OECD/NEA Executive Group of the NSC
(Data Bank Management Committee)
NEA Headquarters, Issy-les-Moulineaux, June 24-25, 2008

Current Status of Neutronics Code System in Japan

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Contents

- Review of developing neutronics code systems in Japan
- MARBLE development project in JAEA
  - Objectives
  - Software Architecture
  - Burn-up analysis system for fast reactors
  - Database of ZPPR experiment and analysis

Review of neutronics codes in Japan

- No standardized software platform for neutronics code system development

- Development projects in Japan
  - Presented in the latest annual meeting of the Atomic Energy Society of Japan (AESJ)
    - AEGIS/SCOPE2 by NFI, NEL and Nagoya Univ.
    - NGM by MHI
    - MOSRA by JAEA-Tokai (former JAERI)
    - … more …

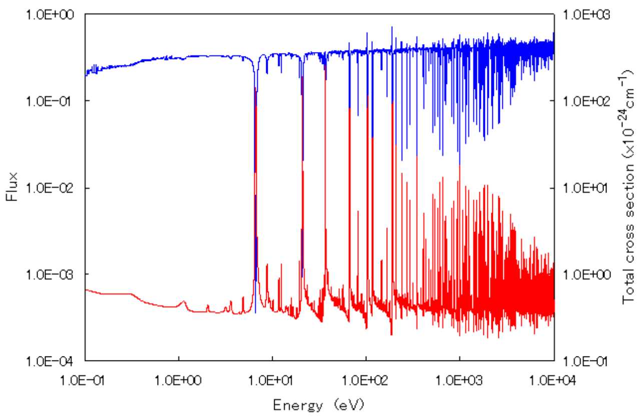
The AEGIS/SCOPE2 System

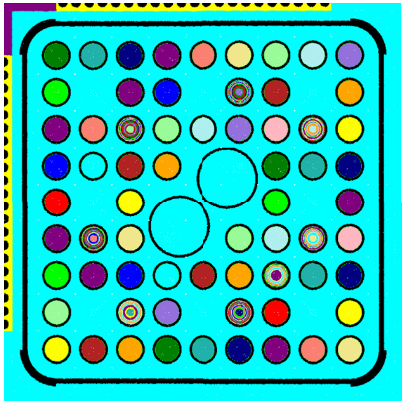
- Next-generation ICFM System by
  - Nuclear Engineering, Ltd. (NEL)
  - Nuclear Fuel Industries, Ltd. (NFI)
  - In cooperation with Nagoya University
- Precise Calculation Models
  - Ultra-fine group spectrum calc. for XS
  - 3-D pin-by-pin calculation (SP3-nodal)
- Practical Computation Time
  - Acceleration and parallel calculation

M. Tatsumi, et al., "Verification of AEGIS/SCOPE2, a Next-Generation In-Core Fuel Management System," PHYSOR 2006, (2006)

Overview of AEGIS

- XS generation
  - Dedicated XS library (AELIB)
    - » H.M 43, F.P. 193, Other 194
  - 32000 gr. UFG spectrum calc.
- Transport calculation
  - 172-group MOC calculation
  - Flexible geometry handling
- Burnup calculation
  - Krylov subspace method
  - Input arbitrary burnup chains

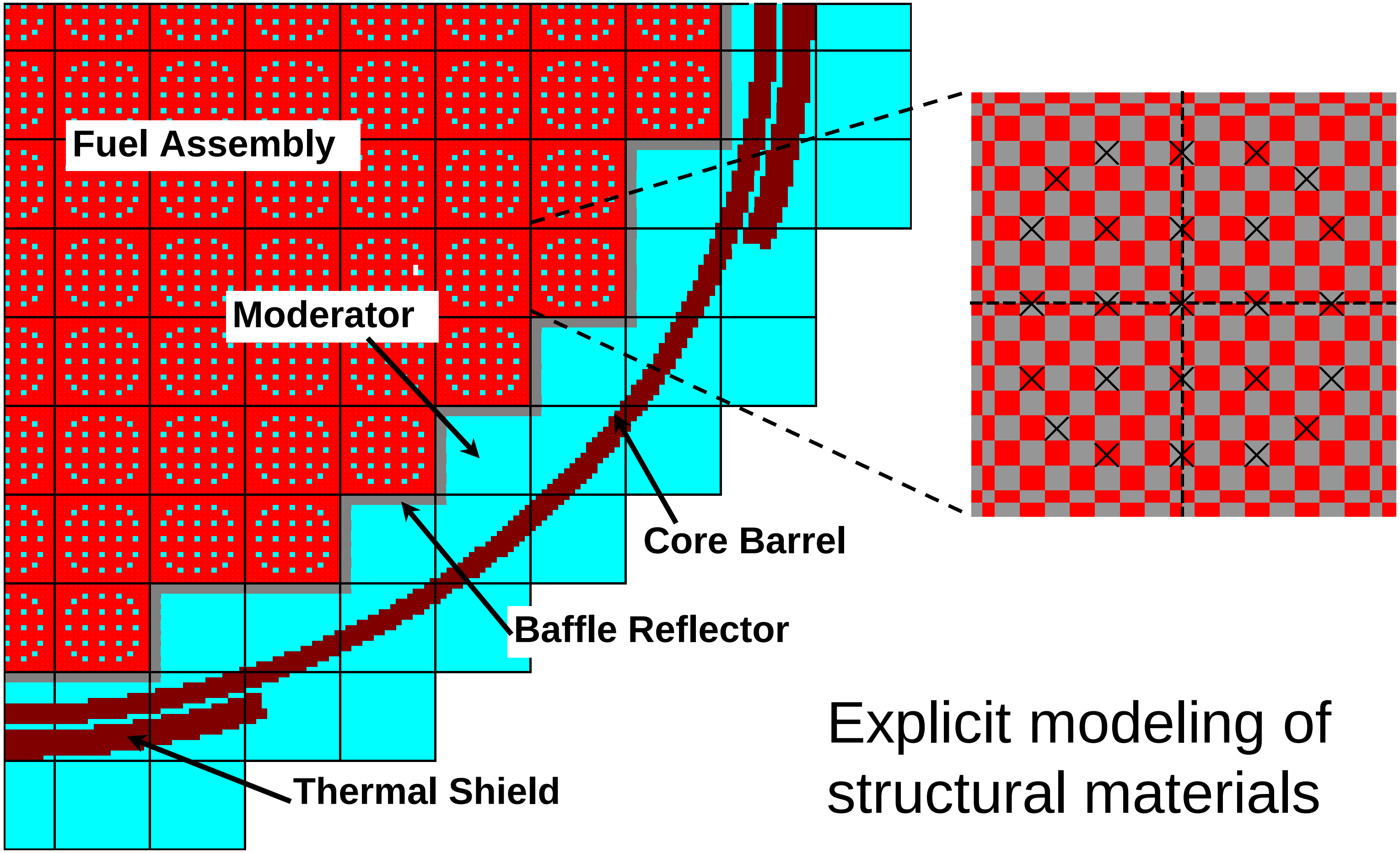




Overview of SCOPE2

- Advanced Core Calculation Code
  - 3-D fine-mesh, pin-by-pin geometry
  - SP3 nodal-transport method
  - 9-group, SPH corrected cross sections
  - Macroscopic/microscopic depletion models
  - Acceleration methods (GCMR, etc)
  - Fully parallelized using MPI (α> 99.7%)
    - » Identical solutions, independent processor configuration

3-D, Pin-by-Pin Fine-Mesh Geometry
(340x340x26 meshes for 4-loop WH type plant)



