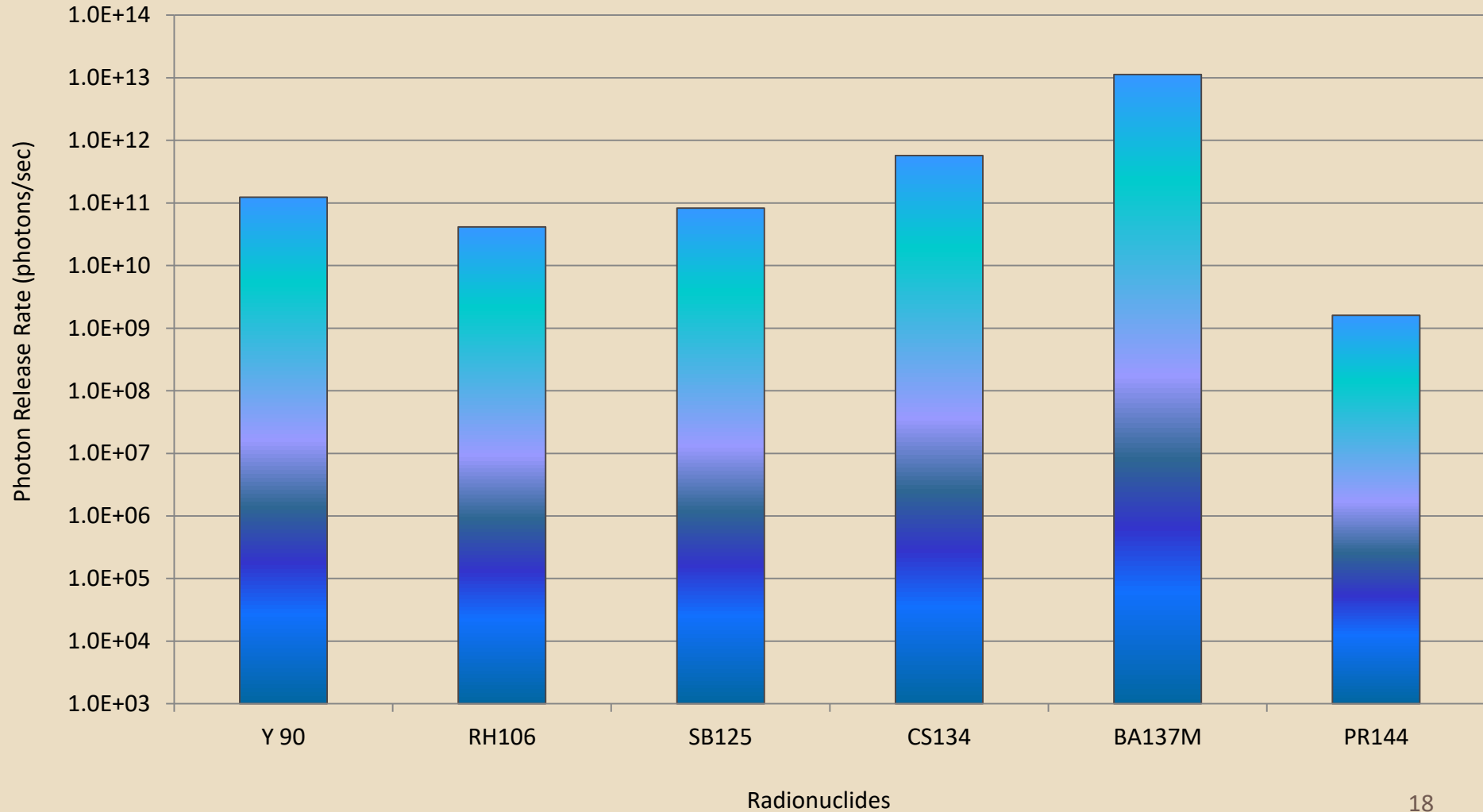
Fission Products	Activity (Curies)
Kr 85	1.8E+01
Sr 90	2.0E+02
Y 90	2.0E+02
Ru106	3.3E+00
Rh106	3.3E+00
Sb125	4.8E+00
Cs134	1.2E+01
Cs137	3.1E+02
Pm147	5.8E+01
Eu154	1.1E+01
Eu155	4.0E+00

Gamma Photons Release in 18 Energy

Groups



Principal Radio-nuclides Contributing to the Energy Group 9 (0.575 MeV)



Cumulative Inventory Required for KANUPP Decommissioning Plan

- Before submitting the decommissioning plan to our National Regulator, preliminary radiological characterisation of whole inventory of KANUPP fuel and in-core reactor components have been performed to provide bundle of information:
 - ❖ Radionuclide Inventory
 - ❖ Radionuclide activities and distribution
 - ❖ Decay Heat

Cumulative Inventory Required for KANUPP Decommissioning Plan (continued...)

