Application of Serpent 2 for fuel debris neutronic modeling

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Content

- Debris removal and its modeling
- Simple falling debris model
- Serpent model optimization
- Current and future tasks

Aim of the work

The purpose of this work is to develop and verify method to justify safety of corium handling operations.

One of subtasks is to find optimization techniques for related neutronic simulations.

Corium

Corium is lava-like remains of fuel, constructive materials, reactor vessel and concrete.

It is highly radioactive and generates heat.

Keeping it in damaged NPPs units is hard and complex engineering task.

Best solution is to remove it to keep in proper place then. To do so, corium needs to be crumbled to debris and extracted.

During this operation recriticality may occur.

Photo of Fukushima’s unit 2 corium

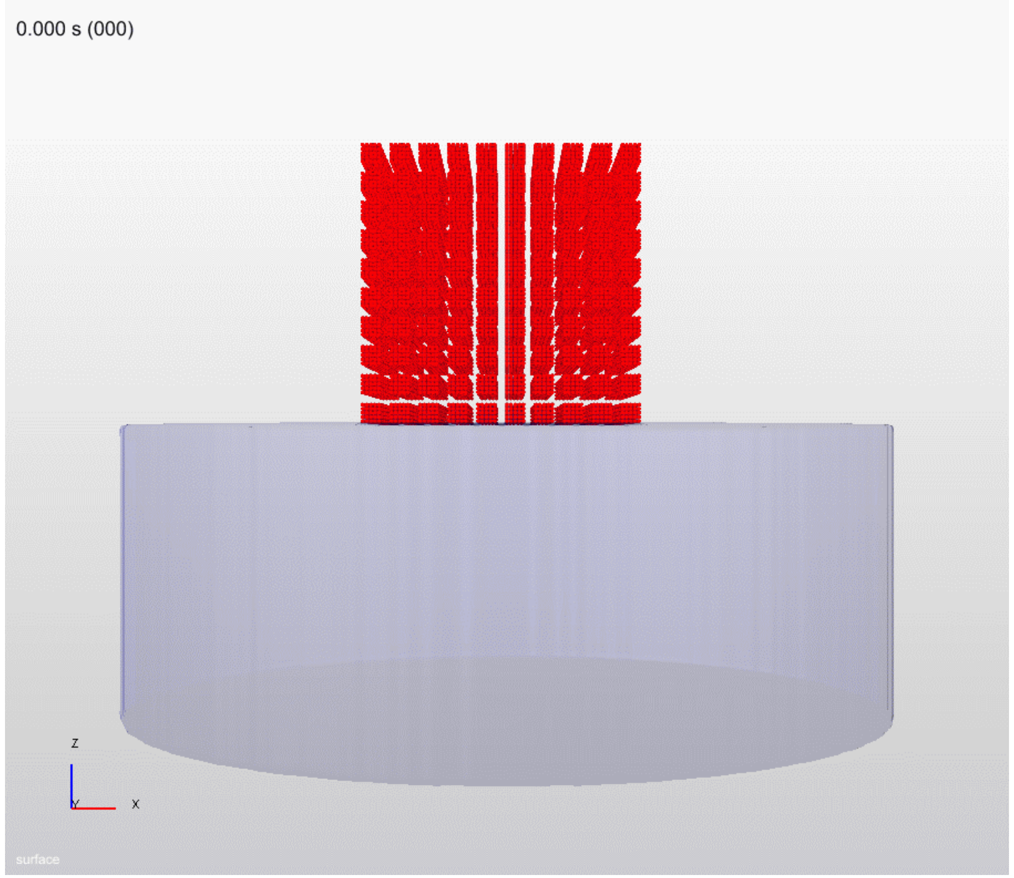
System of debris simulation cases

Three cases were planned to be dealt with:

1. Preliminary analysis of codes and methods with simple model <- done
2. Modeling high amount of debris particles <- in progress
3. Modeling weak coupled neutronic system

Benchmark for justification of safety of debris handling operation will be created based on the experience gained by solving these cases.

