CBZ: the deterministic reactor physics code system

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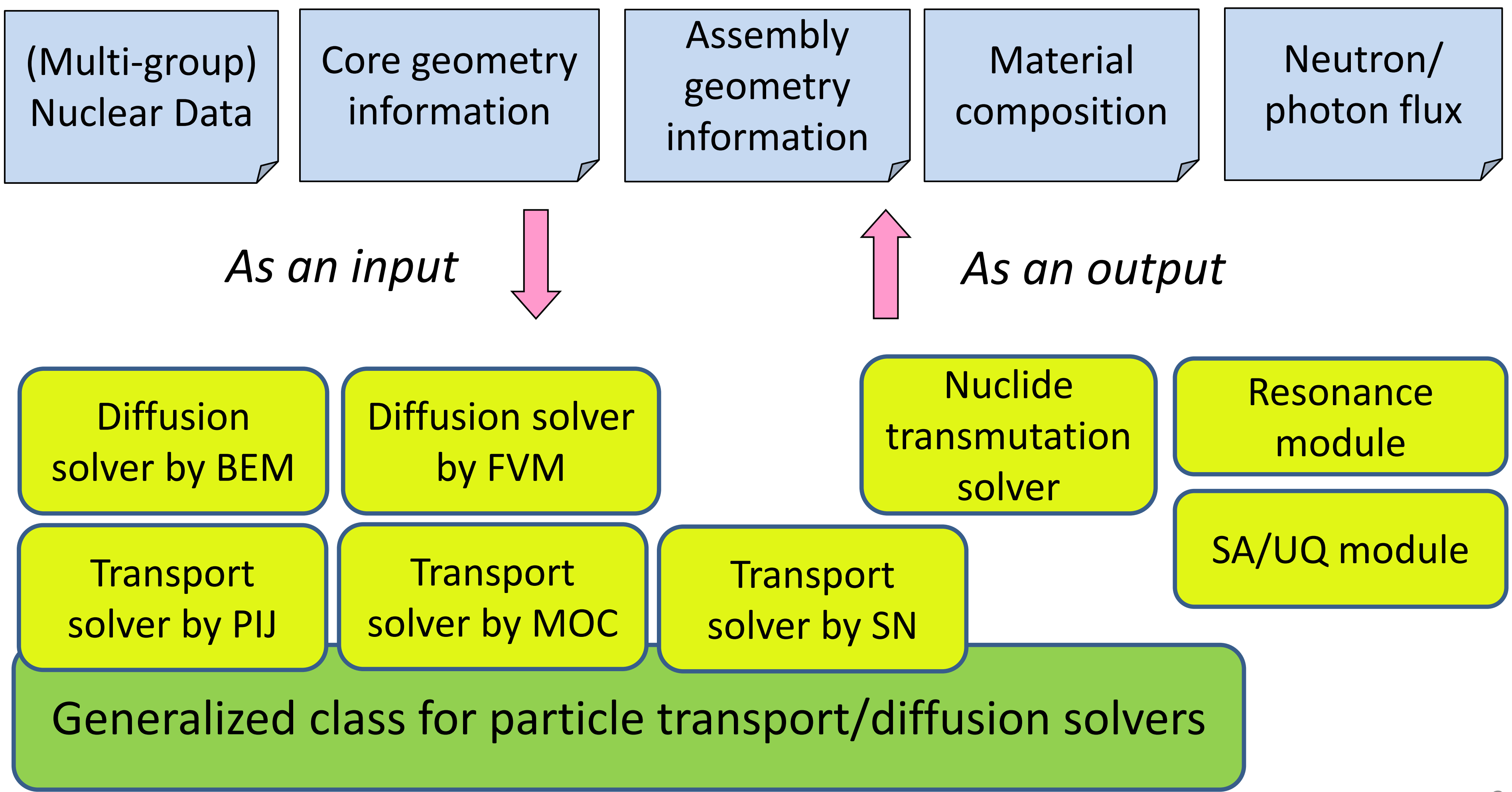
CBZ: a deterministic reactor physics code system

- At JAEA, the new R&D project about the next-generation reactor physics code system was launched in 2002.
- Before that, almost all the reactor physics programs were developed with FORTRAN-77 in Japan. To improve extensibility, maintainability and reusability of code systems, the object-oriented computer languages such as C++ and Python were adopted in this project.
- As one of the prototypes, the original version of CBZ, CBG, was developed by myself with C++.
- After moving to Hokkaido University in 2011, a new version, CBZ, has been being developed.

CBZ: a deterministic reactor physics code system

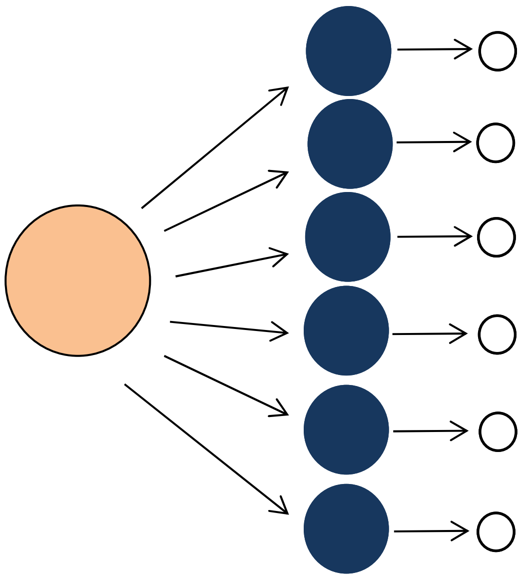
Various kinds of reactor physics calculations can be easily realized by CBZ.



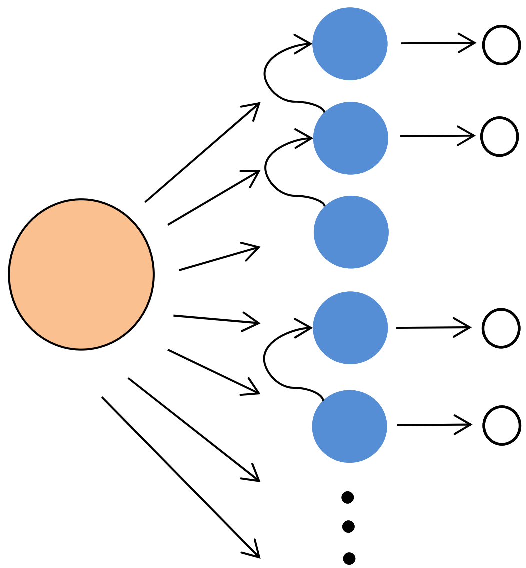
Explicit Fission Product (EFP) model for kinetic calculations

- We have proposed an explicit fission products (EFP) model for spatially-dependent kinetics calculations.
- With this model, time-dependent energy deposition by prompt/delayed neutrons/gamma-rays can be explicitly treated.

Six-(or eight-) group model



EFP model

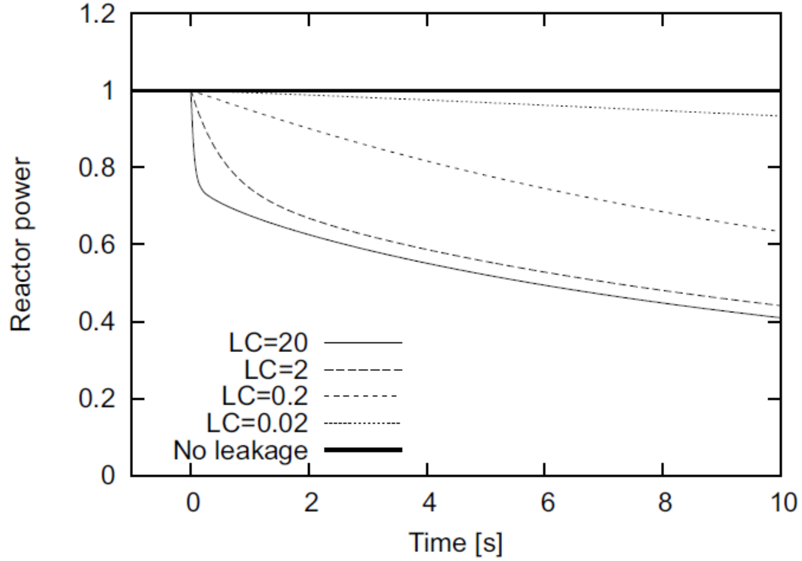


Nuclear data given to each FP such as fission yield, decay constant and Pn values, are directly used.