Explicit modeling of structural materials

NGM: Overview

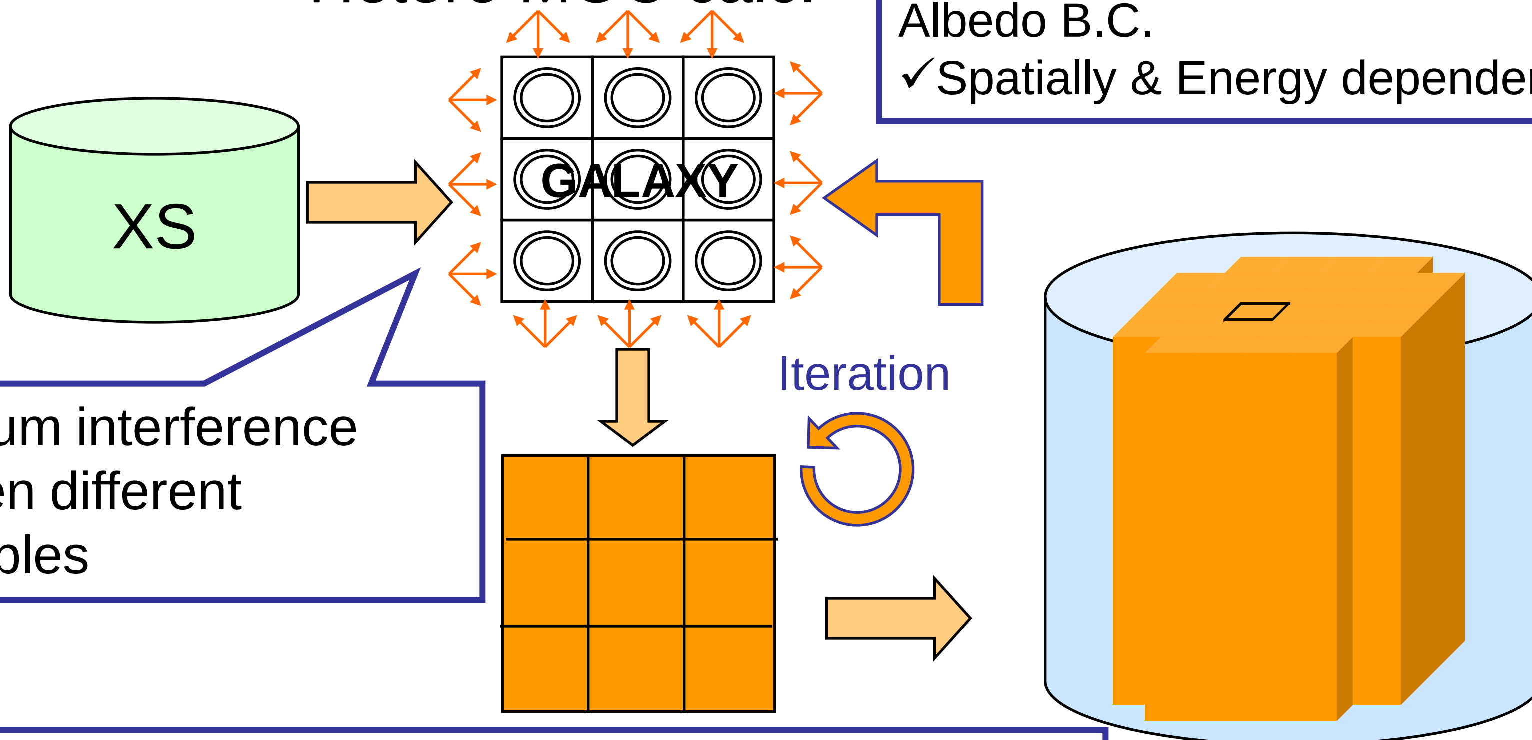
- MHI is developing the next generation method (NGM).
  - High accuracy of pin power
  - Complex geometry such as assembly gap and irregular fuel rod arrangement
- Direct 3D core calculation
  - Pin-by-pin, Multi-group, Transport
- Our NGM can treat cell-heterogeneity.
  - "On-flight" method

⇨ Coupling 2D method of characteristics (MOC) with 3D pin-by-pin S_N

K. Yamaji, et al., "Development of the New Pin-by-Pin Core Calculation Method with Embedded Heterogeneous Assembly Calculation," PHYSOR 2006, (2006)

NGM: On Flight Method

Hetero MOC calc.



Albedo B.C.
✓Spatially & Energy dependent

Spectrum interference between different assembles

Cell homogenous XS
✓Leakage consistent SPH factor
between hetero. and homo. calculation

3D pin by pin
Nodal S_N calc.

MOSRA: Background & Objectives

Development of SRAC

1978 --

:

2007 SRAC2006 Release

Completion of SRAC

- **Obsolete base design**
- **Constraint to extend (e.g. I/O compatibility)**
- **Complexity of the system**

MOSRA (MOdular code System for Reactor Analyses)

Combination, addition and deletion of modules

- **Upgrading of analysis methods**
- **Diversifying into various types of reactors**
- **Reducing costs of maintenance and development**

K. Okumura, et al., "Development of Modular Reactor Analysis Code System MOSRA," AESJ2008, (2008)

MOSRA: System Components

Library processing module (LibMakers)

Cell calculation module (M-SRAC, J-MOC)

Core calculation module (M-Citation, Partisn+, M-Light)

Thermal-hydraulics module (M-Hydro)

Fuel temperature calculation module (M-Fondu)

Feed-back cross section calculation module (M-Macron)

Reaction rate/reactivity editing module (More-MOSRA)

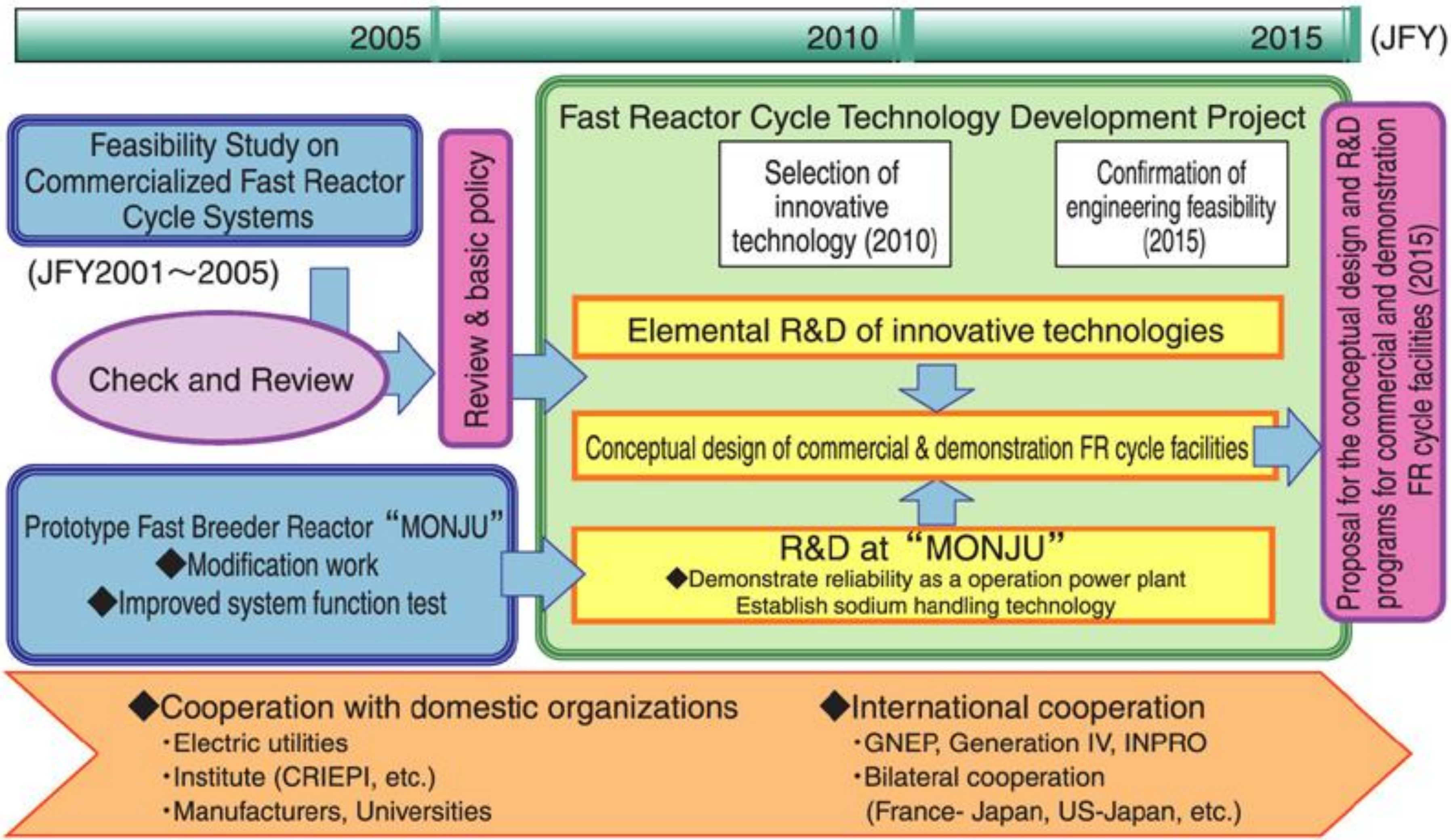
Data interface module (PonPon)