Simple falling debris model



CFD Simulation via ParticleWorks code*:

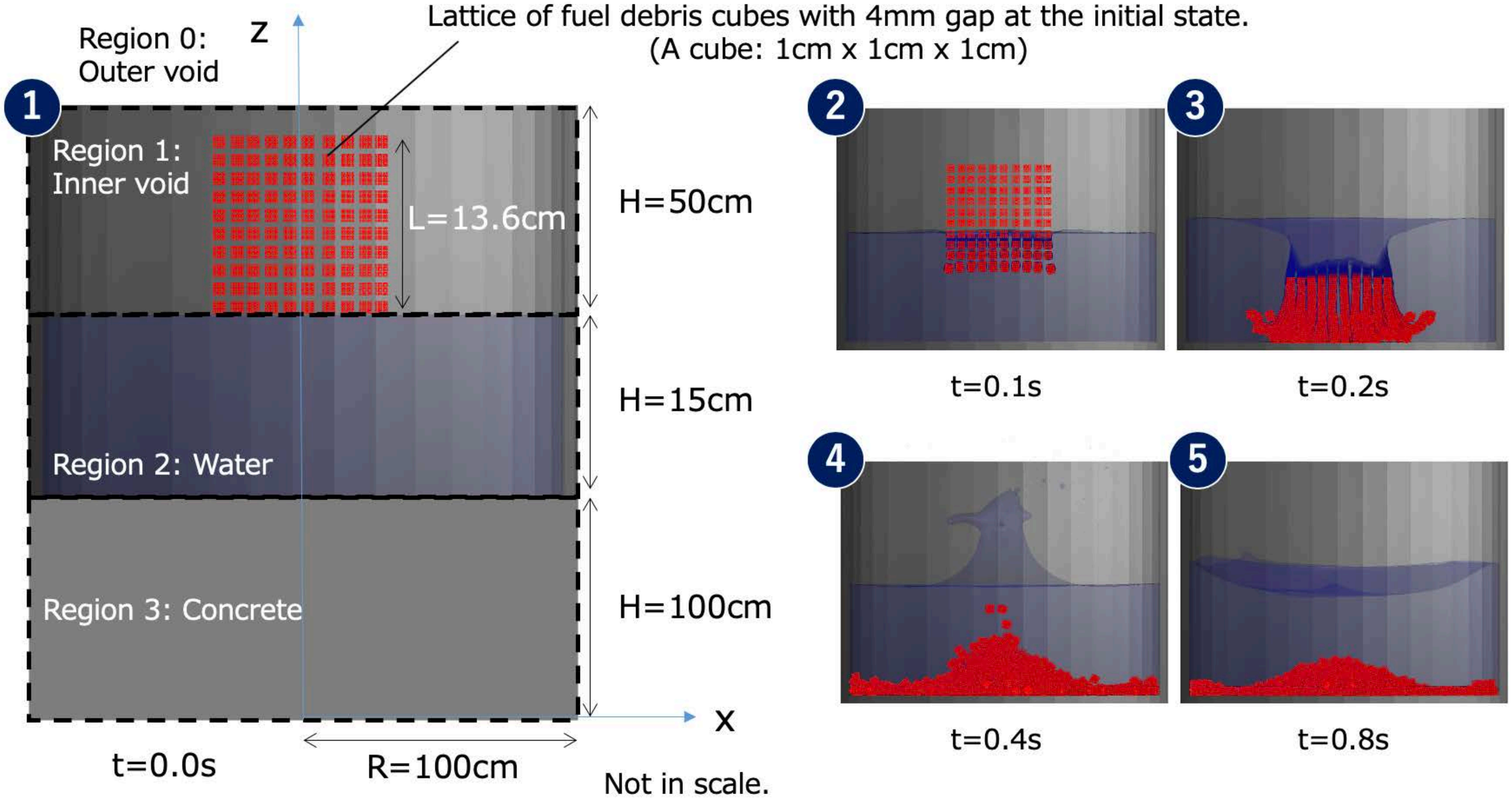
1000 cubes fall to the water

Process takes approximately 1 sec

Five system frames were chosen for further neutronic analysis

** Muramoto T., Nishiyama J., Obara T. Numerical analysis of criticality of fuel debris falling in water // Ann. Nucl. Energy, 2019. Vol. 131. P. 112–122.*

