

Development of ANN-based Dose Conversion Models for Retrospective Dosimetry in External Exposure Scenarios

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Computational techniques in RD

Lookup table based DCC

- Fast
- No expertise required
- For large-scale accident
- Only valid for parallel beams

Dedicated MC simulations

- Long time (Modeling+ simulation time)
- Expertise required
- For small-scale & field test
- Precise

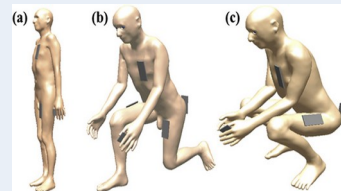
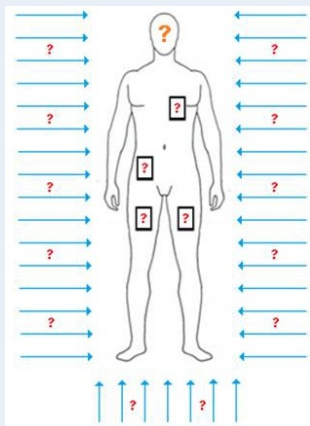


Table 8. Average phone and whole body dose per fluence, calibration factors, and confidence levels for each exposure.

Isotope	Exposure, G	Whole body dose per fluence, $\frac{D_{WB}}{\Phi}$ (mSv/Gcm ²)	Effective dose ^a per fluence, $\frac{D_{EF}}{\Phi}$ (mSv/Gcm ²)	Mean phone dose per fluence, $\frac{D_{P}}{\Phi}$ (mSv/Gcm ²)	Standard Dev., $\sigma_{\frac{D_{P}}{\Phi}}$ (mSv/Gcm ²)	Calibration Factor ^b , C ^b	S ^c (%) ^d	S ^e (%) ^f
Iridium-192	AP	1.64 (0.01)	1.72 (0.01)	1.72 (0.00)	0.00	0.95 (0.00)	22	140
	PA	1.39 (0.01)	1.31 (0.01)	1.34 (0.00)	0.070	1.04 (0.07)	41	130
	LLAT	1.05 (0.01)	1.04 (0.01)	2.05 (0.11)	0.091	0.51 (0.03)	4.1	6.6
	RLAT	1.05 (0.01)	0.98 (0.01)	1.51 (0.00)	0.020	0.68 (0.01)	26	1100
	ISO	1.39 (0.01)	1.01 (0.06)	1.21 (0.00)	0.034	0.91 (0.06)	3.2	3.7
	FLR	0.95 (0.01)	0.85 (0.02)	1.08 (0.00)	0.004	0.78 (0.06)	9.2	12
	ROT*	1.28 (0.01)	1.23 (0.01)	1.65 (0.21)	0.024	0.77 (0.30)	1.7	1.5
Cesium-137	AP	3.02 (0.01)	3.16 (0.02)	3.09 (0.17)	0.06	1.01 (0.06)	21	110
	PA	2.65 (0.01)	2.54 (0.01)	2.46 (0.15)	1.23	1.08 (0.07)	38	93
	LLAT	2.11 (0.01)	2.08 (0.01)	3.63 (0.19)	0.21	0.58 (0.03)	8.2	8.1
	RLAT	2.05 (0.01)	1.92 (0.01)	2.84 (0.19)	1.57	0.72 (0.05)	28	820
	ISO	2.17 (0.02)	2.13 (0.05)	2.32 (0.15)	0.06	0.93 (0.06)	3.3	3.9
	FLR	1.71 (0.01)	1.75 (0.02)	2.13 (0.16)	0.23	0.81 (0.06)	15	18
	ROT*	2.46 (0.01)	2.41 (0.01)	2.98 (0.30)	0.12	0.82 (0.30)	5.3	5.8
Cobalt-60	AP	5.14 (0.01)	5.34 (0.04)	5.01 (0.20)	1.50	1.03 (0.06)	17	81
	PA	4.69 (0.01)	4.55 (0.03)	4.24 (0.20)	1.82	1.11 (0.07)	33	60
	LLAT	3.91 (0.01)	3.90 (0.01)	5.82 (0.33)	0.27	0.68 (0.04)	4.5	6.0
	RLAT	3.84 (0.01)	3.66 (0.03)	4.85 (0.32)	2.40	0.79 (0.05)	23	400
	ISO	3.97 (0.04)	3.96 (0.20)	4.14 (0.27)	0.39	0.96 (0.06)	5.0	4.8
	FLR	3.27 (0.01)	3.30 (0.06)	3.81 (0.20)	0.40	0.86 (0.06)	12	11
	ROT*	4.40 (0.01)	4.36 (0.03)	4.98 (0.60)	0.19	0.88 (0.11)	3.4	5.8