K.Katagiri, G.Chiba Spatially-dependent nuclear reactor kinetic calculations with the explcit fission product model, Ann. Nucl. Energy, 133, pp.202-208 (2019).

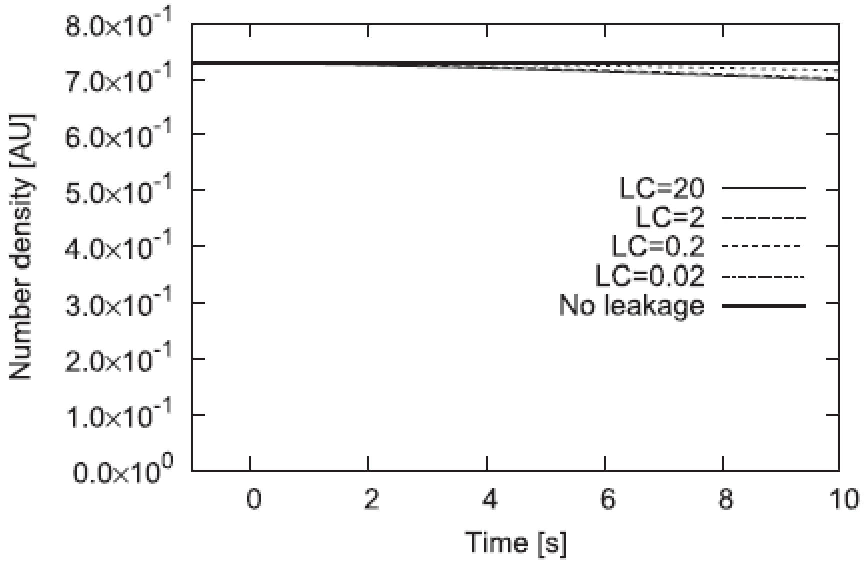
Explicit Fission Product (EFP) model for kinetic calculations

Transient of gaseous FP (Kr, Xe, I) leakage in a critical condition can be simulated:

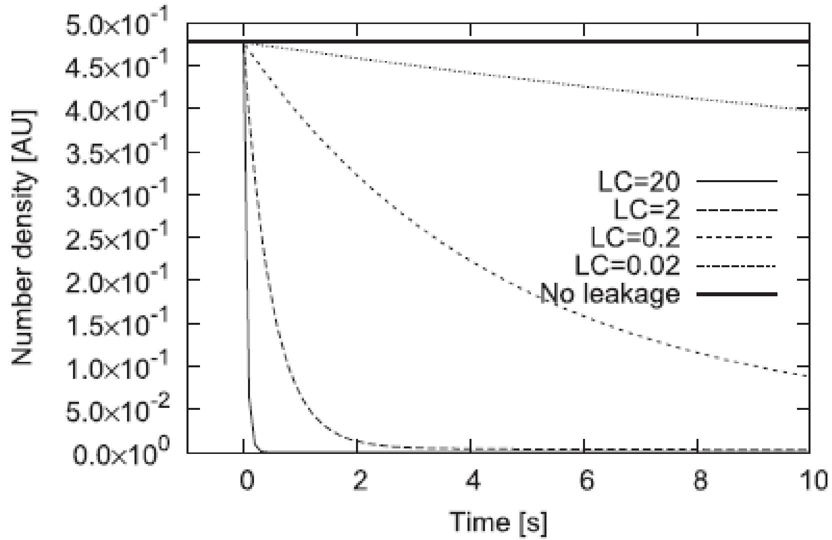


- Negative reactivity is inserted because of the leakage of I-137, one of main delayed neutron precursors.
- Inserted negative reactivity is dependent on the leakage constant of the gaseous FP.

(a) Br-87

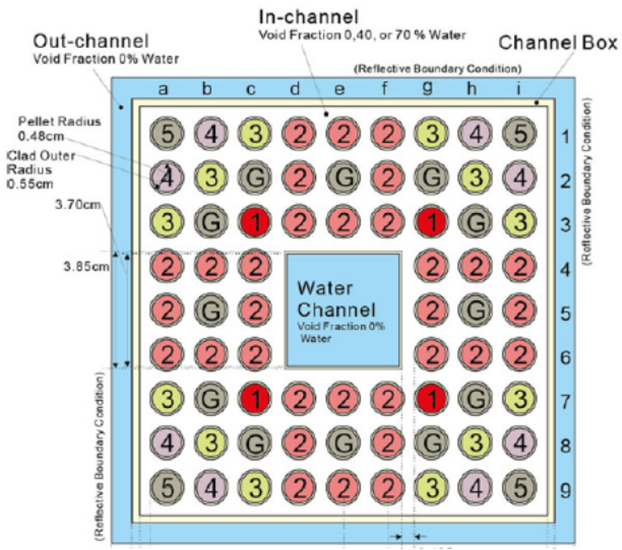


(c) I-137

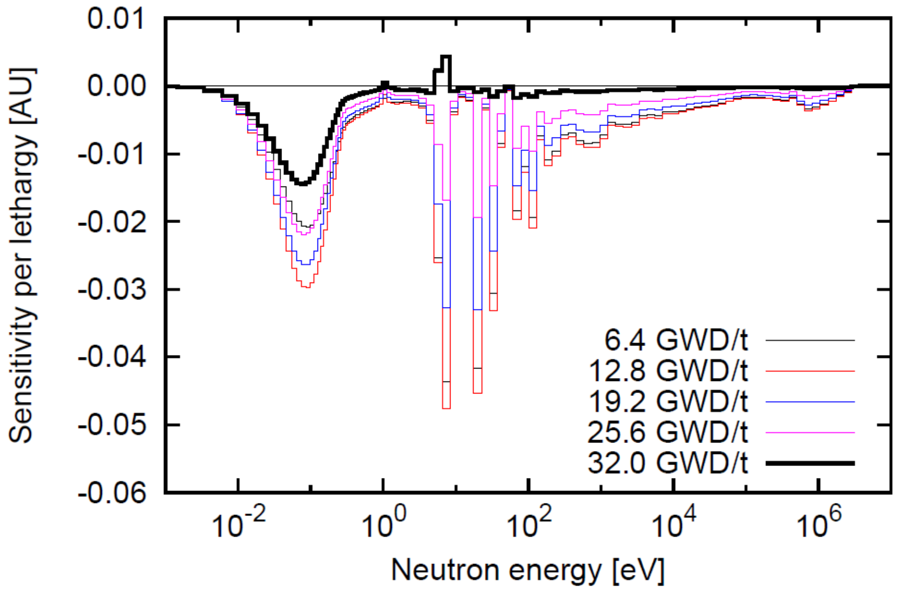


Sensitivity calculation of fuel assembly burnup property

- We have implemented a new capability to calculate sensitivity of k-inf and nuclide inventories during burnup of LWR fuel assemblies with respect to nuclear data such as reaction cross section, fission yield and decay constant.
- Nuclear data-induced uncertainties can be quantified without statistical uncertainties.



Energy profile of sensitivity of k-inf to U-238 (n,γ)

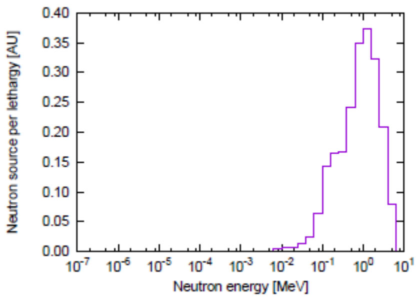


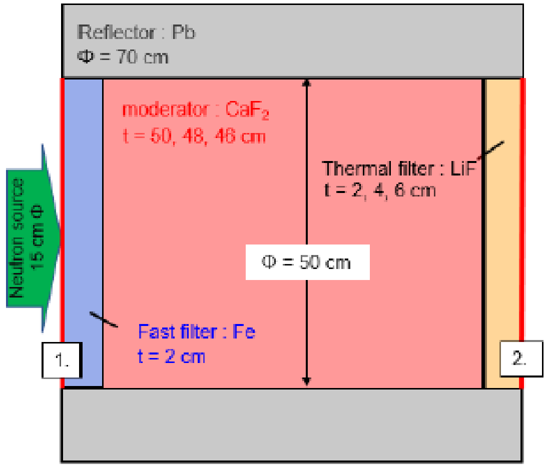
- G. Chiba, Perturbation theory for nuclear fuel depletion calculations with predictor-corrector method, J. Nucl. Sci. Technol., 55, p.290 (2018).
- G. Chiba, K. Honta, Sensitivity and uncertainty analyses of fission product nuclides inventories for passive gamma spectroscopy, J. Nucl. Sci. Technol., 57, p.1265 (2020).
- G. Chiba, Sensitivity analysis of neutron multiplication factors during nuclear fuel burnup in light water reactors regarding gadolinium isotopes nuclear data, Ann. Nucl. Energy, 151, 107949 (2021).

