Assessment of Proliferation Resistance Requirements for Fast-reactor Fuel-cycle Facilities

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Safeguards Approaches for Fast Breeder Reactors & Associated Fuel Cycle Facilities

- Based on a generic fast breeder reactor design
- Use information available in the public domain

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World's long-term energy supply through FBRFC

- Sustainability
- Reliability
- Security

Vast potential of the FBRFC technology

- Breeding of ^{239}Pu from the abundant ^{238}U.
- A hundred-fold energy extraction potential
- Incineration of all long-lived heavy elements

Asian countries Japan, India, & China: Active R&D in this area

The United States, France & Japan MOU in Fast Reactor R&D

The GEN IV International Forum (GIF) 6 proposals:

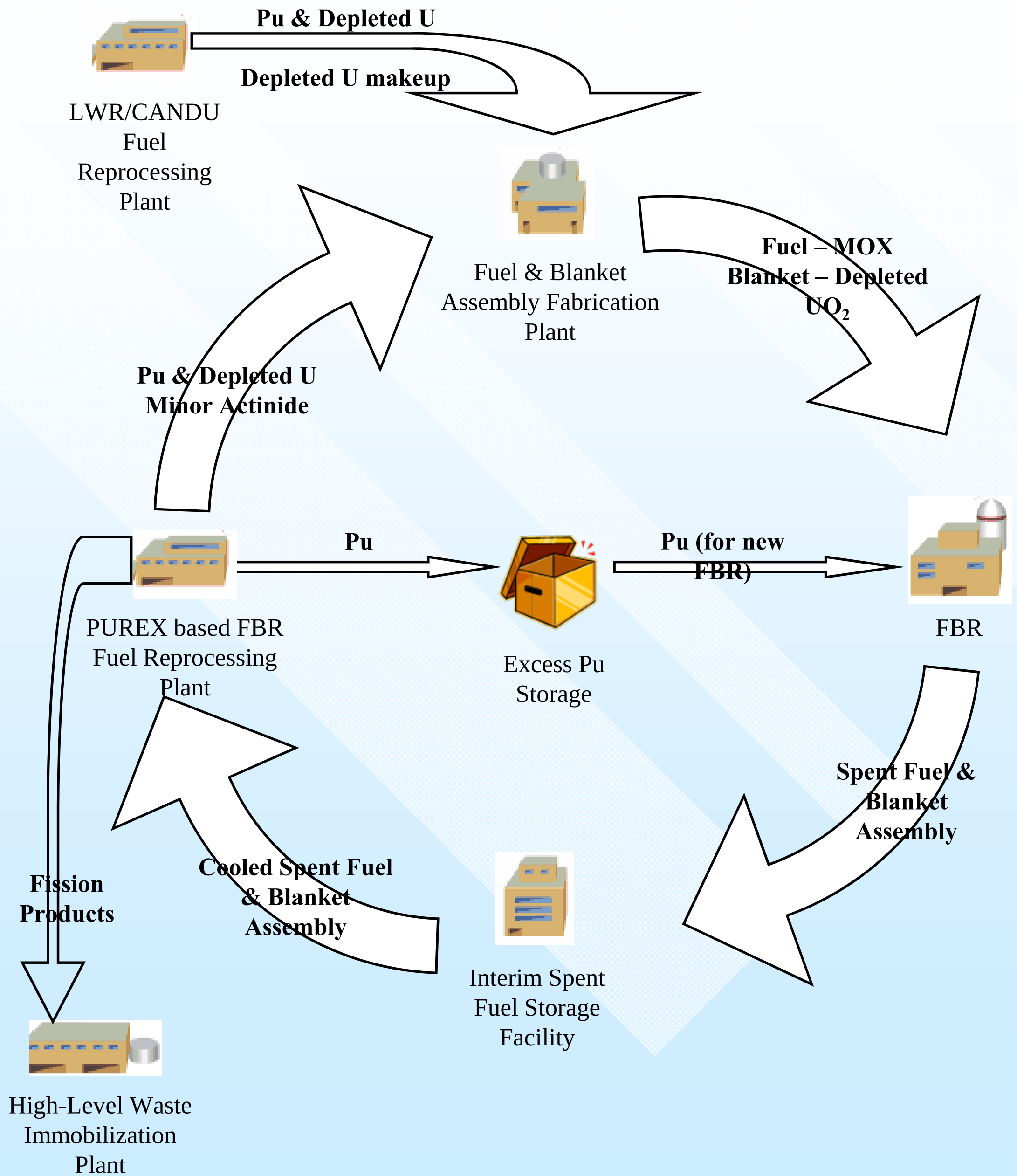
- gas cooled fast reactor system (GFR)
- lead cooled fast reactor system (LFR)
- sodium cooled fast reactor system (SFR)

Safeguards Concern:

- breeding of high purity ^{239}Pu
- envisaged use in large quantities

Prudent to address PR along with other issues like radioactive waste, economics and safety

Schematic of Fast Breeder Reactor Fuel Cycle



PR METHODOLOGIES / APPROACHES BY DIFFERENT INSTITUIONS

INPRO	INternational PROject on innovative nuclear reactors and fuel cycle methodology presented by IAEA
PRPP	Proliferation Resistance and Physical Protection expert group, (expert group, consists of US, Canada, EU, France, Japan, Korea and IAEA as an observer) approach
AFCI	**Advanced Fuel Cycle Initiatives methodology presented by TAMU**
FS Project	Feasibility Studies on commercialized fast reactor cycle system) presented by JNC (currently known as JAEA)
TOPS	Technological Opportunities to increase the Proliferation resistance of global civilian nuclear power Systems methodology
BNL	Brookhaven National Lab Markovian probabilistic methodology
SNL RIPA	Sandia National Lab Risk Informed Probabilistic Analysis
SAPRA	Simplified Approach for PR Assessment of nuclear systems

The MAUA:

- a well-established decision analysis methodology
- evolved since its first publication in 1978

Consists methods to compile several factors to make a single decision

The important task: obtain an utility function

- consists of multiple attributes
- describe the attractiveness of a system

For the present study: material flow routes in a generic FBRFC

semi-quantitative MAUA can fit into PR&PP methodology

Multiplicative Form of the MAU Function

$$1 + Ku(x_1, x_2 \ldots x_i) = \prod_i^n (1 + Kk_i u_i(x_i))$$

Equation to arrive at the scaling parameter, K

$$1 + K = \prod_i^n (1 + Kk_i)$$

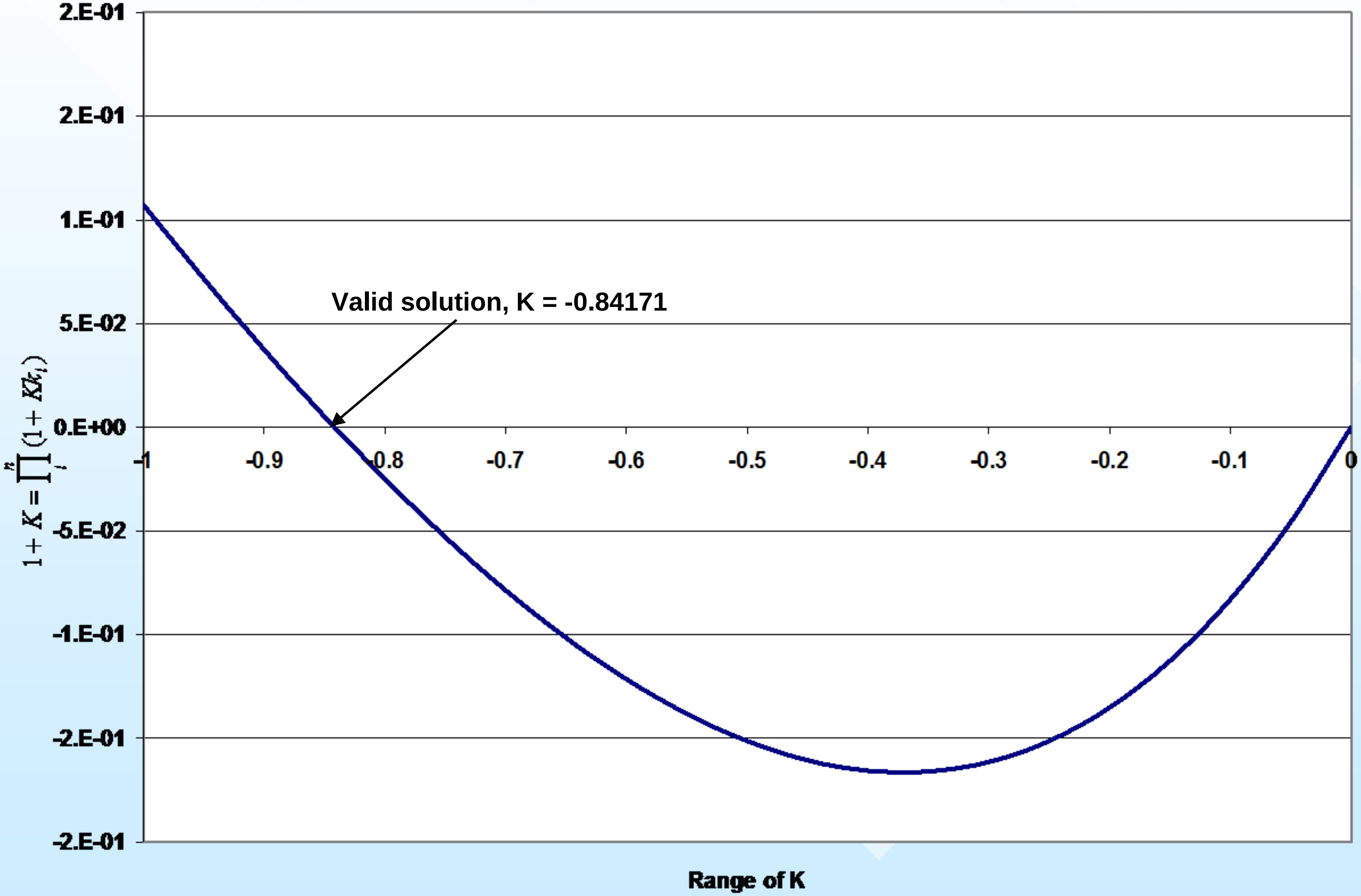
Conditions

$$\sum_1^n k_i > 1$$

$-1 < K < 0$

$0 < u_i \le 1$

Solution of K from the normalizing condition



– Four Stages of Proliferation Resistance Analysis

- Material Diversion
- Material Transportation
- Material Transformation
- Weapons Fabrication

List of Attributes Selected for PR Analysis

Diversion Stage

Material handling difficulty during diversion

1. Mass/SQ of nuclear material
2. Volume/SQ of nuclear material
3. Number of items/SQ
4. Material Form
5. Radiation level in terms of dose
6. Chemical reactivity
7. Temperature of Source Process
8. Heat load of material

Difficulty of evading detection by the accounting system

9. Uncertainty in accountancy measurements
10. Expected vs. Actual MUF
11. Frequency of measurement

12 Amount of Material Available

Difficulty of evading detection by the material control system

13. Probability of detection

Difficulty of covertly making facility modifications

14. Is there enough physical space to make modifications?
15. Number of People for Modifications
16. Remote handling tools required?
17. Specialized tools required?
18. Requirement for the process to be halted for modifications
19. Risk of Modification (safety)
20. Risk of penetrating containment

Difficulty of evading IAEA with covert facility modifications

21. Probability of being caught

Transportation Stage

Material handling difficulty during transportation

22. Mass/SQ of nuclear material
23. Volume/SQ of nuclear material
24. Material Form
25. Radiation level in terms of dose
26. Heat load of material
27. Chemical reactivity
28. Immediate Chemical toxicity
29. Time Average Chemical toxicity

Difficulty of evading detection during transport

30. Mass of material and transportation container
31. Volume of material and transportation container
32. Heat load of material
33. Shield thickness to reduce radiation to10 mR/hr
34. Host country size
35. Number of declared nuclear facilities
36. IAEA imagery analysis rate

Transformation Stage

Facilities and equipment needed to process diverted materials

37. Number of process steps to metallic form
38. Number of export controlled/equipment/materials
39. Minimum electrical requirement

Workforce required for transformation

40. Number of unskilled workers required (e.g. construction)
41. Number of skilled workers required (e.g. electrician)
42. Number of advanced degree work (e.g. Grad Student Work)
43. Number of Technical Experts (e.g. Adams on Transport)

Difficulty of evading detection of transformation activities

44. Additional Protocol in force?
45. Environmental sampling rate
46. Sensitivity of IAEA equipment
47. Isotopic signatures
48. Facility size
49. Heat load of transformation process
50. Sonic load
51. Radiation load
52. Volume of non-naturally occurring gases emitted
53. Undiluted volume liquid emissions

Weapons Stage

Difficulty associated with design

54. Spontaneous fission production Rate
55. Radiation exposure at one meter
56. Heating rate of weapons material
57. Can use ballistic assembly methods?
58. Number of phases in the phase diagram