Falling debris model



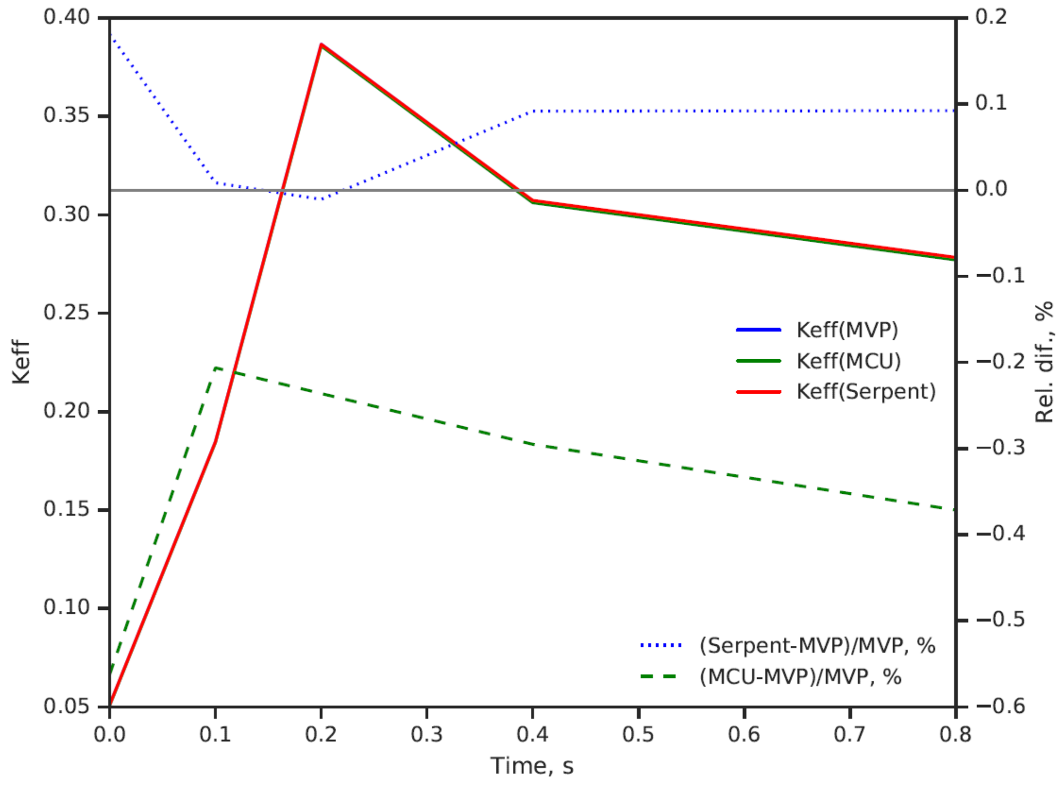
Codes and conditions

Three codes were used:

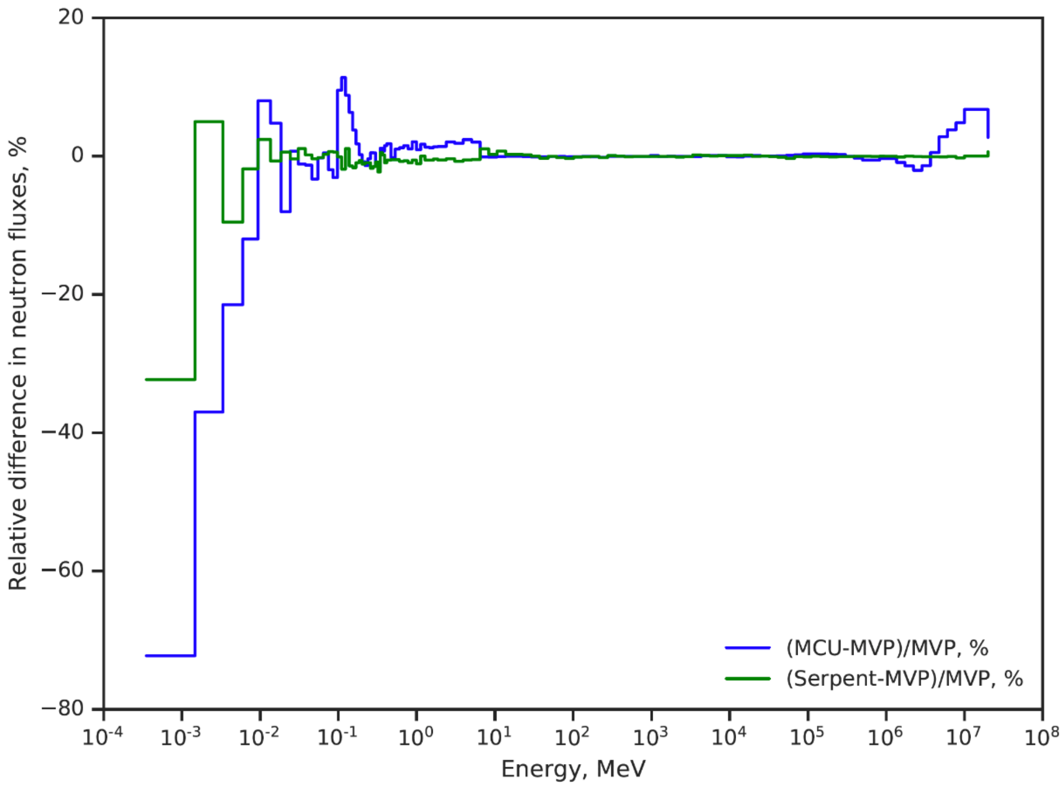
- Serpent
- MVP (Japan - Nuclear Science and Engineering Center JAEA)
- MCU (Russia – Kurchatov Institute)