Design optimization for neutron source in medical application

The Sn transport module in CBZ is applied to neutron source calculations.

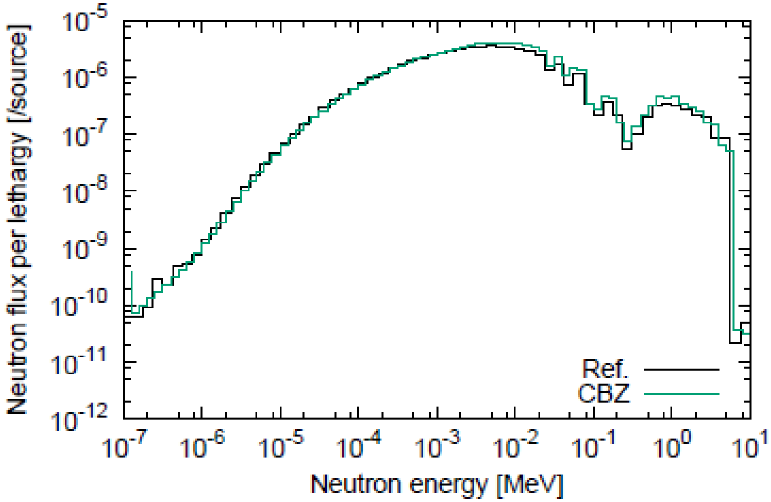
Neutron source from Be(p,n)



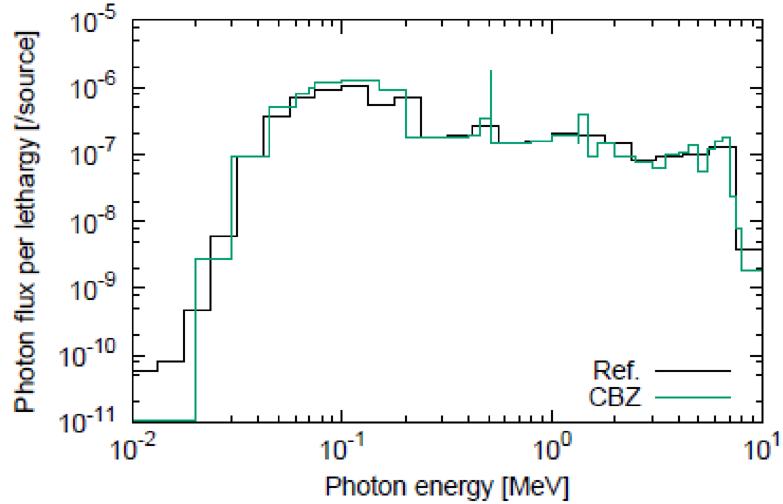


Neutron and photon fluxes are calculated

Neutron flux



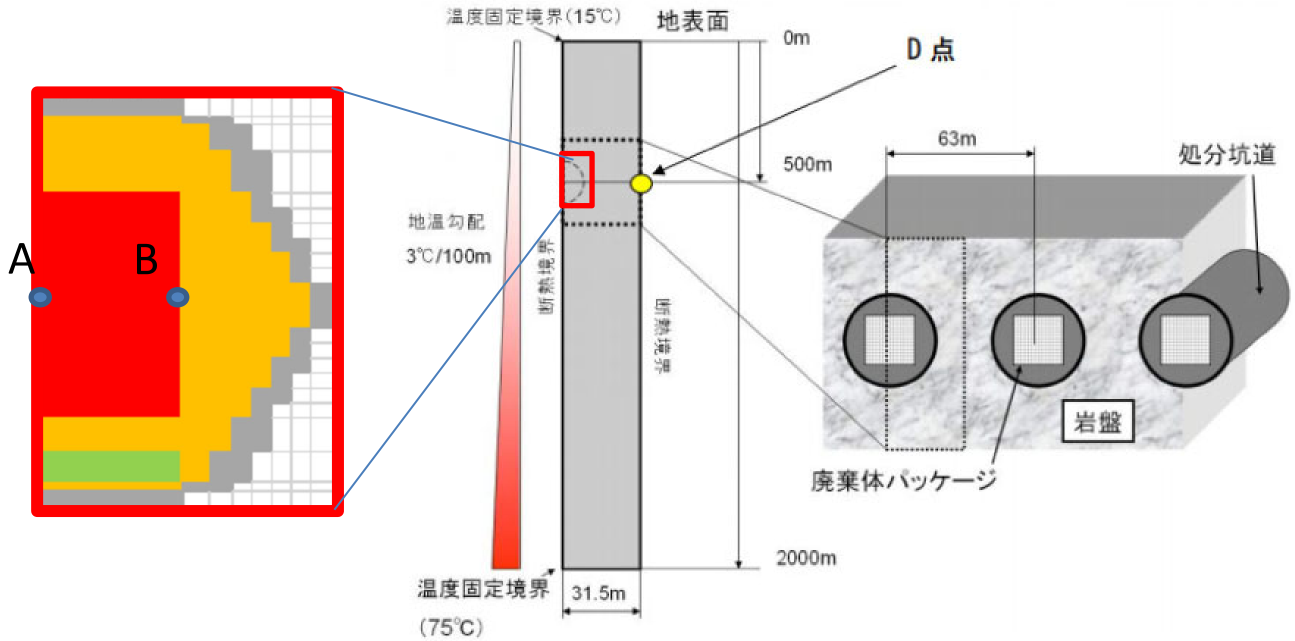
Photon flux



Numerical results which reasonably agree with the PHITS results can be quickly obtained.

TRU waste repository site temperature simulation

From nuclide inventory calculations in TRU wastes to temperature profile calculations at the waste repository site can be conducted with CBZ.

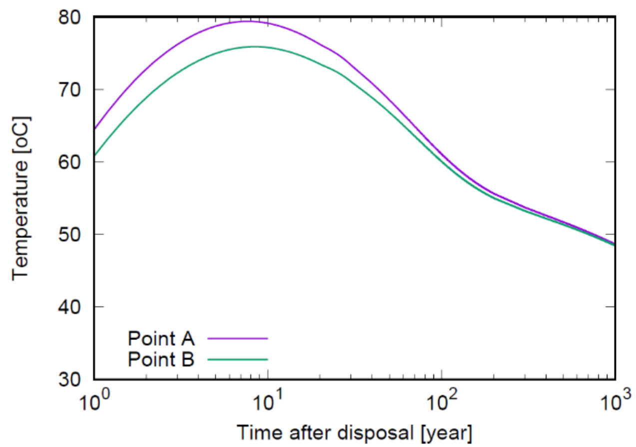


Nuclear fuel depletion calculations with pincell/assembly

↓

Nuclides decay calculations → Heat conduction calculations at the repository site →

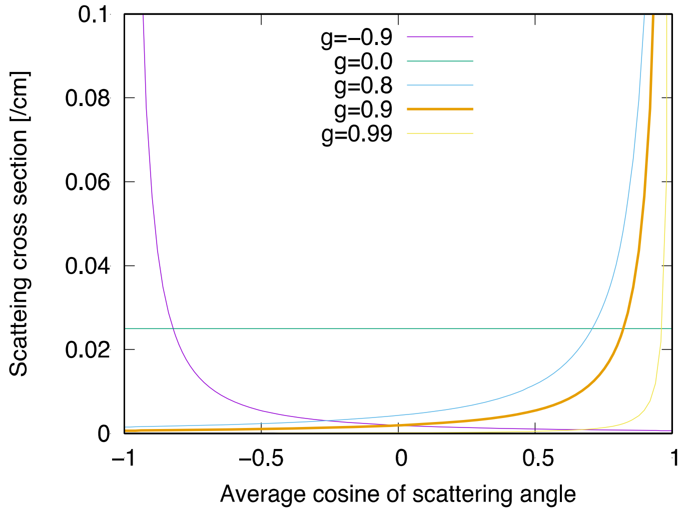
Temperature profiles at points A and B



Light propagation calculations with specific scattering kernel

In the light propagation calculations in the field of bio-optics, the following HG scattering kernel is generally used for photon:

$$\Sigma_s(\mu) = \Sigma_{s,0} \cdot \frac{1}{2} \frac{1-g^2}{(1+g^2-2g\mu)^{3/2}}$$



To treat such significant anisotropy, not the Legendre expansion but the Direct Angular Representation (DAR) in the Sn transport calculations is generally adopted in the field of bio-optics.