Handling difficulties

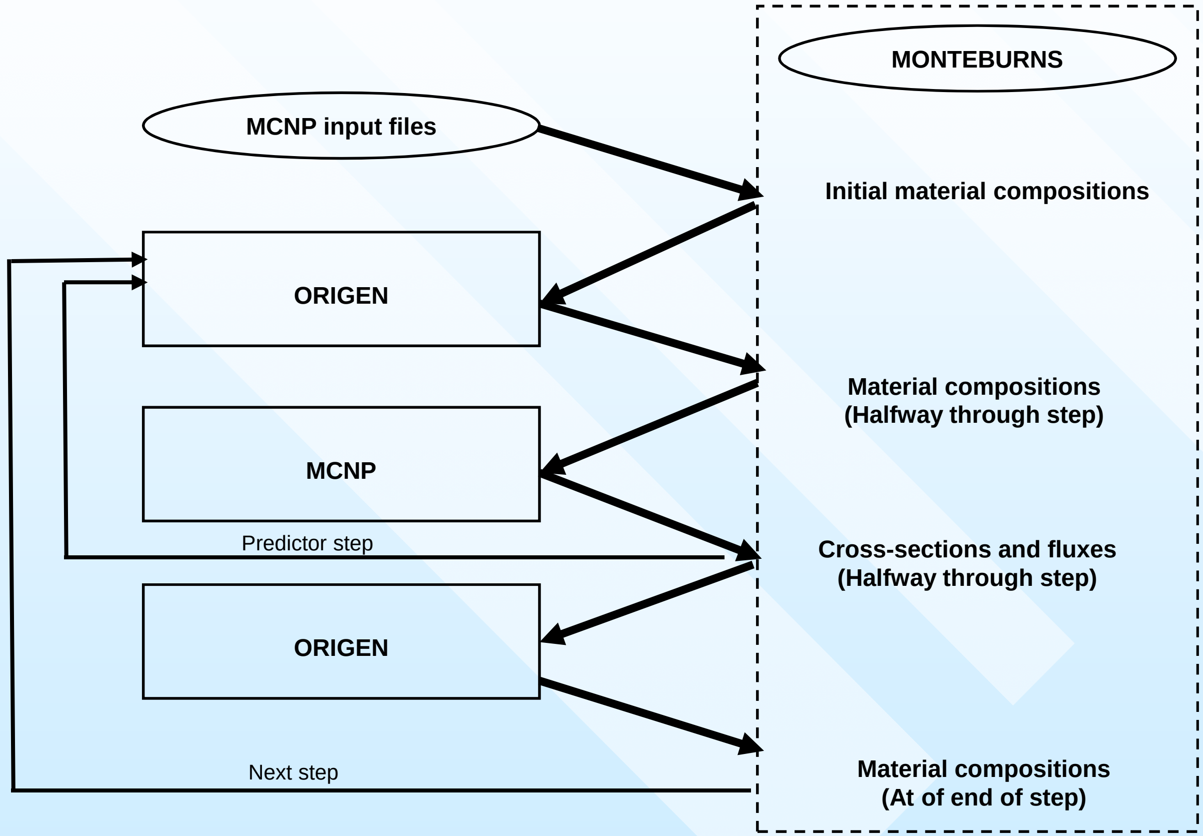
59. Radiation level in terms of dose
60. Chemical reactivity
61. Radio-toxicity