Calculation conditions for all codes are the same: isotopic compositions, temperatures, XSLib – ENDF-B/7.0, target std.dev. for Keff – 0.01%.

Brief results overview



Multiplication factors and relative errors



Neutron flux for frame 0.2 sec

Default Serpent model

- each cube is unique cell
- single universe
- extremely poor performance

Optimization: Delta-tracking

It appears to be, that by default delta-tracking is not used for some energy regions of the model.

Frame	Performance (relative to default)
0	1.42
1	8.13
2	7.17
3	5.70
4	5.77

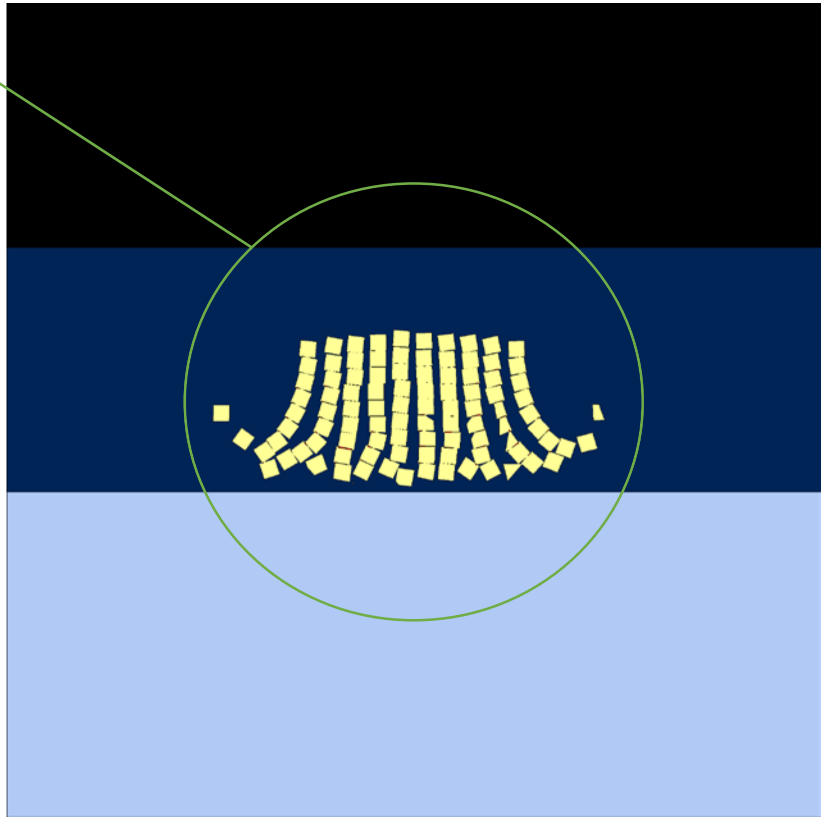
For such geometry it has significant impact.

Optimization: Debris region separation

Complex part of geometry relatively small

This part can be placed in another universe

Frame	Performance (relative to default)
0	8.31
1	5.37
2	2.59
3	2.08
4	3.60



Optimization: Explicit stochastic geometry

ESG structure is set of spheres placed in background geometry

```
X1 Y1 Z1 R1 U1
X2 Y2 Z2 R2 U2
.. .. .. .. ..
XN YN ZN RN UN
```