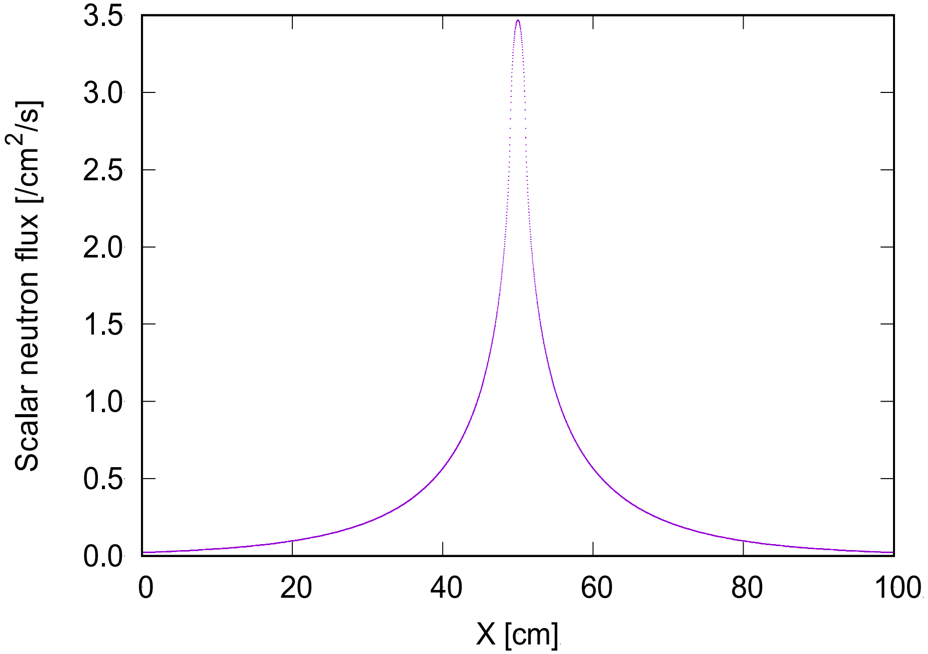
(Legendre expansion) $$S_{scat}(x,\mu) \approx \sum_{l=0}^{L} (2l+1) P_l(\mu)\, \Sigma_{s,l} \phi_l(x)$$

(DAR) $$S_{scat}(x_i,\mu_n) \approx \sum_{m=1}^{N} \Sigma_s(\mu_m \rightarrow \mu_n) \psi(x_i,\mu_m) w_m$$

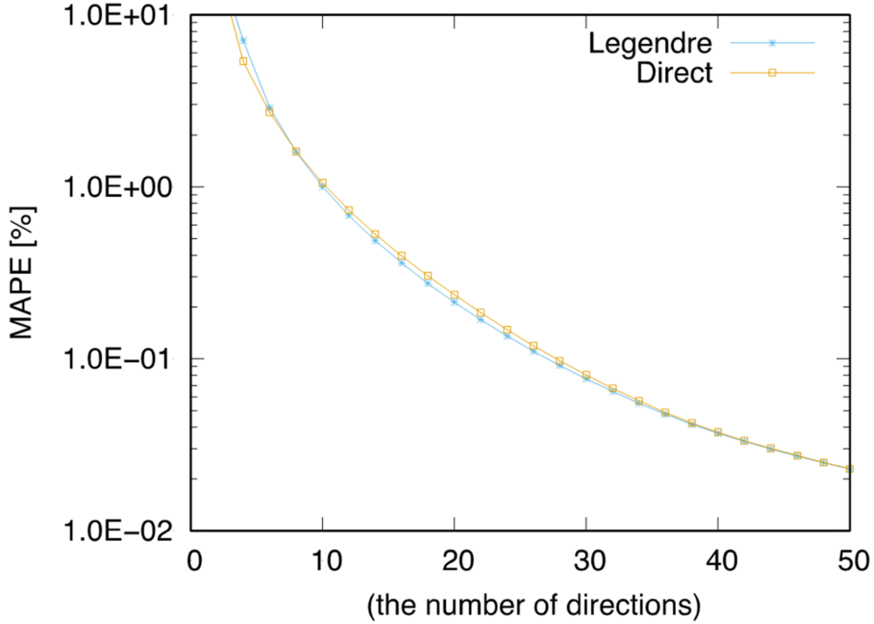
Light propagation calculations with specific scattering kernel

We have tested this treatment in a slab system, and the Legendre expansion works better rather than the DAR. In future, the similar comparison will be made in multi-dimensional system with a point source.