Coupled neutronics/thermal-hydraulics core burn-up calculation frame (M-FCBT1)

MARBLE by JAEA-Oarai

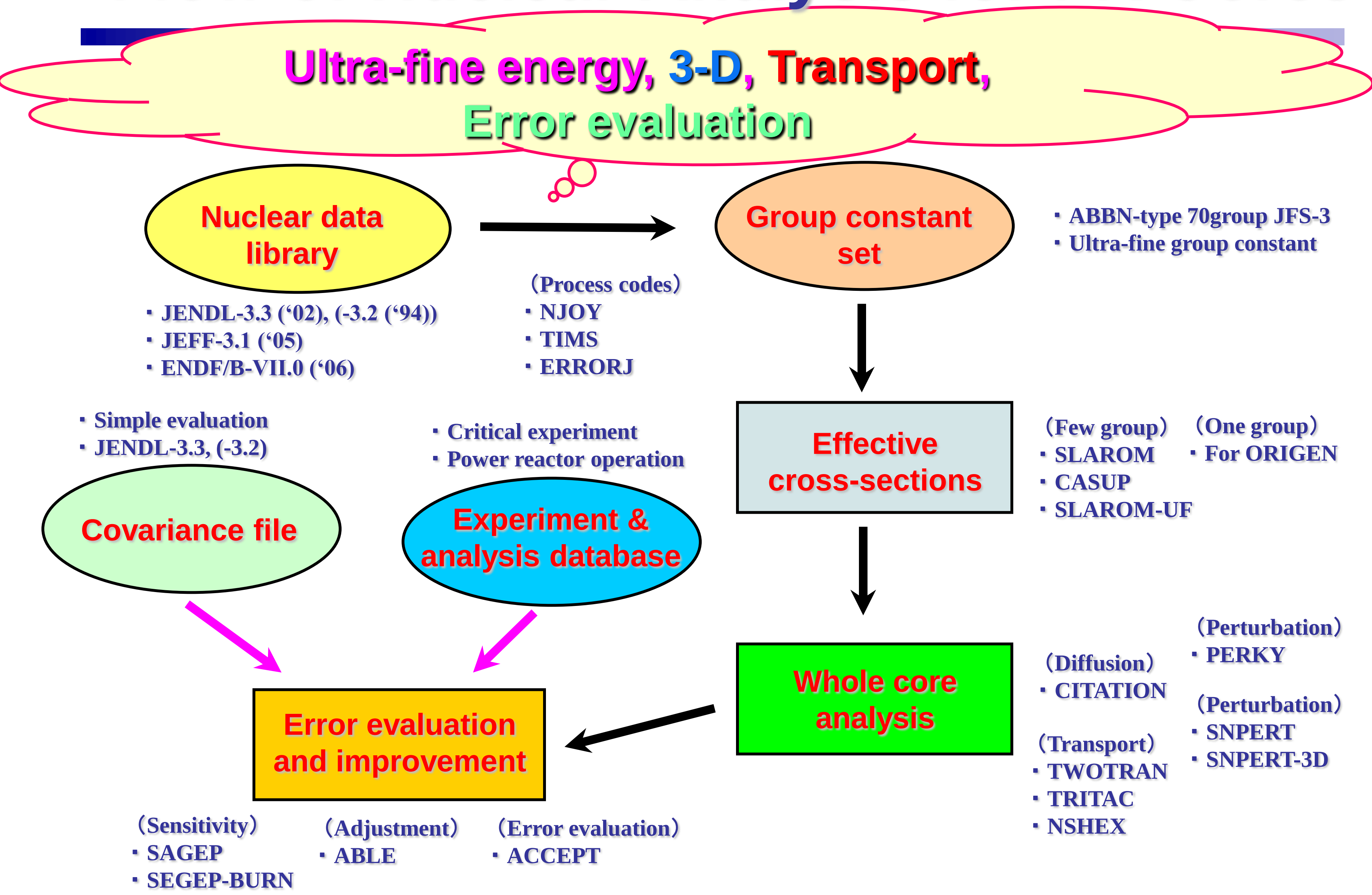
- Background
- Objectives
- Software architecture
- Burn-up analysis system for fast reactors
- Database of ZPPR experiment and analysis

FaCT Project in JAEA



Fast Reactor Cycle Technology Development Project (FaCT)

Flow of Nuclear Analysis for FR Cores

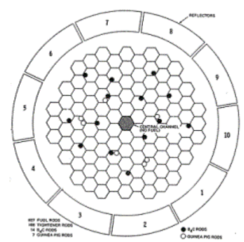


Core Experimental Data

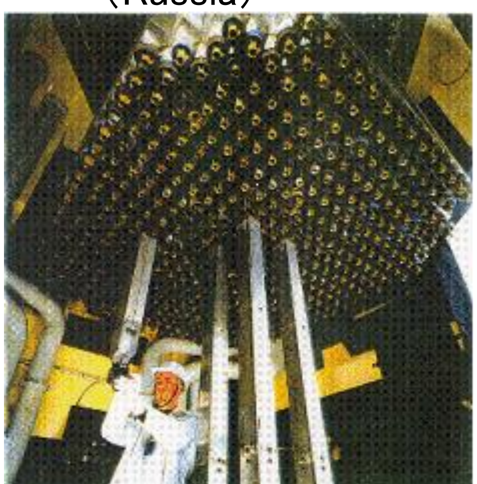
BFS-2
(Russia)

JOYO（Japan）

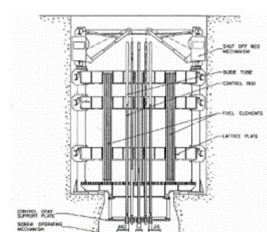
ZPPR（USA）



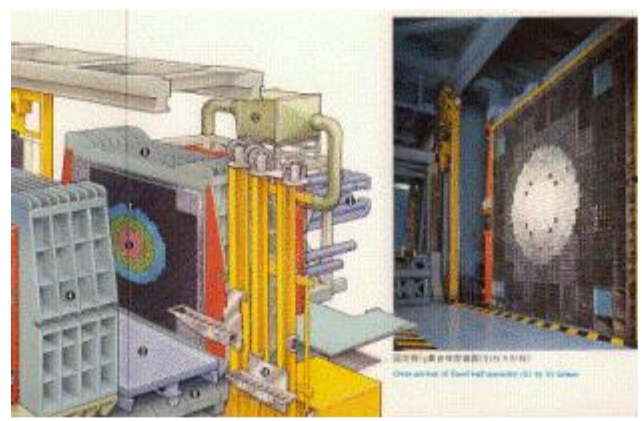
SEFOR（USA）



MASURCA（France）



ZEBRA（U.K.）



FCA（Japan）

Problems in Conventional System

- Troublesome and/or too-many inputs
- Complicated input cards
- Difficulties in data conversion among codes

⇨

- **Inefficient processes in analysis**
- **Poor quality management**

Aim for improved efficiency and quality with rational automation mechanism.