Knowledge and skills needed to design and fabricate

62. Knowledge and skill level for material/weapon type alternatives

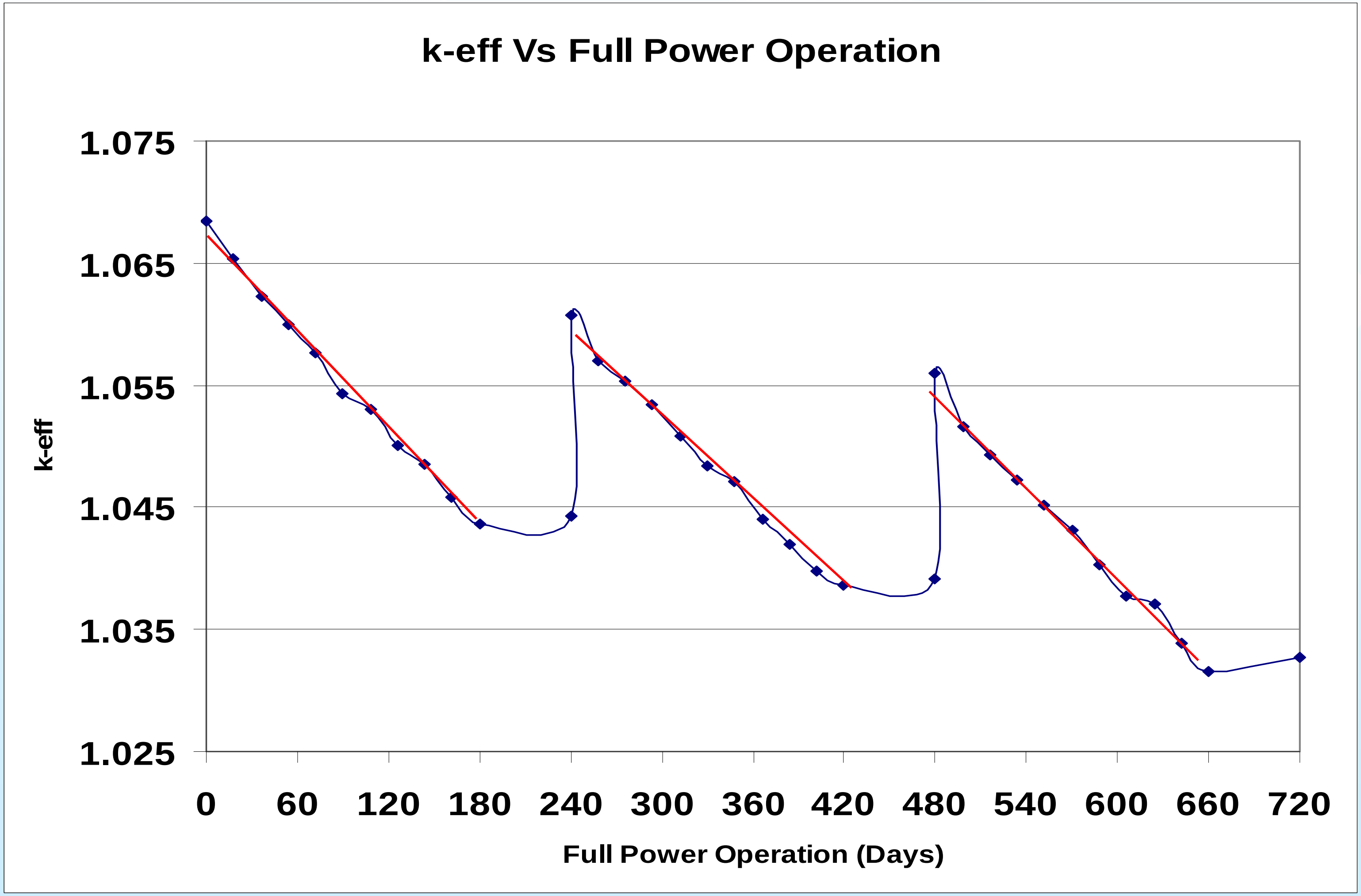
Computer codes used

MCNP5, ORIGEN-2.2, MONTEBURNS



Interaction of MONTEBURNS with MCNP & ORIGEN

Simulation Results
(MCNP, ORIGEN & MONTEBURNS)