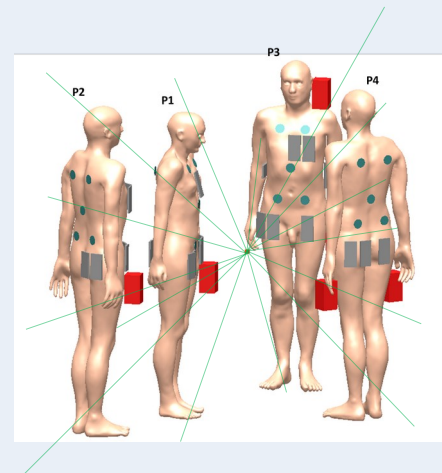
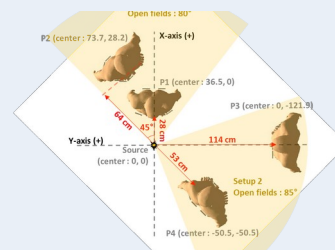
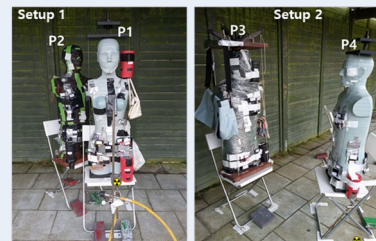
^a Defined for a given exposure as the standard deviation of the distribution of the mean phone doses from the four locations.

^b Defined as the ratio $C = \frac{D_{WB}}{D_{P}}$ (G/Gcm²).

^c Defined in equation (4a) to provide a conservative estimate of the potential over-response from using C^b.

^d Defined in equation (4b) to provide a conservative estimate of the potential under-response from using C^b.

^e Note: Bracketed values denote one standard uncertainty, representing just the statistical variance from the Monte Carlo calculations.



Lesson learned from previous ILC studies

- **The DCC approach**

- Not validated for scenarios that are not included in the lookup table
- Exhibiting high errors for adjacent sources
- Selection of DCC for the same scenario can be subjective (Jon et al., 2024)

- **Dedicated MC simulations**

- Provide low statistical uncertainty
- High errors due to uncertainties of geometries
- In the past field test, all computational participants showed high errors (Kim et al., 2025): $\pm 65\%$ in the slope (Meas. vs Calc.) for P2 and P4 cases.

→ A new strategy is needed to extend the DCC scenarios, where statistical uncertainty may be increased as a trade-off.

Objectives

Developing ANN-based dose conversion models trained on a large number of exposure scenarios

Key questions to be addressed

- Is this approach feasible?
- How much data is required?
- How long does it take to acquire a sufficiently large dataset?
- What factors influence the model performance?
- How does the performance compare with conventional DCC approaches and Monte Carlo simulations?
- What advantages does this approach offer over database-based dose regression such as interpolation?
- What level of error margin is acceptable for practical applications of ANN-based models?

Feasibility study (simple slab phantom)

- Feasibility study was already published and presented last AM in WG10.
- Key factors, such as data distribution, data volume, parameter scaling methods, and other influencing variables, was verified.
- The effectiveness of the ANN model was demonstrated compared to the generic model and even traditional regression (interpolation) methods.