MARBLE Project (1/2)

New reactor physics analysis code system MARBLE (Phase 1: JFY2006—JFY2009)

- To improve the quality of analysis and software
  - Reliability, reusability, maintainability, and extendibility
- Power reactor analysis with fuel depletion
- Common data model for major calculation routes

*MARBLE: Multi-role Advanced Reactor Physics Analysis System Based on Language of Engineering

MARBLE Project (2/2)

Developing Schedule

MARBLE		H17 (2005)	H18 (2006)	H19 (2007)	H20 (2008)	H21 (2009)
						Ver.1
Burnup analysis system of fast reactors	Phase 1	Design	Prototype			
	Phase 2				Final	
Framework for two-layer system	Framework		Design	Implementation		
	Cross-section adjusment & design accuracy evaluation system				Design Implement	
Database Development	Experiment/analysis database					
Tool developmemt	Interface of interchangeablity					
Solver development	Cell caculation solver	SLAROM-UF		V1		V2
	Whole core calculation solver	Prototype	V1			V2
	Burnup calculation solver		Design・implementation			
	Perturbation & sensitivity solver			Restructuring		
	Cross-section adjusment & design accuracy evaluation solver		Design Implementation			
	New physics model			Basic theory study		

- **Resources**
  - **~5 man / yr**
  - **90,000 euros / yr**
- **Scope**
  - **Until JFY2009**
    - **Replacement of the conventional code system for fast reactors**
  - **After JFY2010**
    - **Extension of functionality**
    - **Application to other types of reactors**

End of JFY2009
MARBLE Ver. 1

Goals for MARBLE Ver.1 (1/2)

- All major existing calculation routes on new software architecture
  - Replacement of JOINT-FR and SAGEP-FR
  - Two-layer system with object-oriented languages Python and C++
  - Based on common data models
    - both for critical assemblies and power reactors

- Extension of calculation routes
  - Burn-up analysis for fast reactors

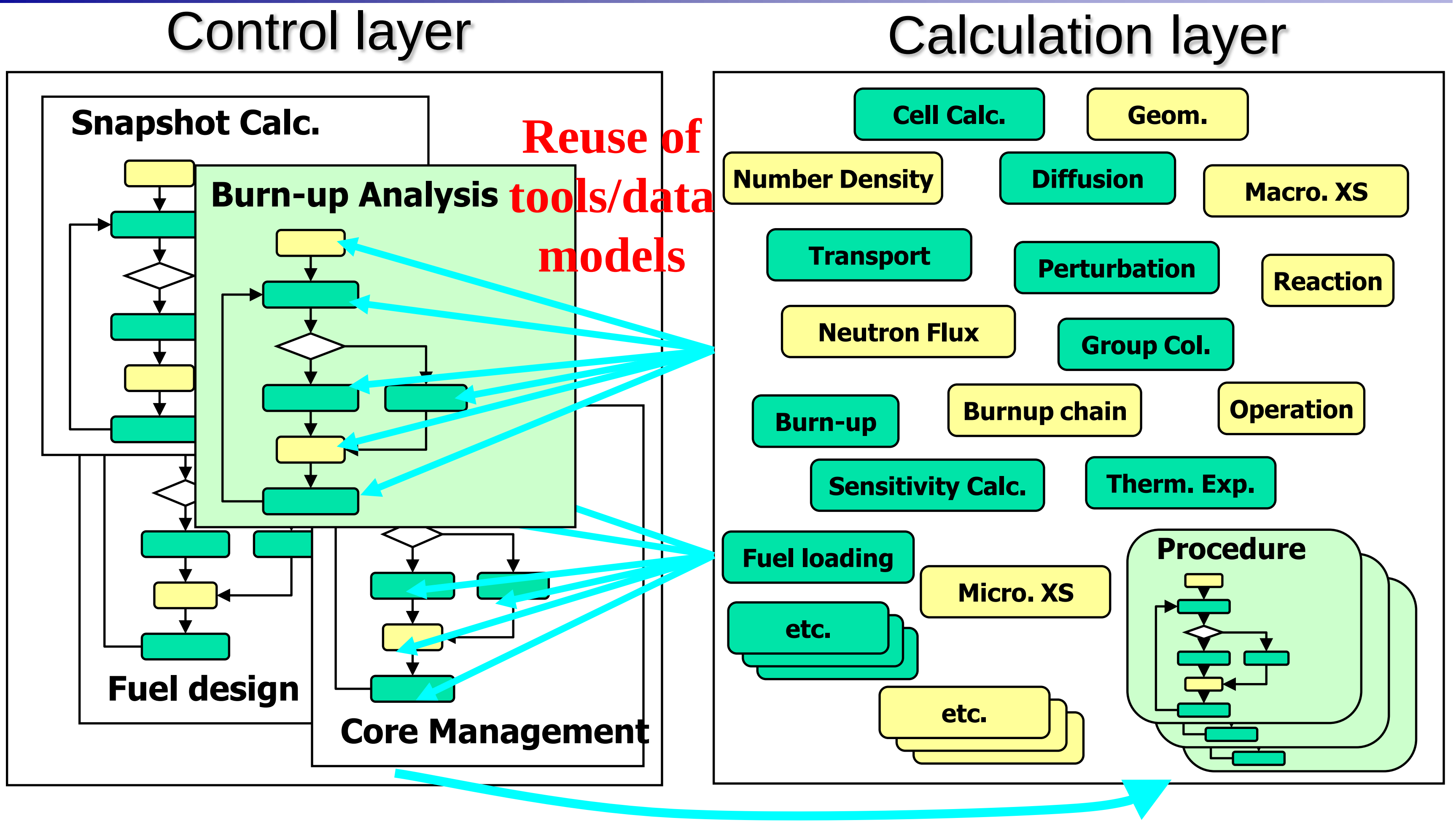
Goals for MARBLE Ver.1 (2/2)

- Improvement of operating efficiency
  - Management of database for fast reactor core nuclear design (~2000 parameters)
  - Semi-automatic analysis with the database

Target time order for major calculation routes

Calculation route	Model	Calculation example	Target time order
Critical assembly	Detail	Recalculation DB for XS adjustment (~200 parameters)	week
Power reactor	Detail	"JOYO" tracking calculation (~30 cycle)	day
Design analysis	Simple	A major parameter for a new fast reactor	minute

MARBLE Architecture



- MARBLE consists of common tools/data models
- New sub-system (e.g. burn-up analysis) also consists of common tools/data models