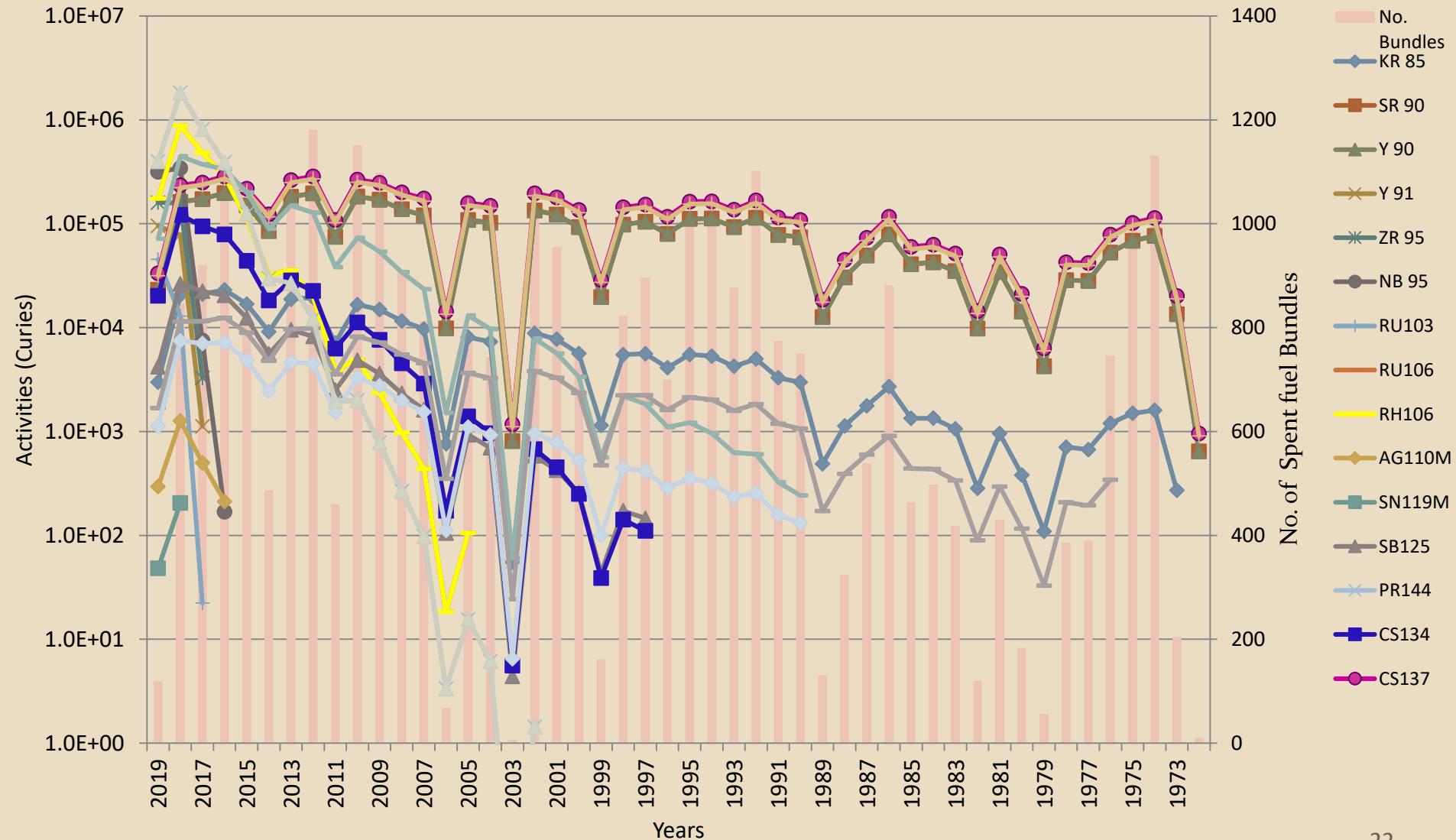
- Basis for:
 - ❖ KANUPP Decommissioning Plan and Strategy
 - ❖ Cost Estimation of Decommissioning Project
 - ❖ Environmental and Personnel Safety Assessment
 - ❖ Provide dose assessments for the workers during the implementation of decommissioning
 - ❖ Planning of National Repository