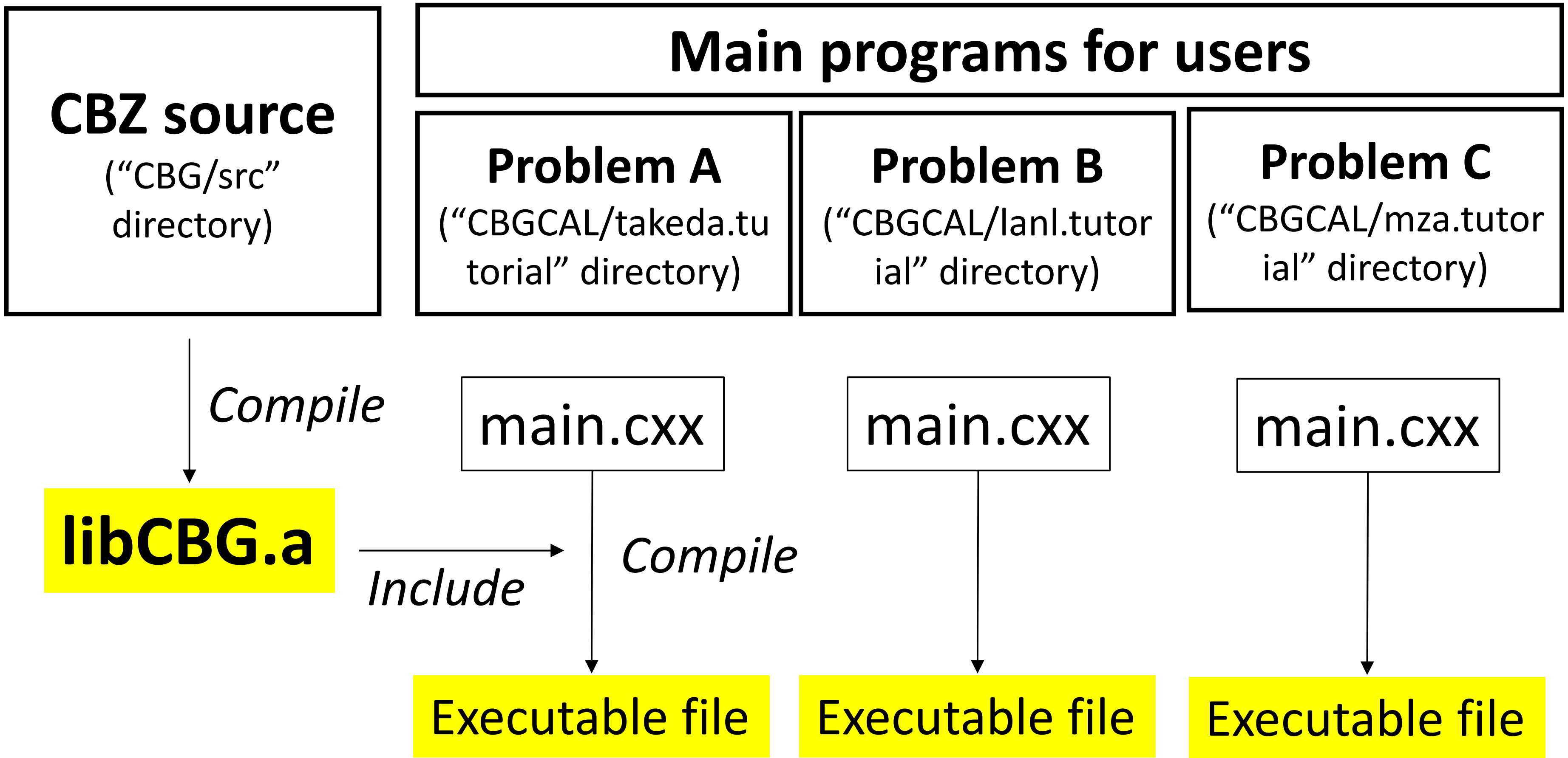
Scalar flux spatial distribution



Mean absolute percentage error in scalar flux



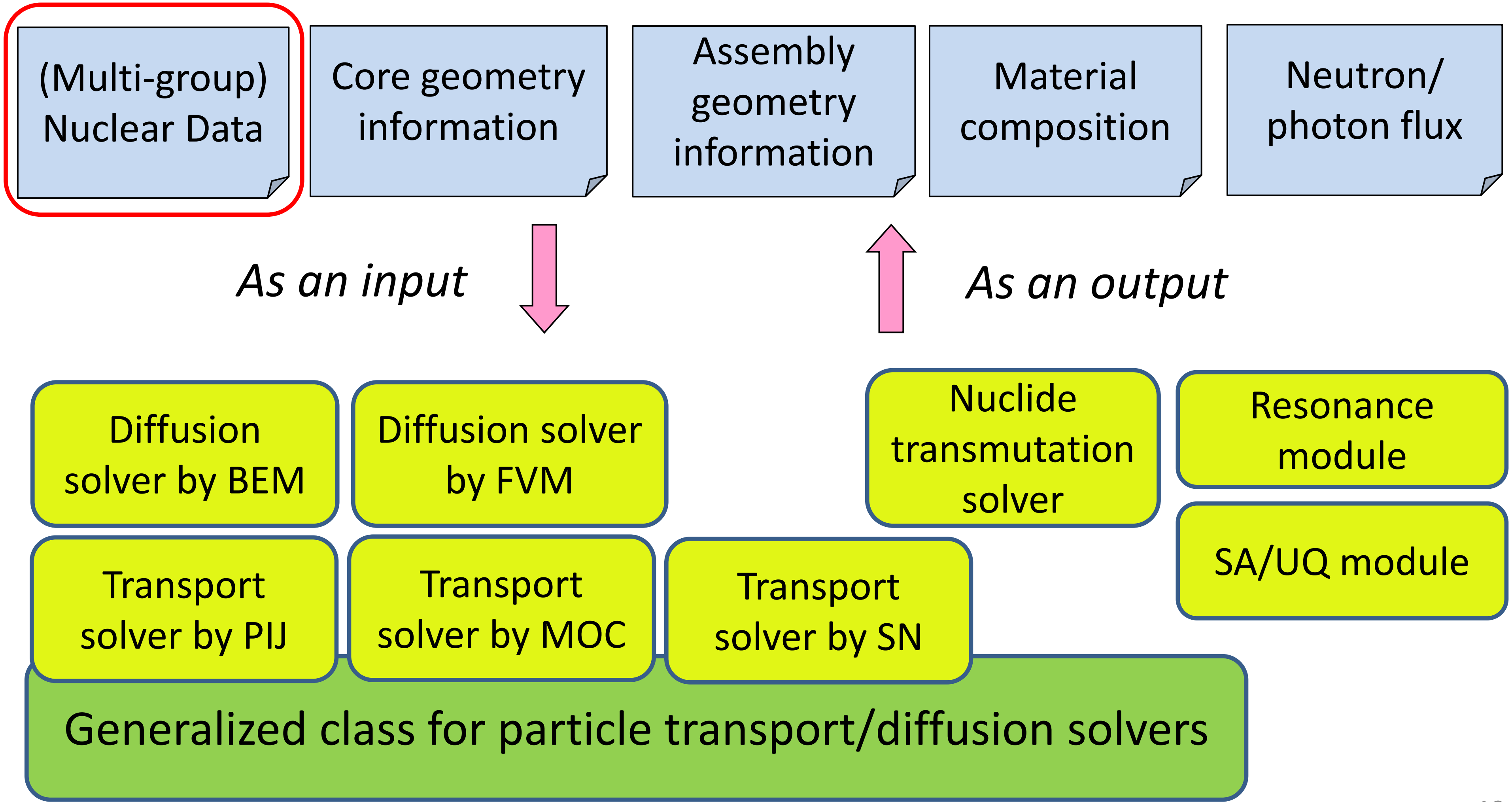
Code system structure



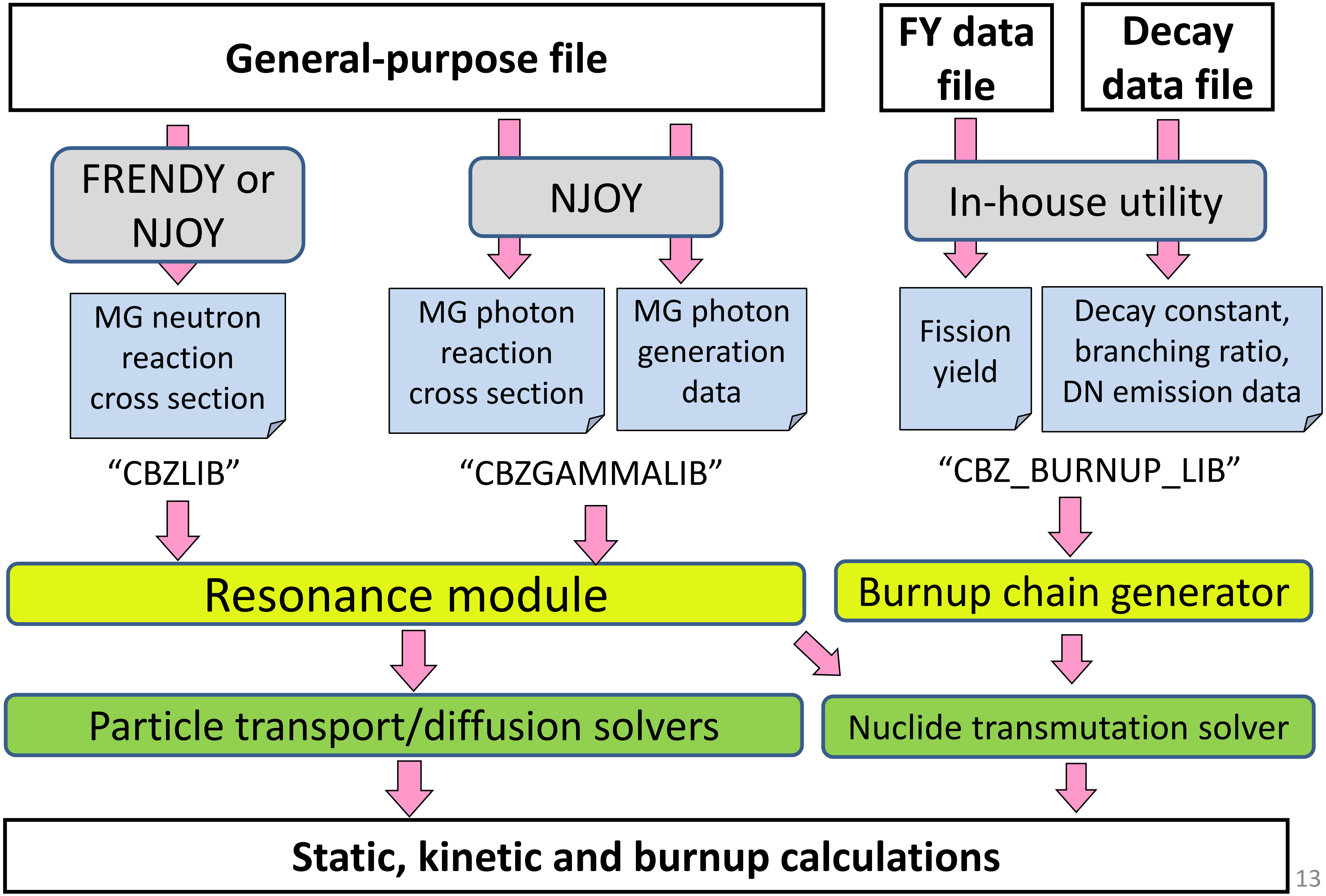
CBZ is written by C++ and various classes are prepared. Users need to prepare a main program in C++, which uses instances of the CBZ classes. Several "templates" for main programs are prepared, so it is not difficult for young students to do calculations with CBZ.