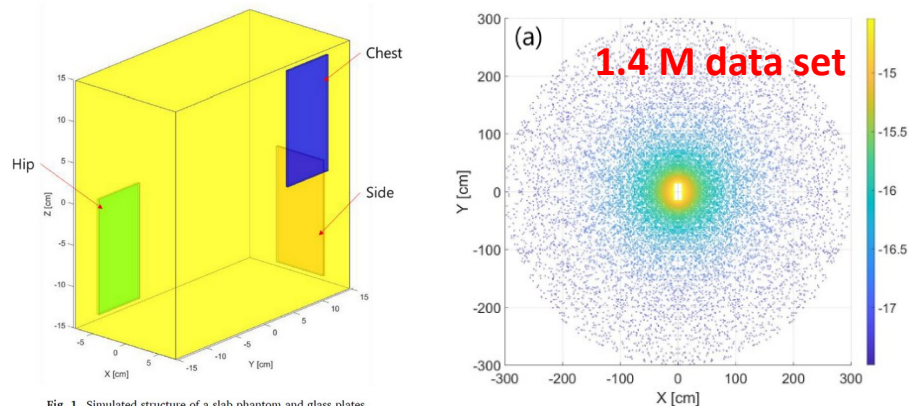
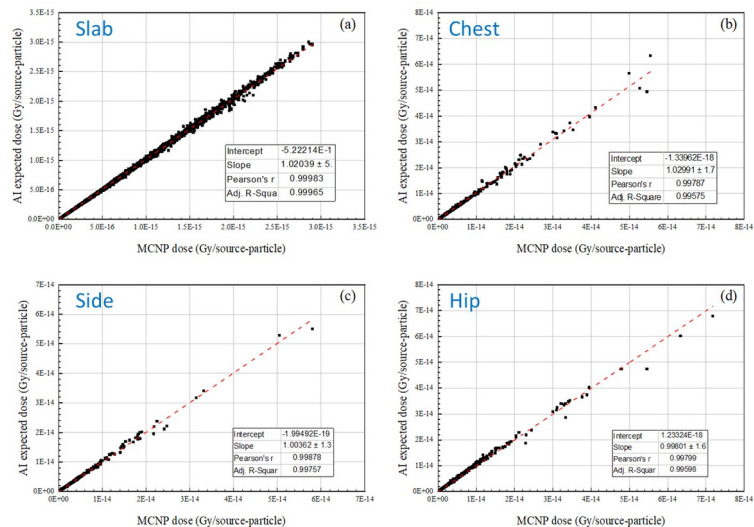


Fig. 1. Simulated structure of a slab phantom and glass plates.

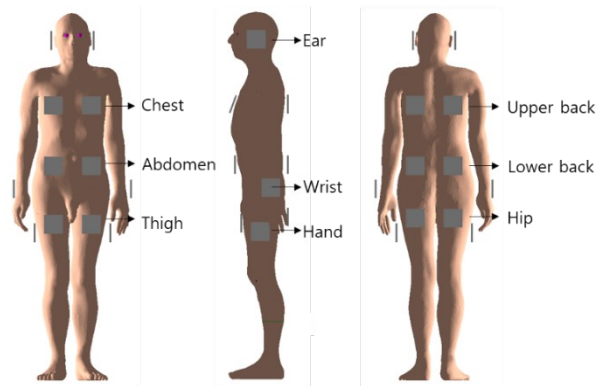
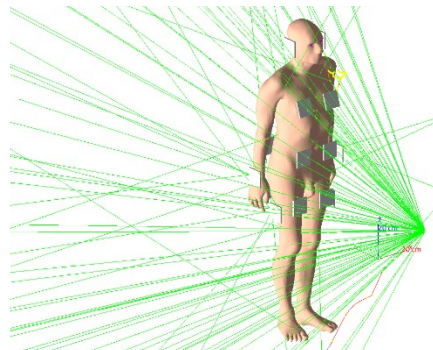
98% of tested data are within $\pm 3\%$ error



(Kim et al, 2025, Radiation measurements, 181, 107382)