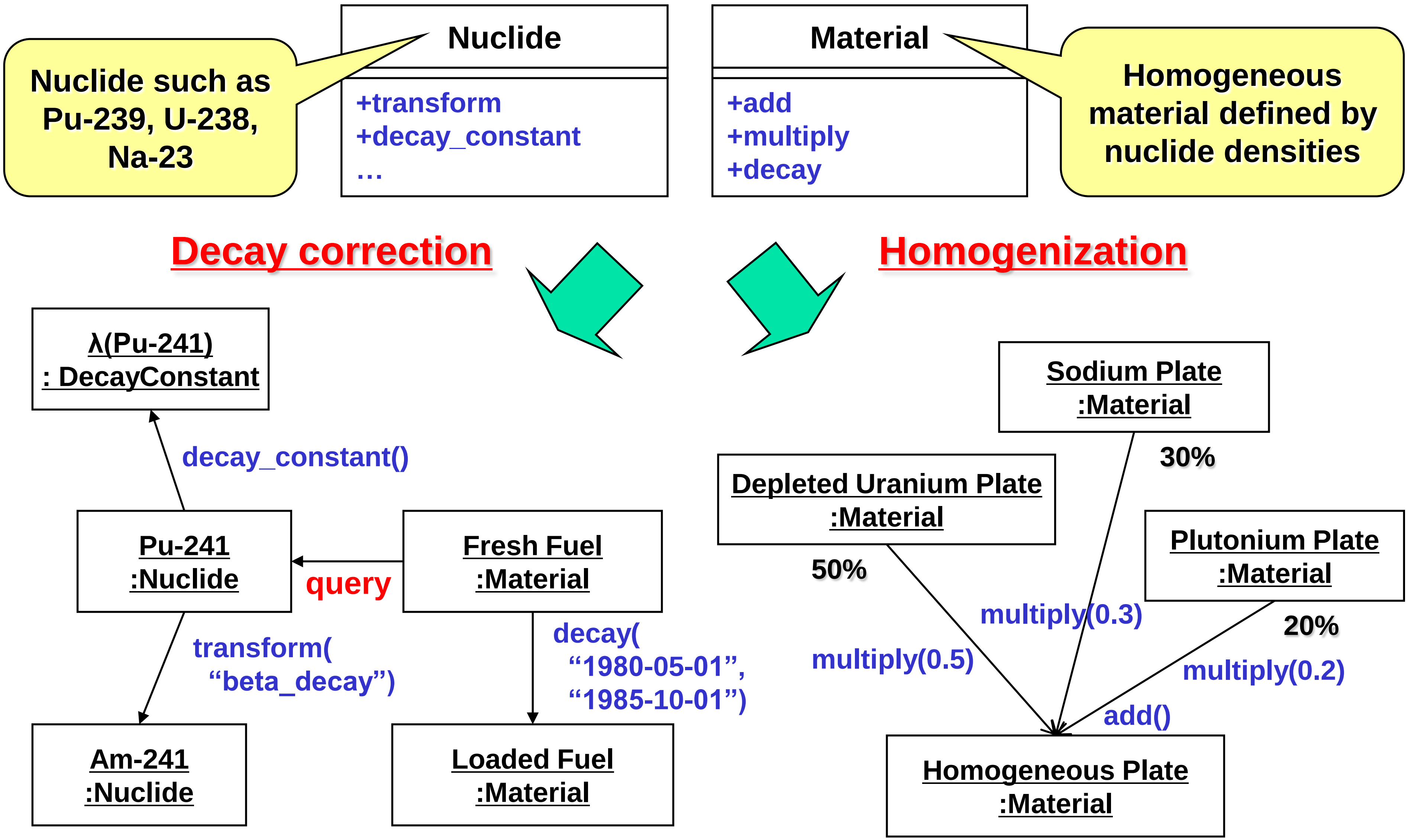
MARBLE Modules

Common Data Models

- Model
  - Quantity
    - Mass, Length, Substance, …
  - Material
    - Nuclide, Material, ReactionType, EffectiveCrossSection, …
  - Coordinates
    - Xyz, Triz, Hexz, Zone, …
  - Geometry
    - Point, Line, Circle, Hex, …
  - Mesh
    - MeshConverter,…
  - Pattern
    - Assembly, LoadingPattern, …
  - Info
    - CoreInfo, CrossSectionInfo, …
  - Solver
    - CitationSolver, TritacSolver, …
- Orpheus (burn-up analysis)
  - Input
    - CalcCondition, InputInterface
- Code
  - Adjust
    - XSAdjustment, BiasMethod, Parameter, Covariance,…
  - Burn
    - Burnup, BurnupChain, …
  - CBG
    - PLOS (diffusion)
    - SNT (transport)
- Utils
  - ConventionalCodeUtils
    - SLAROM-UF
    - JOINT-FR
    - SAGEP-FR
  - Python
    - FortranUtils

Designed to be re-usable and identical to neutronic concepts

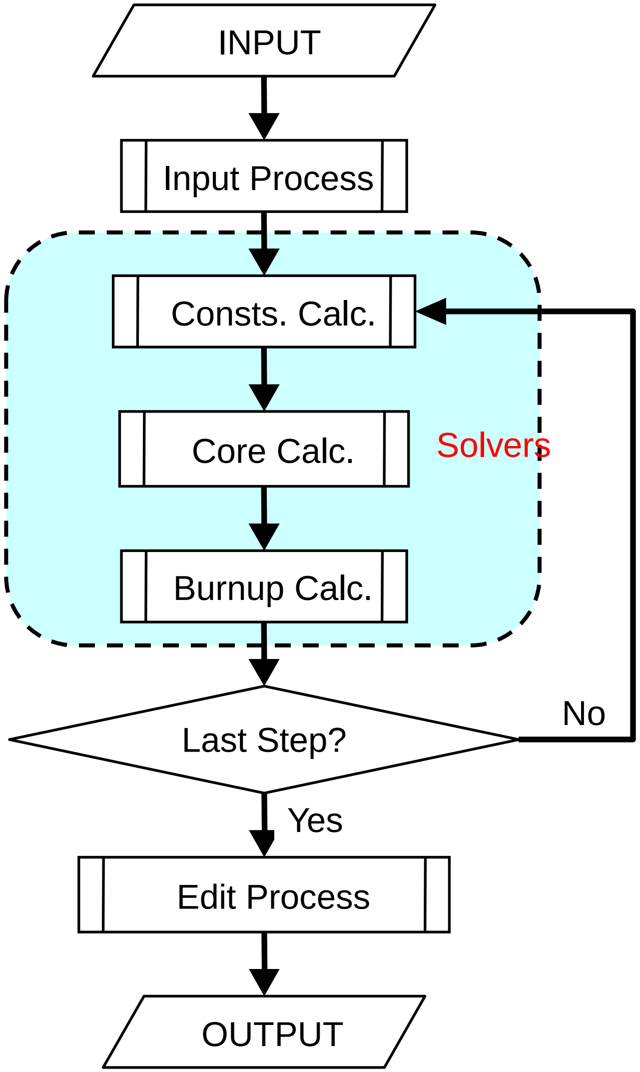
Re-use of Data Models



Requirements for Burn-up Analysis

- Adopt arbitrary calculation codes : lattice code, diffusion/transport codes…
- Treat “meta inputs” such as geometry/material composition/fuel loading pattern…
- Realize automatic input/output conversion among various codes
- Switch codes for analysis routes with ease