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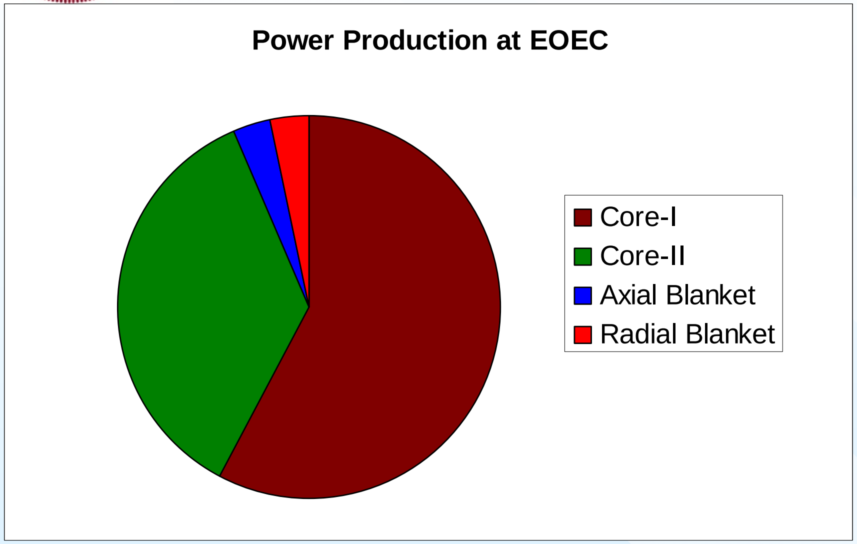