CBZ: a deterministic reactor physics code system

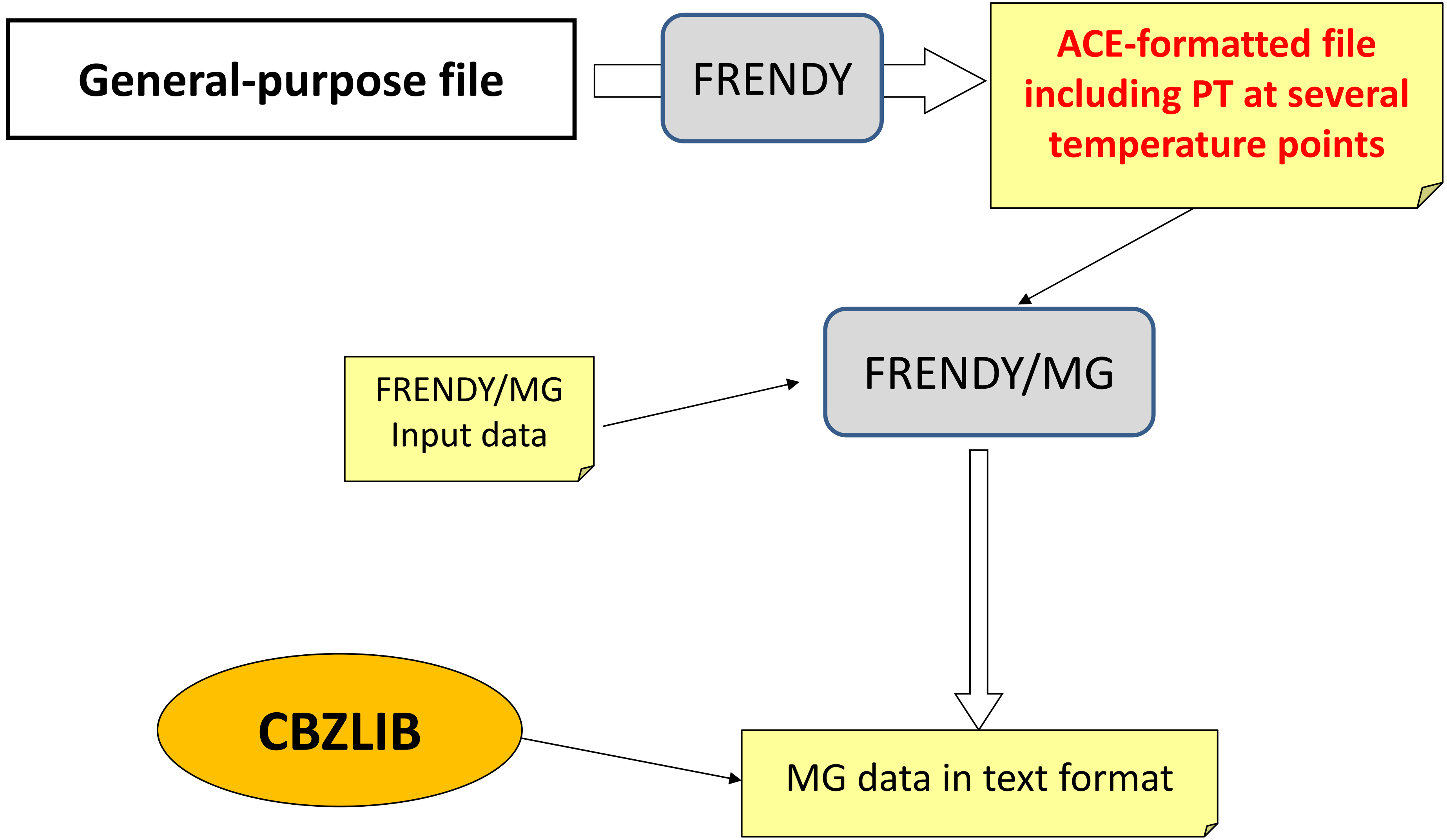
CBZ is based on the **deterministic** procedure, so **energy-averaged** (**multi-group, MG**) nuclear data are essential.