Burn-up Analysis System Overview

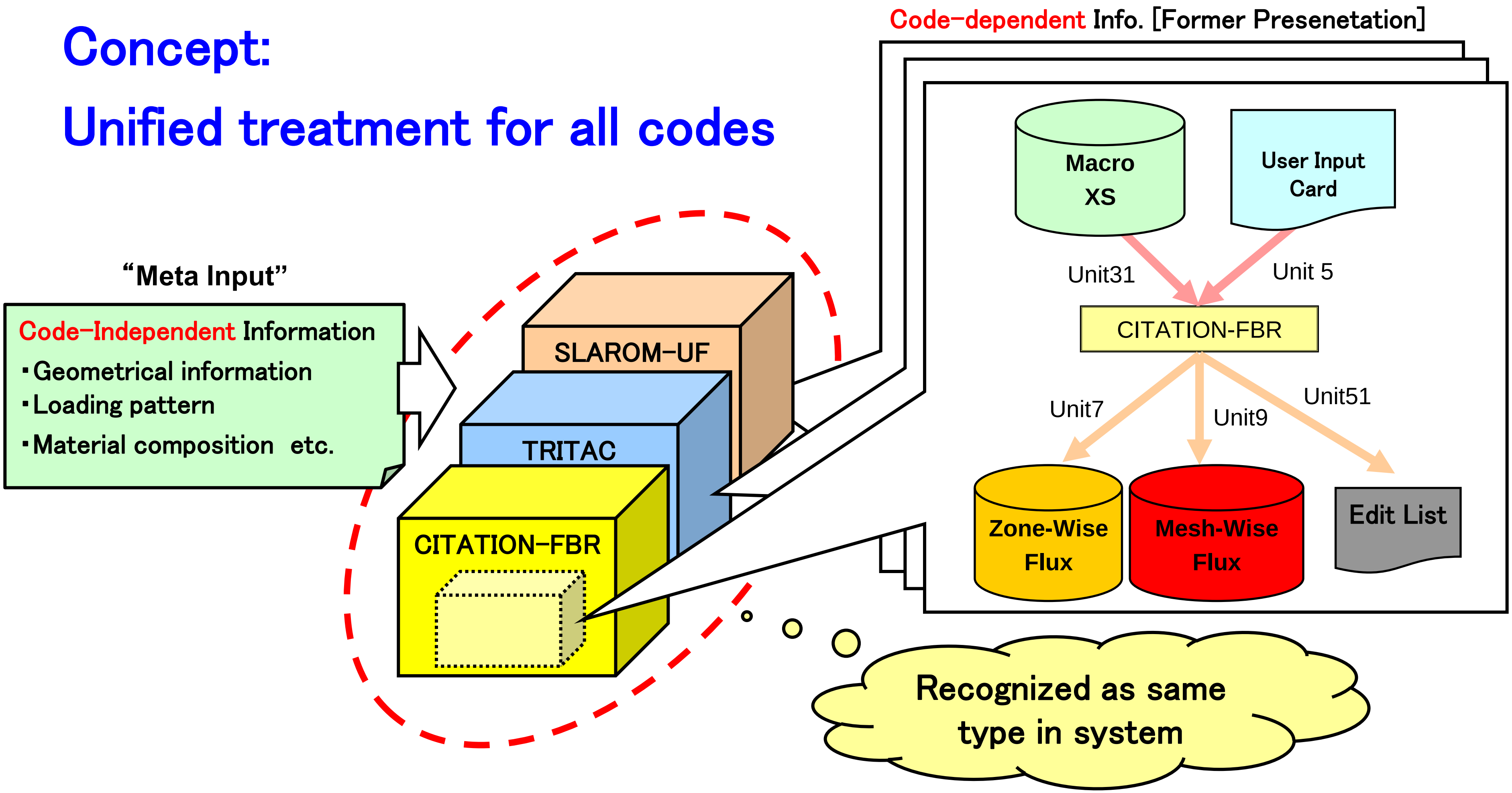


- Input Process
  - Input read, data preparation
- Constants Calculation
  - Calc. of microscopic cross sections
- Core Calculation
  - Calc. of neutron flux/reaction rates
- Burnup Calculation
  - Number densities
- Edit Process

Design and Implementation of
Solver Management Mechanism

Solver Management (1/3)

Concept:
Unified treatment for all codes



Control calculation codes with "meta input"

Solver Management (2/3)

Material Composition

```
material:
- name: fuel1
  composition:
  - ["U-234", 1.0e-20]
  - ["U-235", 0.00196132]
  - ["U-236", 7.76703e-10]
  …
```

Fuel Loading Pattern

```
fuels:
  - label: PFD066
    type: fuel_pfd1

load_fuels:
  - { address:  1A1, label: PFD066 }
  - { address:  1C1, label: PFD067 }
  - { address:  1E1, label: PFD068 }
  - { address:  2B1, label: PFB010 }
  - { address:  2E2, label: PFC010 }
…
```

Calc. Condition

```
calc_system:
  coordinates:
    core  : xyz
    burnup: xyz

solver:
  core:
    name: tritac
  burnup:
    name: burnup

step:
  - period: 13.905
    power : 97.394

  - period: 13.905
    power : 97.394
…
```

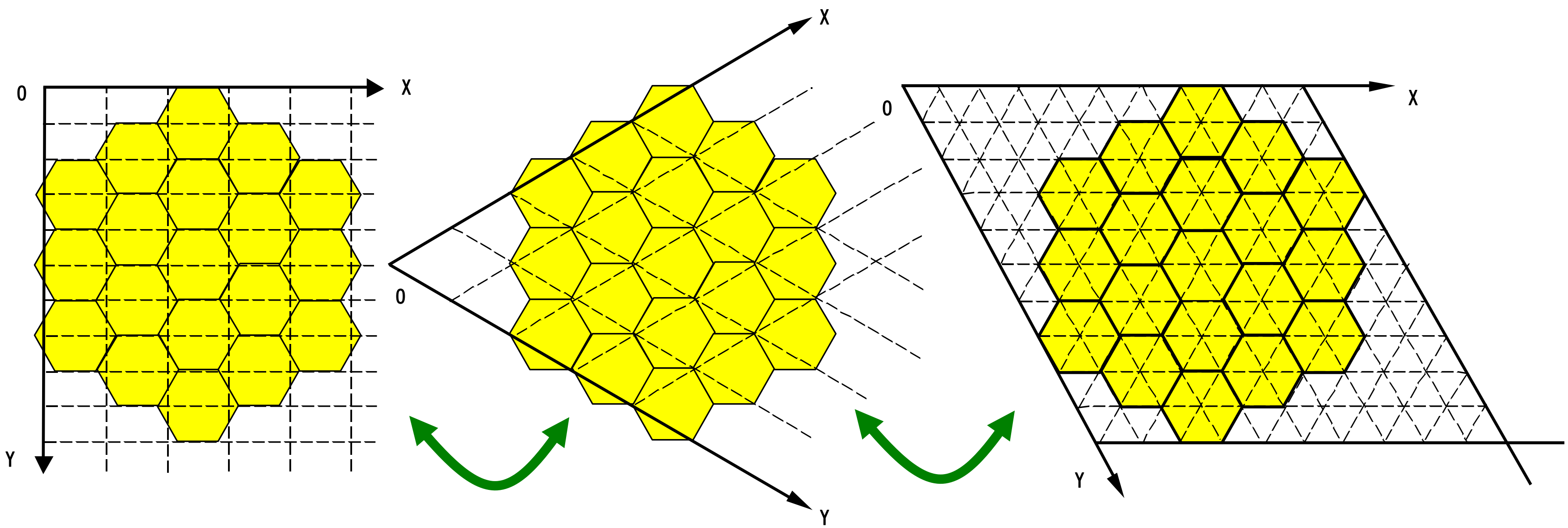
TRITAC：XYZ System

```
JOYO MK-2 Burn-UP  100.00MW x 27.81day  2781.00MWD  0cy  13.9050day x 2
        0
  1  1  0    0    0         0  1  1  0
       21        42        96        70        555        8
       21        42        18
        0         0         0         0         0         0
 1.00000E-04 1.00000E-04 1.00000E-05    1    10 99999.00000    0.00000
       10 1.00000E-02 1.00000E+00       900
   1   1   1   1   1   1   1   1   1   1   1   1
   1   1   1   1   1   1   1   1   1 E
   1   1   1   1   1   1   1   1   1   1   1   1
   1   1   1   1   1   1   1   1   1   1   1   1
   1   1   1   1   1   1   1   1   1   1   1   1
   1   1   1   1   1   1 E
   5  17  10   6   6   1   3   2   1   4   2  10
   1   3   3  12   2   8 E
    0.0000     7.0855     14.1710     21.2565     28.3420     35.4275
   42.5130    49.5985     56.6840     63.7695     70.8550     77.9405
   85.0260    92.1115     99.1970    106.2825    113.3680    120.4535
  127.5390   134.6245    141.7100    148.7955  E
    0.0000     4.0908      8.1816     12.2724     16.3633     20.4541
   24.5449    28.6357     32.7265     36.8173     40.9082     44.9990
   49.0898    53.1806     57.2714     61.3622     65.4531     69.5439
…
```

Minimum change to switch the calculation code!