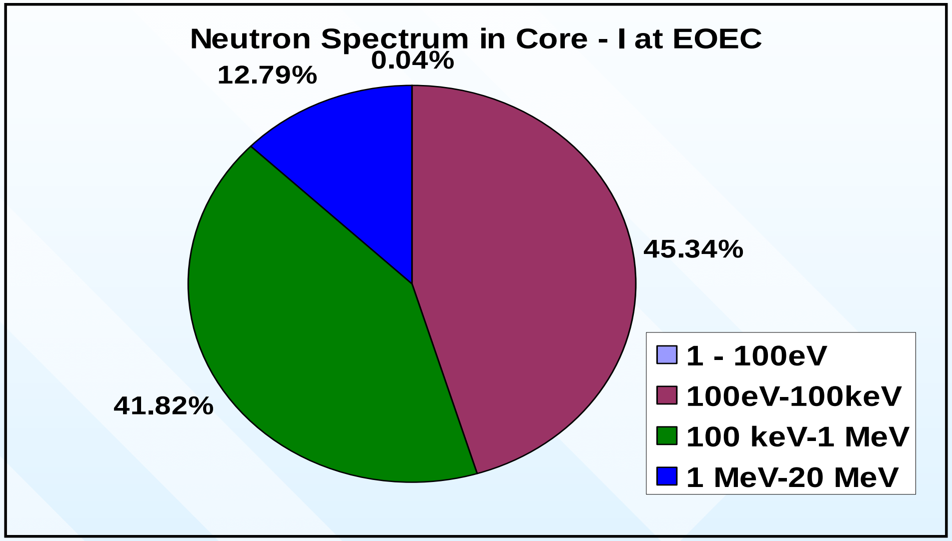
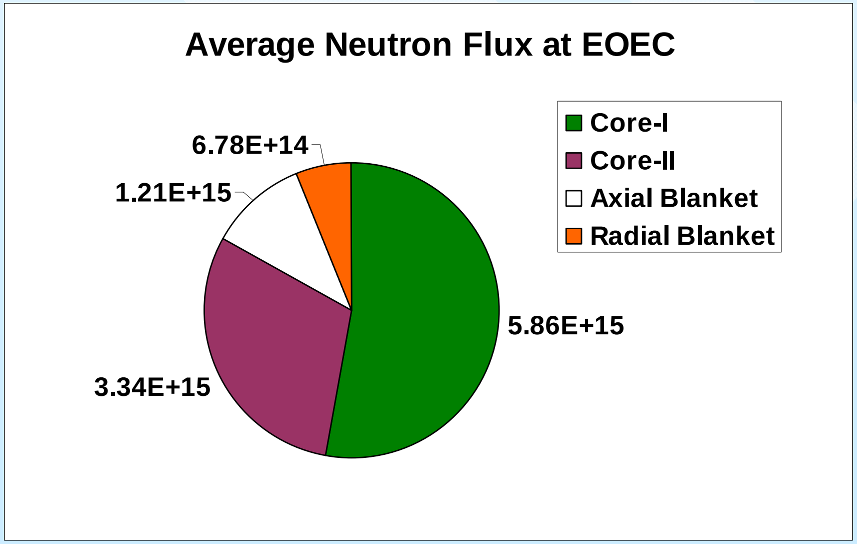
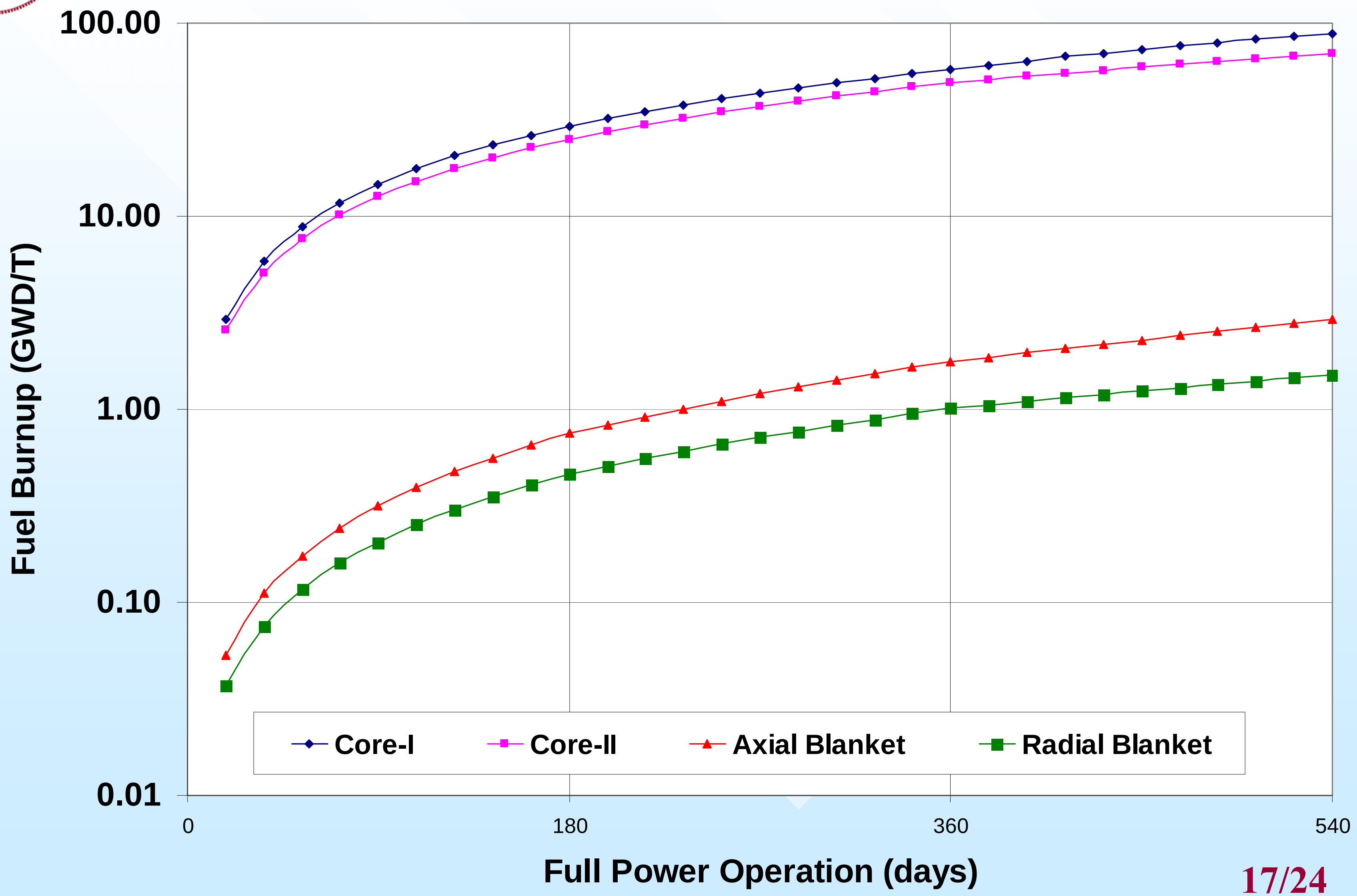