Results

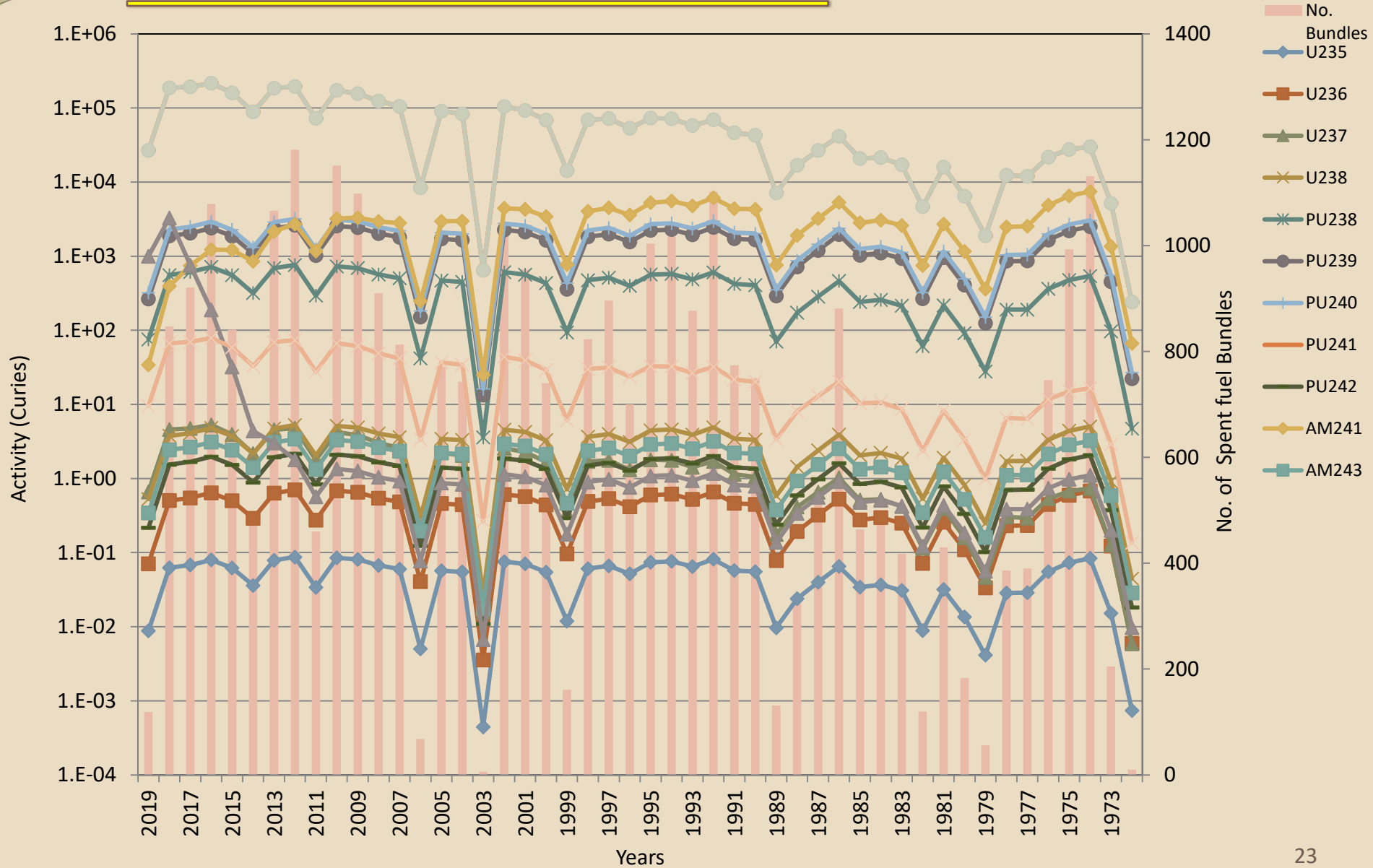
Total No. of Spent	Total Mass	Total Activity	Thermal Power
Fuel Bundles	(Kg)	(Curies)	(Watts)
31303	5.2E+05	3.9E+07	1.3E+05