Solver Management (3/3)

- Automatic construction of computational mesh system with lattice geometry information and fuel loading pattern
- Interoperability between different mesh system
  - Ex. Tri-Z for core calculation and Hex-Z for burnup calculation

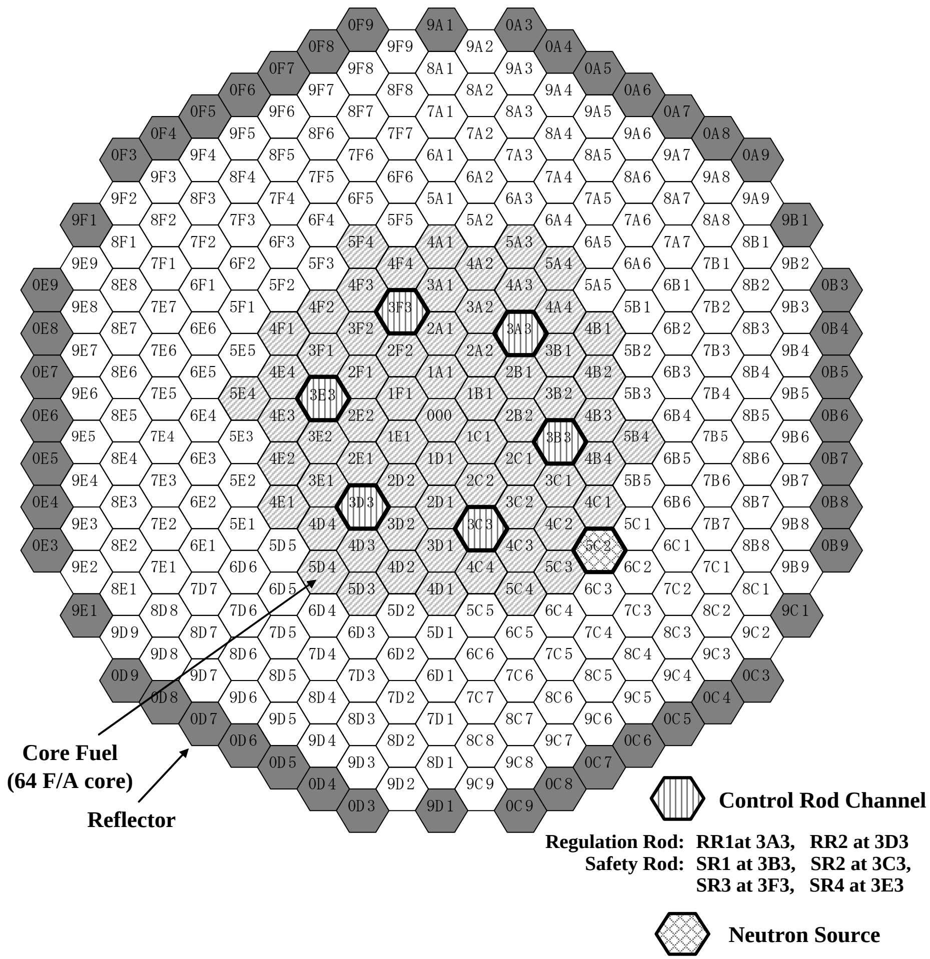


XYZ System **Hex-Z System** **Tri-Z System**

No need to worry about mesh conversion!

Verification (1/2)

- Burn-up reactivity coefficient of JOYO MK-I



Item	Specification
Core fuel Pu weight fraction (w/o) Fissile Pu ratio (w/o)	U-Pu mixed oxide 17.7 80.4
Blanket fuel	Depleted-U oxide
Coolant	Sodium
Absorber	Boron carbide
Reactor thermal power (MW)	50
Core fuel height (mm)	600
Equivalent core diameter (mm)	~720
Axial blanket thickness (mm)	400
Radial blanket thickness (mm)	~300

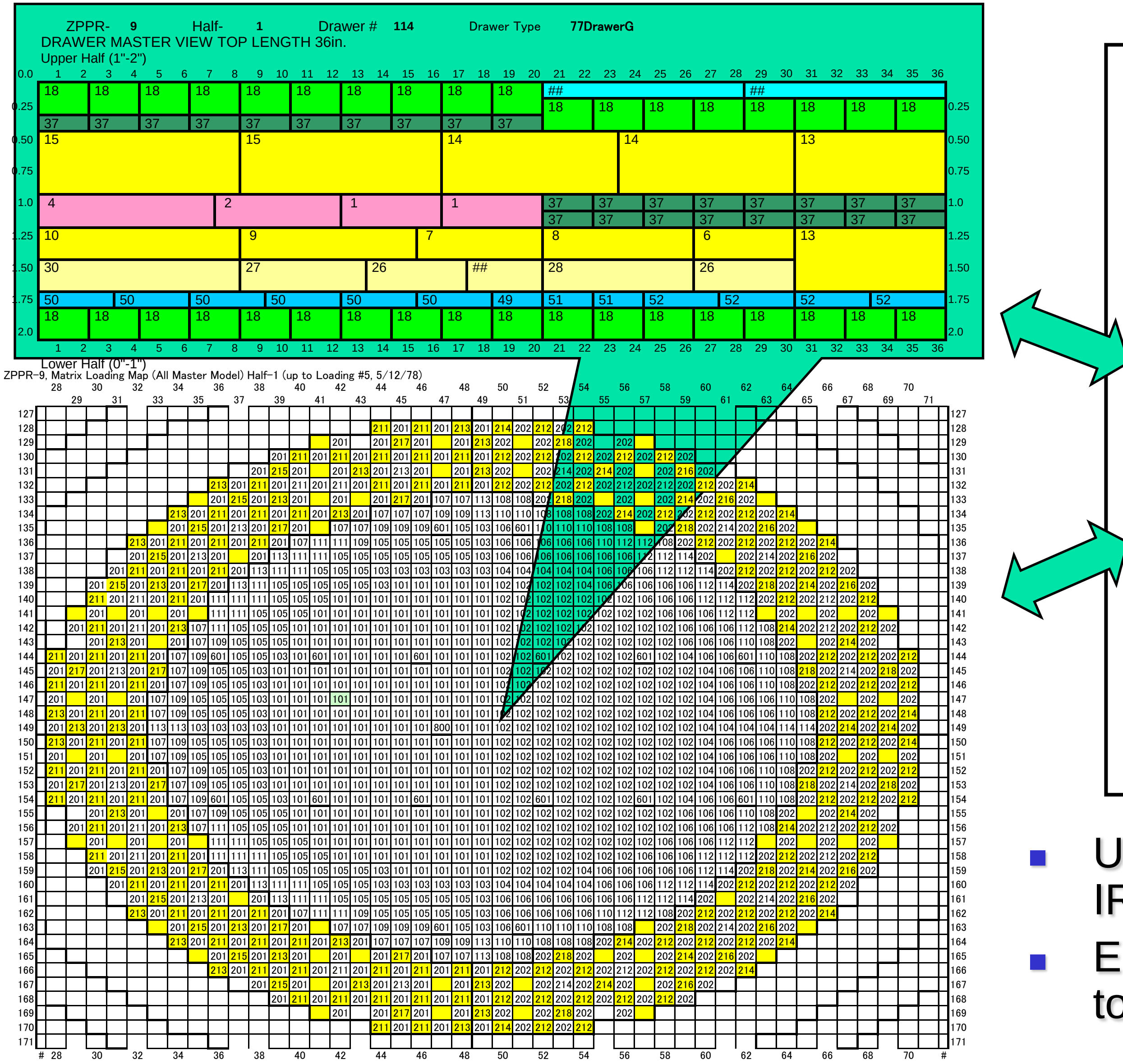
Verification (2/2)