Simulation Results
(MCNP, ORIGEN & MONTEBURNS)
Fuel Burnup Vs Fuel Power Operation



Simulation Results
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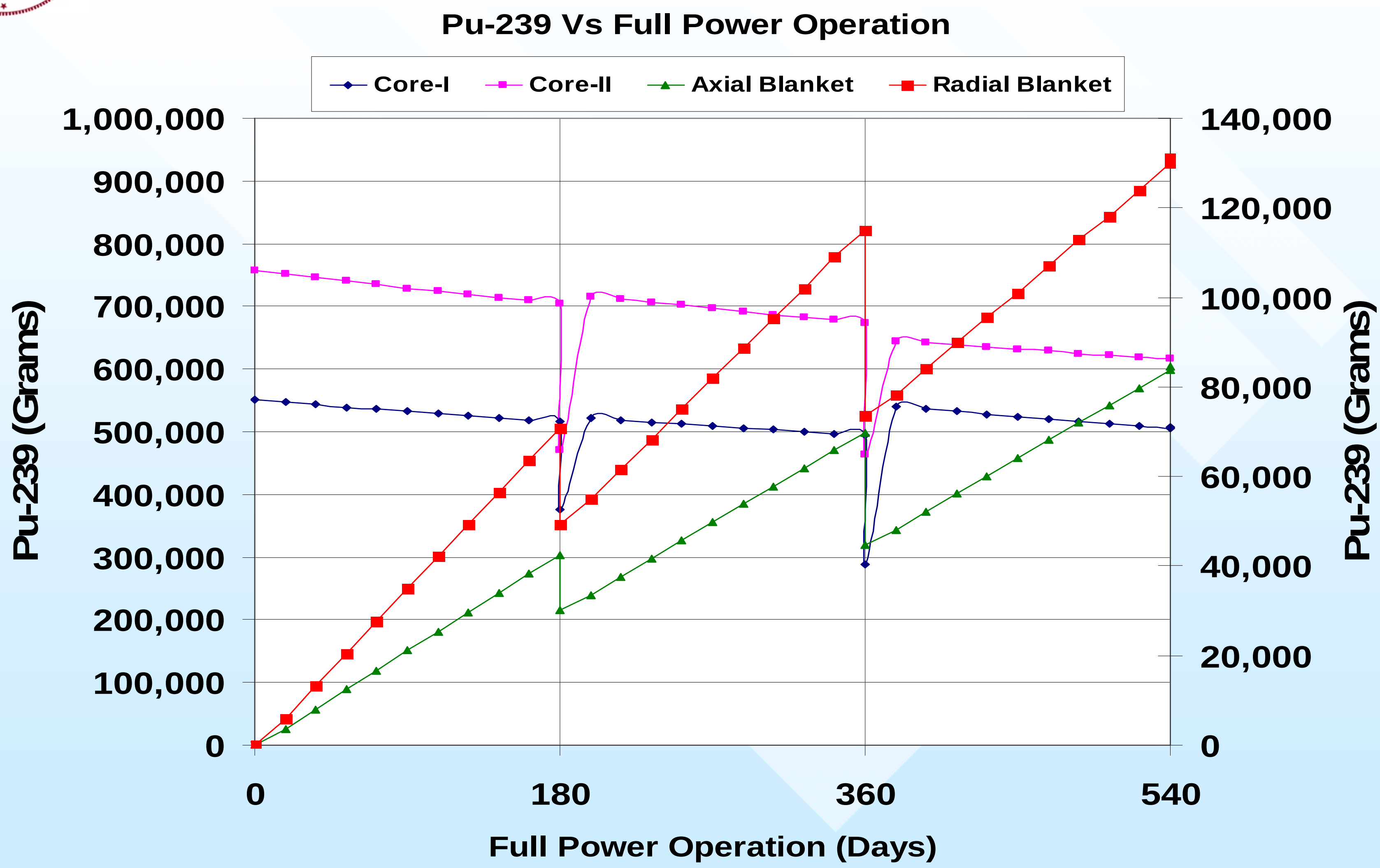