How to get nuclear data information

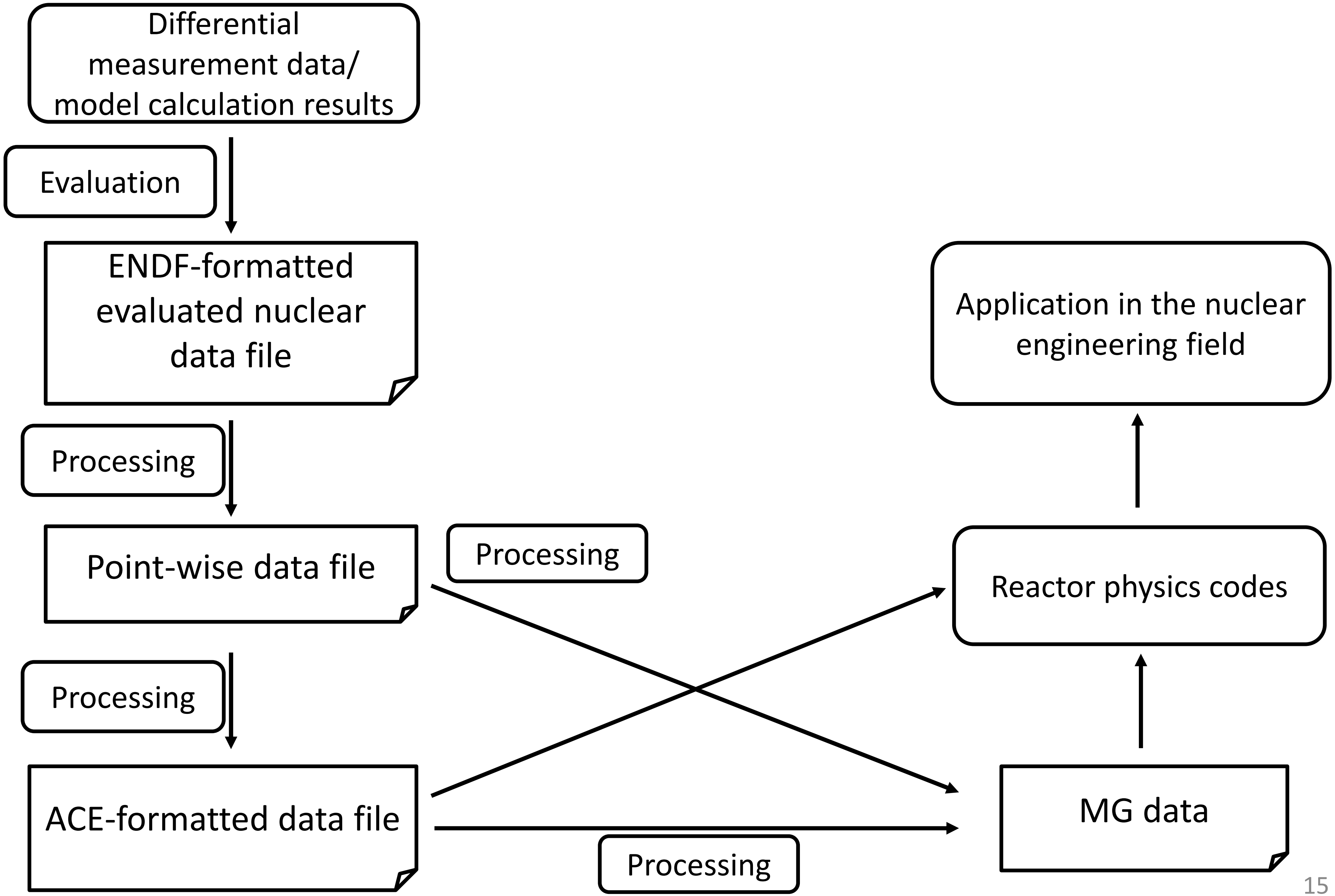


New MG data generation system with FRENDY



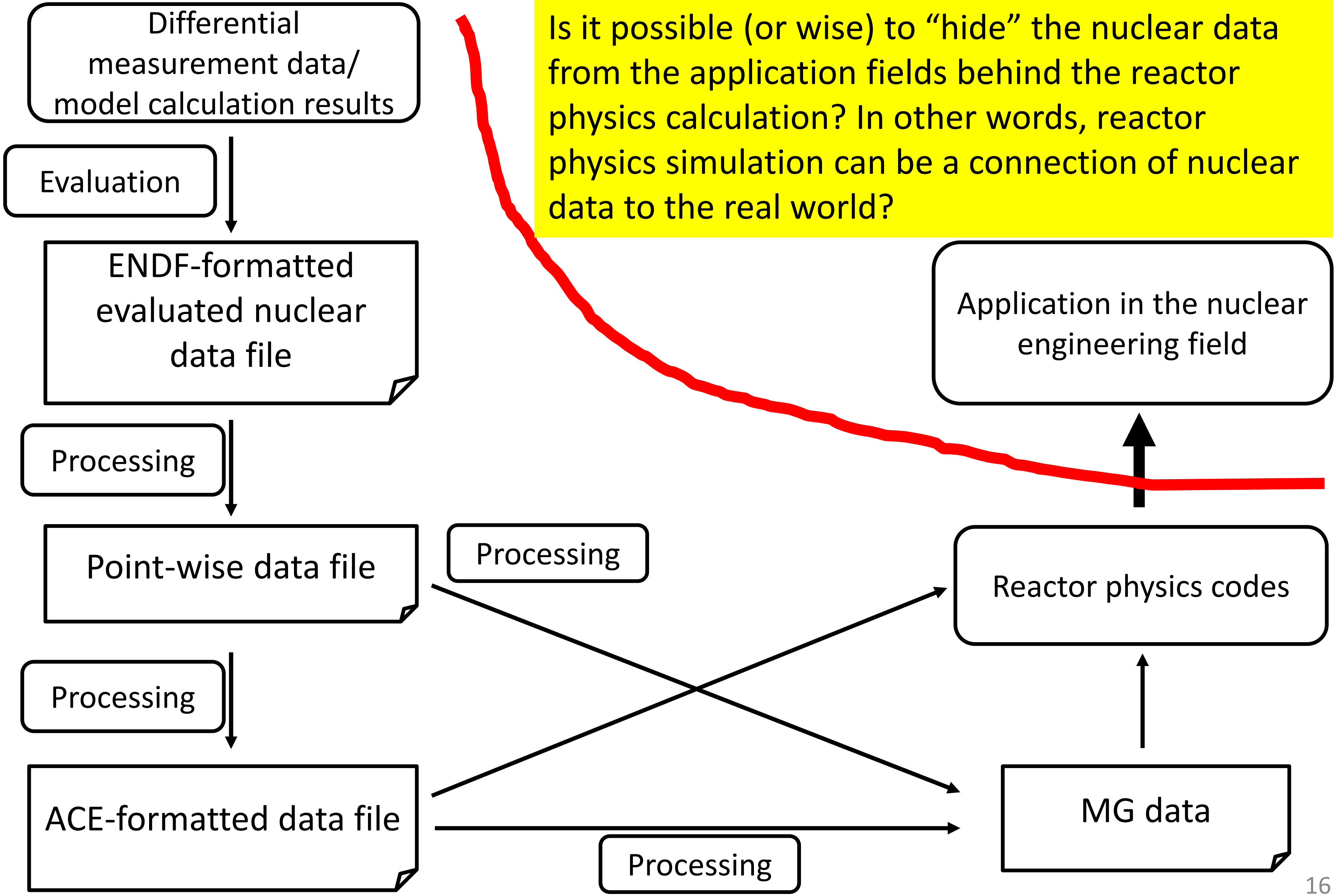
All the calculations relevant to neutrons can be conducted with CBZLIB generated from the general-purpose file **only with FRENDY**.

Nuclear data and its application fields



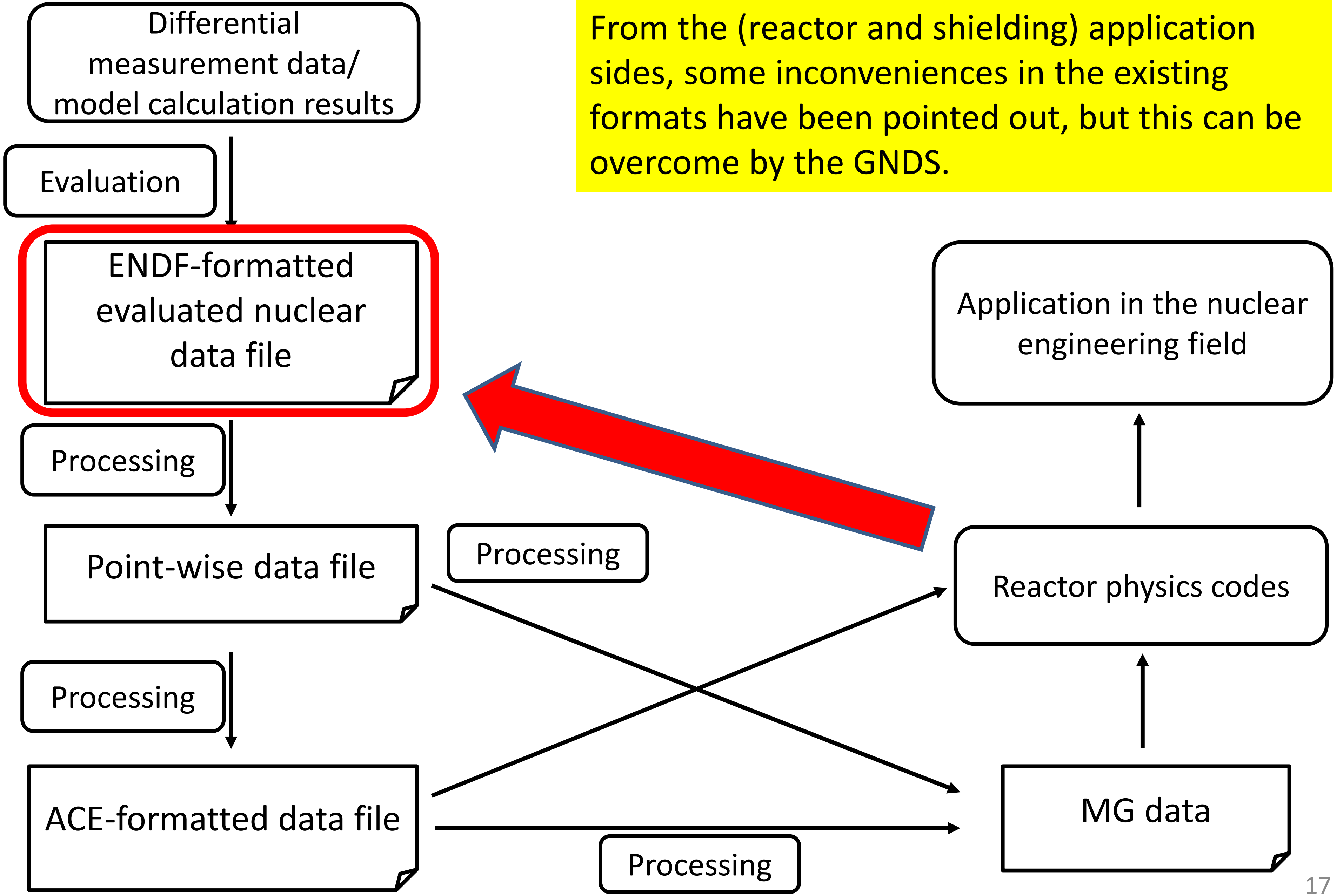
Nuclear data and its application fields

Is it possible (or wise) to “hide” the nuclear data from the application fields behind the reactor physics calculation? In other words, reactor physics simulation can be a connection of nuclear data to the real world?