No. of In-Core	Total Activity	No. of Booster	Total Activity
Fuel Bundles	(Curies)	Assemblies	(Curies)
2266	9.5E+07	8	1.8E+03

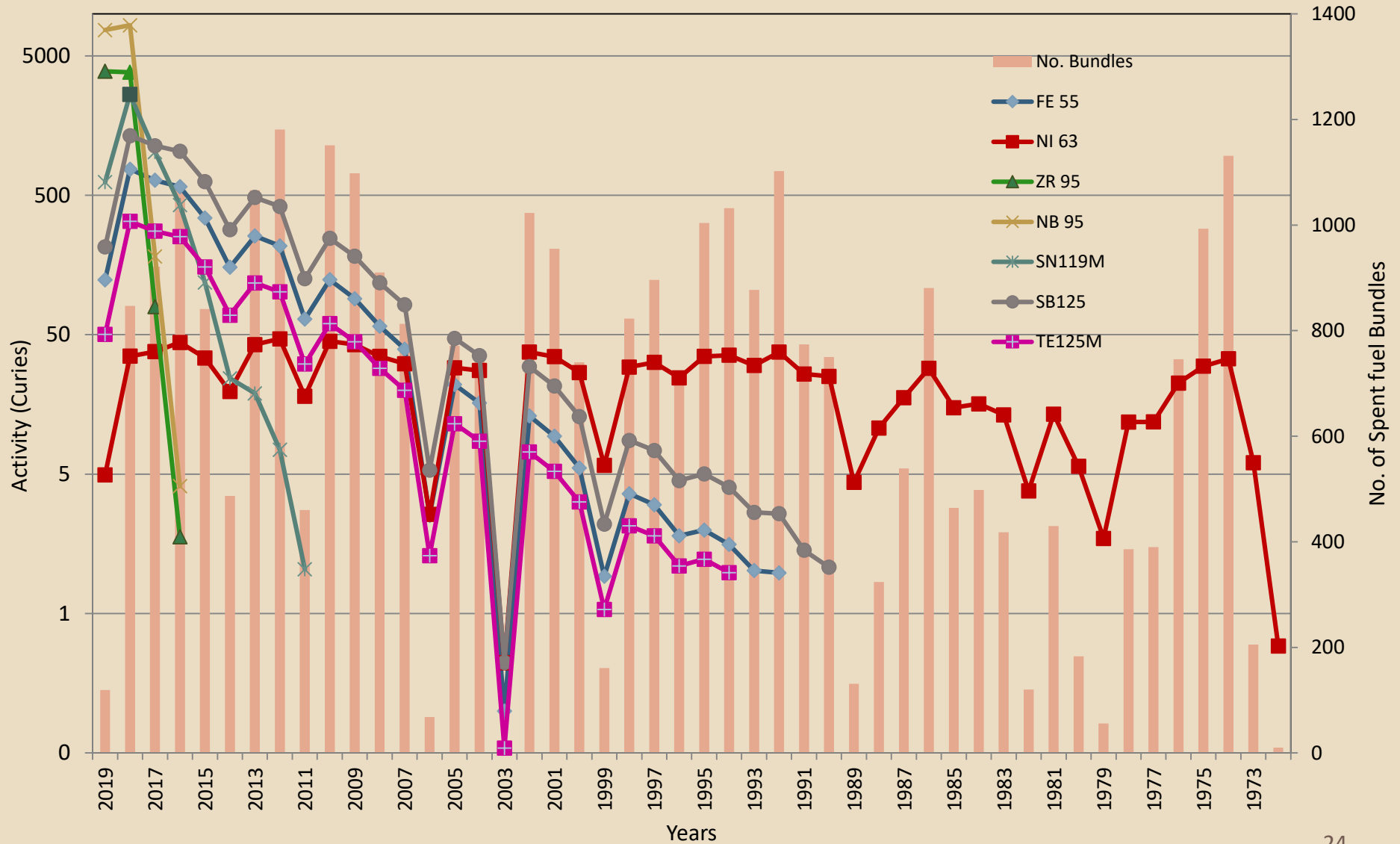
Distribution of Fission Products



Distribution of Actinides



Distribution of Activation Products



Summary

- The characterization study has defined the Source Term required for shielding design of a spent fuel storage cask.
- 4 KANUPP storage casks have been shifted to spent fuel dry storage facility.
- Dose rate measured at the cask surface is in agreement with the dose rate calculated using ORIGEN generated source term

THANKS