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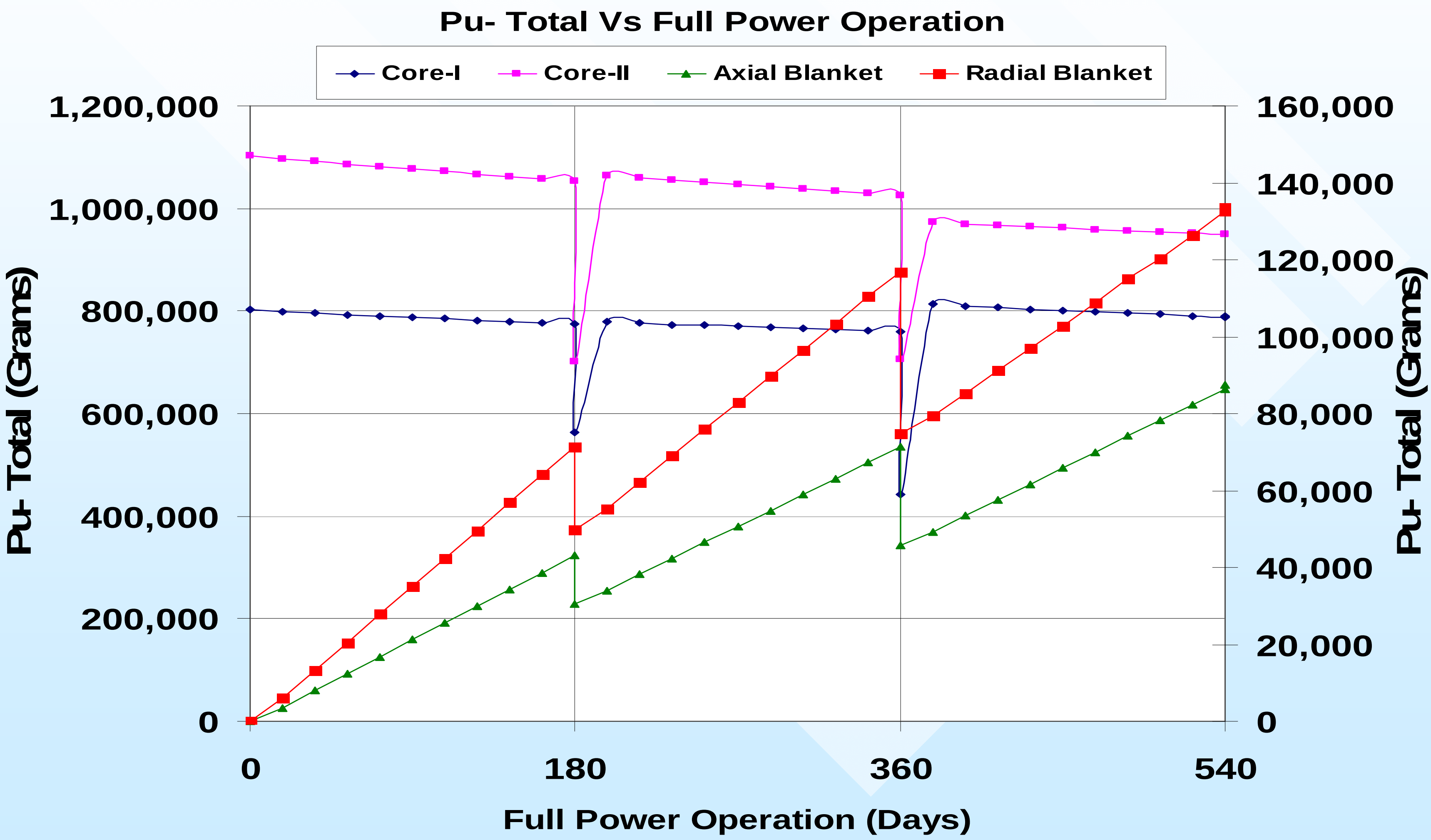

SUMMARY

- A research project on PR assessment of FBRFC is initiated
- Literature survey has been completed on:
  - nuclear material flow diagram
  - PR assessment methodologies
- Assumptions:
  - feed plutonium from spent fuel of CANDU/LWR
  - PUREX for reprocessing
  - depleted uranium in blanket regions
- Computational frame work for material flow diagram:
  - MCNP5 to model FBR core
  - ORIGEN2.2 for burn-up calculations
  - Coupling by MONTEBURNS
- Attribute values PR assessment from Computations
- Semi-quantitative multiplicative MAUA for PR assessment
- The selection of metrics to suit full quantitative GEN IV PR&PP methodology

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