Calculation results of the burn-up reactivity coefficient measured in JOYO MK-I 50MW power-up test

		JENDL	
		3.2	3.3
Base calculation [a]		-0.797	-0.801
Correction factor [c]	Heterogeneous cell	0.998	
	Ultra-fine group	0.999	
	Transport & mesh	1.012	
	CR position [b]	1.036	
Corrected calculation		-0.835	-0.831
Experiment [a]		-0.80	
C/E		1.038	1.041

[a] burn-up reactivity coefficient (unit: 10^{-4} dk/kk'/EFPD)
[b] control rod interaction effects evaluated by JOINT-FR (conventional code system)
[c] Calculated with JENDL-3.2

ZPPR Database



ADEN data
(Isotopic weight per plate)
…
Plate No. 93 : Pu-239 130g
…

Drawer data
(Plate arrangement in a drawer)

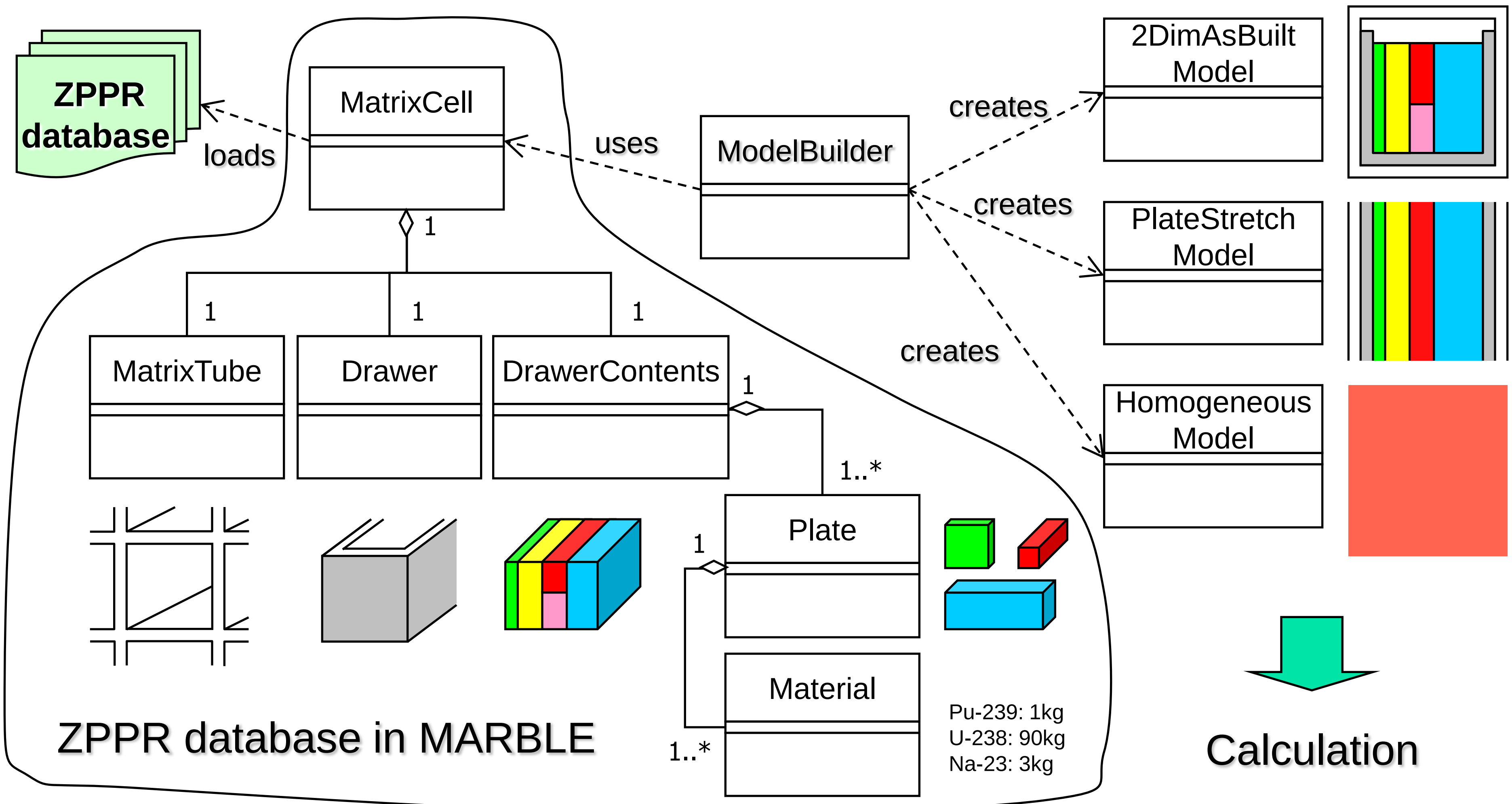
AMM Map data
(Drawer position In a ZPPR core)

ZPPR database

- Under re-evaluation for IRPhE project
- Enormous number of data to be managed

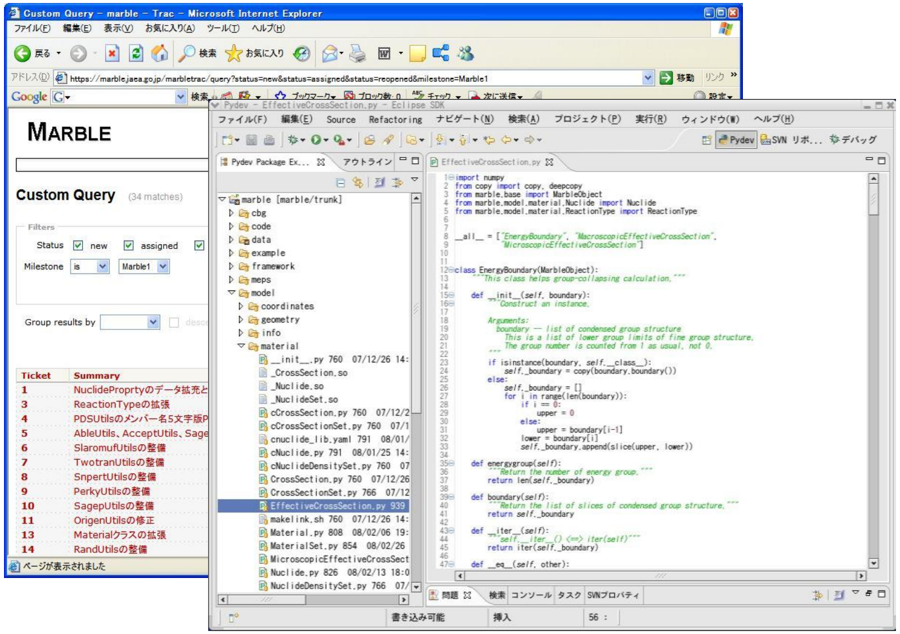
Database Management

- Keeping all as-built data and supplying the data to users
- Systematic creation of calculation models



Development Methodology

- Object-Oriented Analysis and Design
  - Modeling in UML（Unified Modeling Language）
  - Agile Development Scheme
  - Iterative and incremental development
  - Test-first programming
  - Active refactoring, …etc.



- Rapid Implementation with Python Scripting Language

- Development Tools
  - Subversion(version control), Trac (bug tracking), Eclipse (IDE) etc.

Improved quality and efficiency in development using modern practices and tools

Concluding Remarks

- Review of recent developing projects in Japan
  - A lot of efforts for next generation code systems
    - AEGIS/SCOPE2 by NFI, NEL and Nagoya Univ.
    - NGM by MHI
    - MOSRA by JAEA

- Development of MARBLE by JAEA
  - MARBLE Ver.1 for fast reactors (end of JFY2009)
    - Replacement of the conventional code system JOINT-FR and SAGEP-FR
    - Better burn-up analysis system for nuclear design
    - Improving database management for experiment and analysis