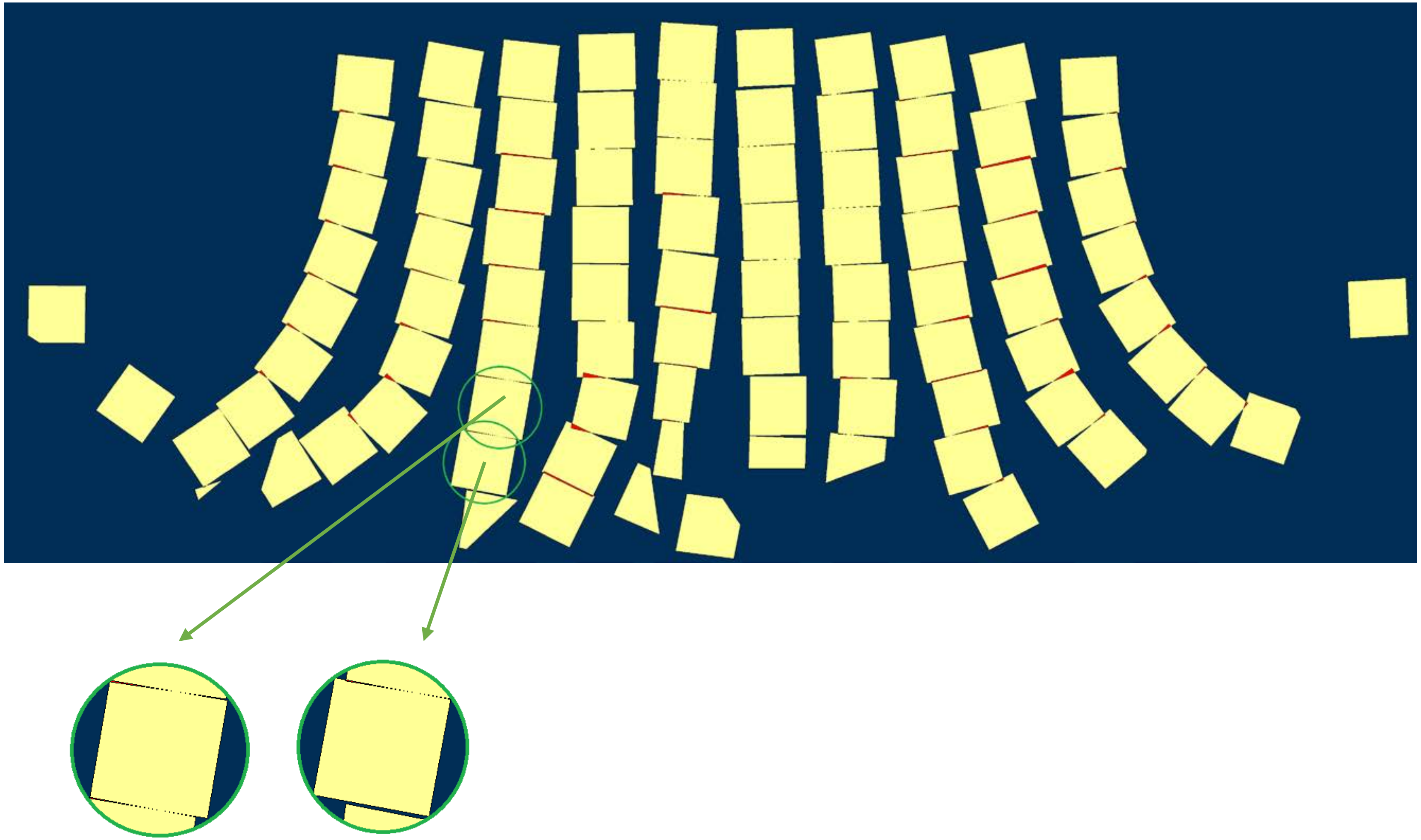
Each sphere has its own position, radius and universe filling it

This geometry type is more flexible that STGM, which is essential for debris related task

Optimization: Explicit stochastic geometry

Geometry construction pipeline:

1. Extract 1000 spherical parts of default geometry
2. Create universe for each spherical part
3. Fill elements in ESG with these universes (coordinates of ESG spheres are coordinates of corresponding cubes)



Optimization: Explicit stochastic geometry

Using of ESG greatly affects performance

Frame	Performance (relative to default)
0	5.30
1	6.43
2	44.34
3	60.26
4	67.49

Optimization effectiveness

Frame	Performance (relative to default), expected	Performance (relative to default), obtained	Simulation time (1E+7 neutrons), min*
0	62.54	14.89	2.15
1	280.72	76.63	2.61
2	823.41	51.65	4.86
3	714.44	66.67	4.14
4	1401.90	73.65	4.06

*20 threads on Intel(R) Xeon(R) Gold 6230 2.10GHz

Further work

Case 2: more debris particles:

- 5000 debris particles
- cubes are replaces by spheres

Case 3:weak neutron coupling:

- larger amount of particles
- concrete bed is replaced by corium bed