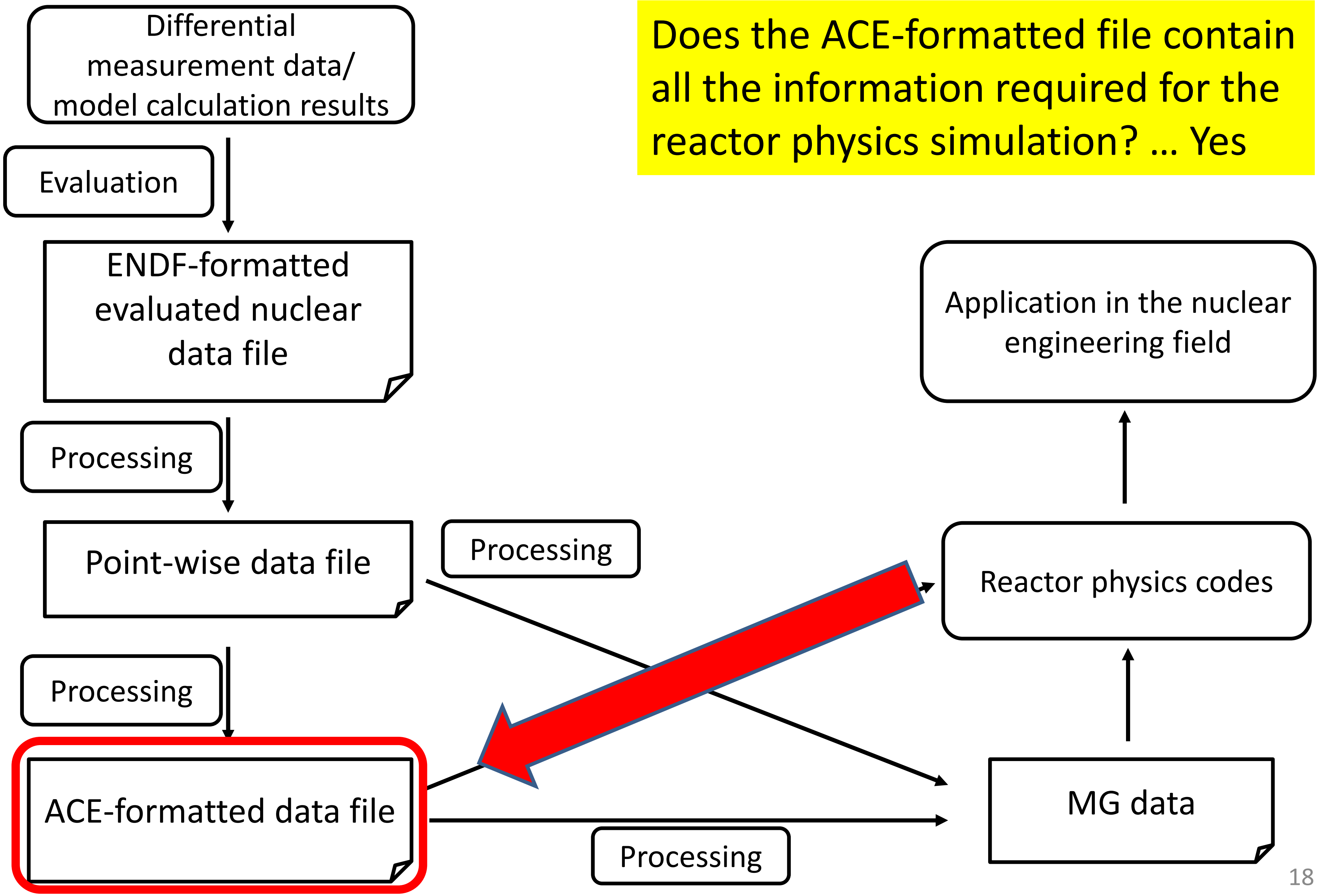


Nuclear data and its application fields

From the (reactor and shielding) application sides, some inconveniences in the existing formats have been pointed out, but this can be overcome by the GNDS.

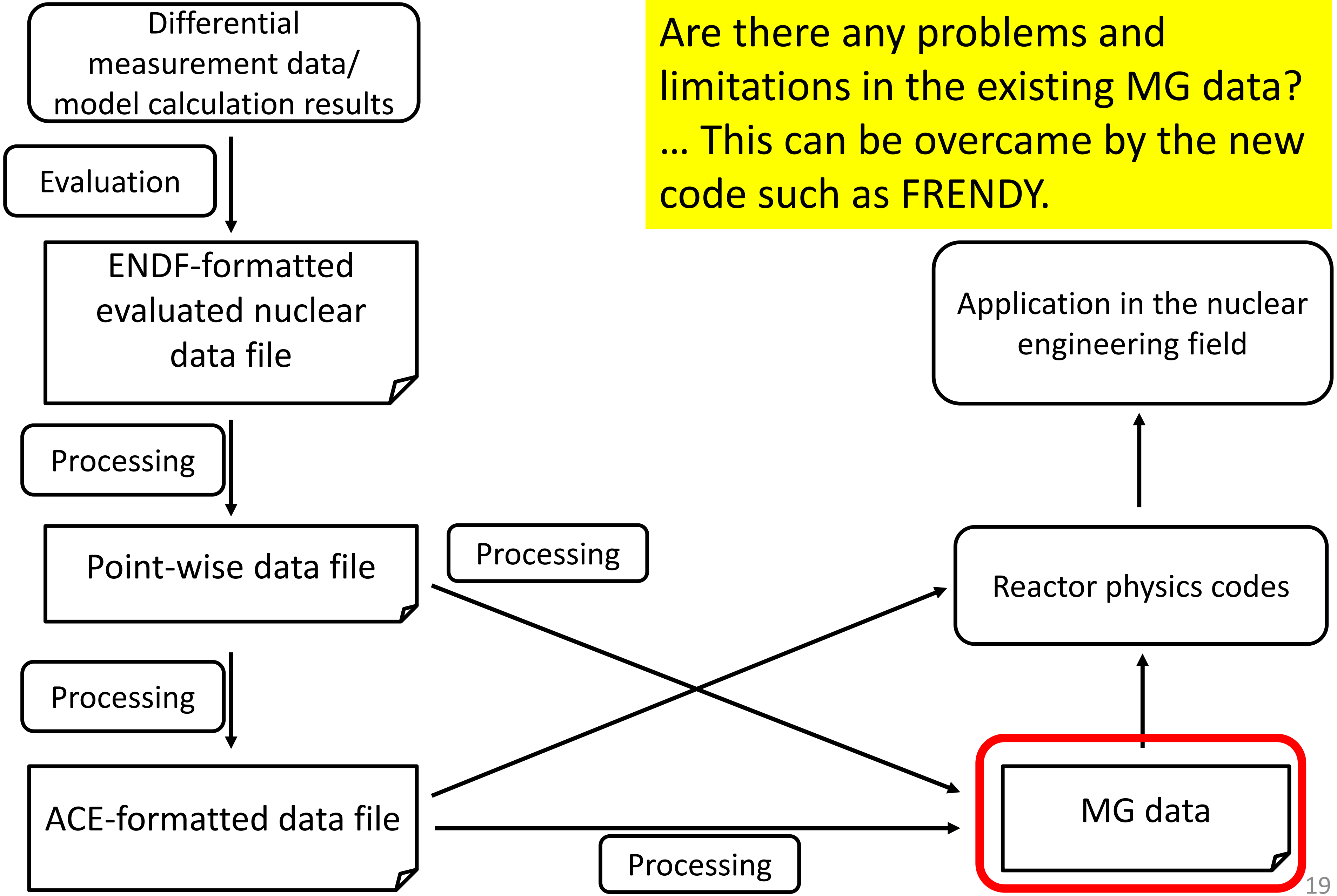


Nuclear data and its application fields



Nuclear data and its application fields

Are there any problems and limitations in the existing MG data? … This can be overcame by the new code such as FRENDY.



Concluding remarks

- We have been developing a general-purpose reactor physics code system CBZ.

- With CBZ, various kinds of numerical simulations in the field of nuclear reactor physics are realized.

- The application areas of CBZ have been recently expanded.

- Actually I have not felt any inconveniences in the current evaluated nuclear data files and their processing codes; Those are well-designed and well-structured (my personal view).

To Kawano-san (some techniques to avoid negative scattering)

- L. Mao, J. P. Both, J. C. Nimal, “Transfer matrix treatments in TRIMARAN-II, nonequally probable step function representation in multigroup Monte Carlo,” Nucl. Sci. Eng., 130, p.226 (1998).

- J. M. DelGrande, K. A. Mathews, “Nonnegative anisotropic group cross sections: hybrid Monte Carlo-discrete elements-discrete ordinates approach,” Nucl. Sci. Eng., 139, p.33 (2001).

- J. W. Kim, N. Z. Cho, “An efficient deterministic method for generating non-negative scattering cross-sections,” Ann. Nucl. Energy, 34, p.967 (2007).