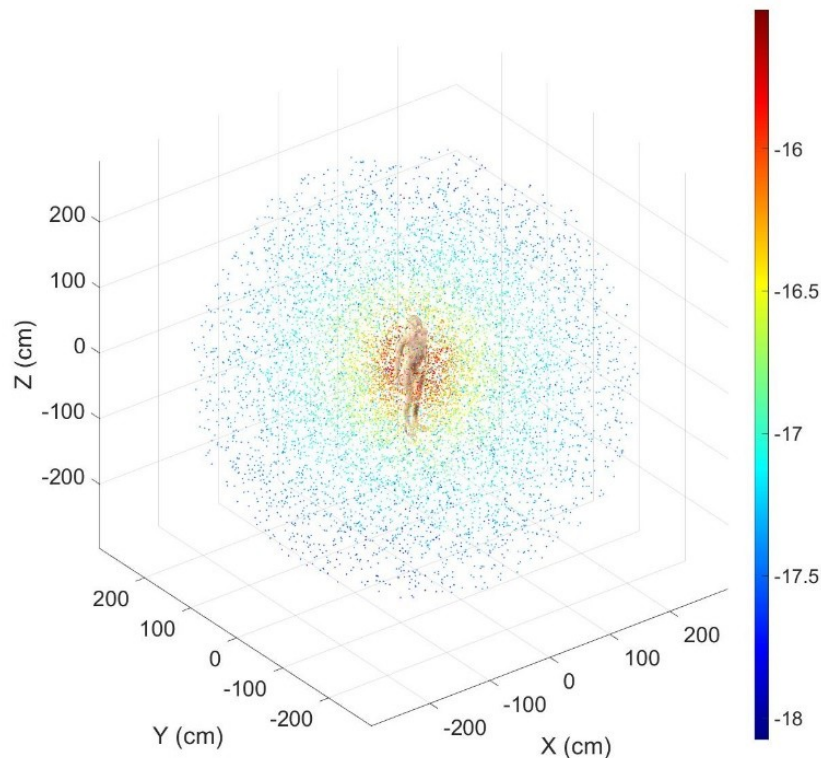
Research expansion (Anthropomorphic phantom)

- Code: Geant4 (11.1.1)
- Anthropomorphic phantom: MRCP (ICRP)
- Fortuitous dosimeters (5 materials)
 - Buildup layer: PMMA
 - Detector: Al_2O_3 , Dis. glass, LiF, RPLD, tissue
- Dosimeter positions (18 positions)
 - chest, thigh, hand, hip, abdomen
 - lower back, upper back, ear, wrist
- Beam: 1 MeV point source
- NPS: 10^7 with beam biasing $\rightarrow < 1\%$
- Output
 - Whole body: D_{WB}
 - Organs: > 30 doses
 - Dosimeters: 90 doses



Research expansion (Anthropomorphic phantom)

- MC data generation:
 - Point source distribution
 - $r < 3$ m
 - Density
 - # of simulations: 700,000
 - Output file size: 6 GB
 - Time consumption: 4 months
using a 9 nodes server

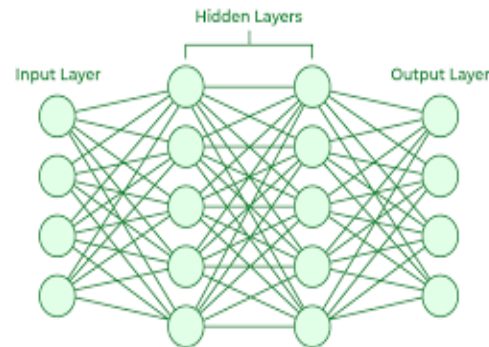


Research expansion (Anthropomorphic phantom)

- ANN model training:

- TensorFlow (2.17) + CUDA (12.3)
- [7 input + various output] features
- Scaling and transformation were essential
- HPO using Bayesian optimization
- Loss function: MSE
- Epoch and batch sizes were optimized
- Training (72%), validation (18%), and test (10%) sets
- Model size : ~10 MB
- Time consumption: ~1 day/model

7 features:
Energy
 x
 y
 z
 r
 θ
 ϕ



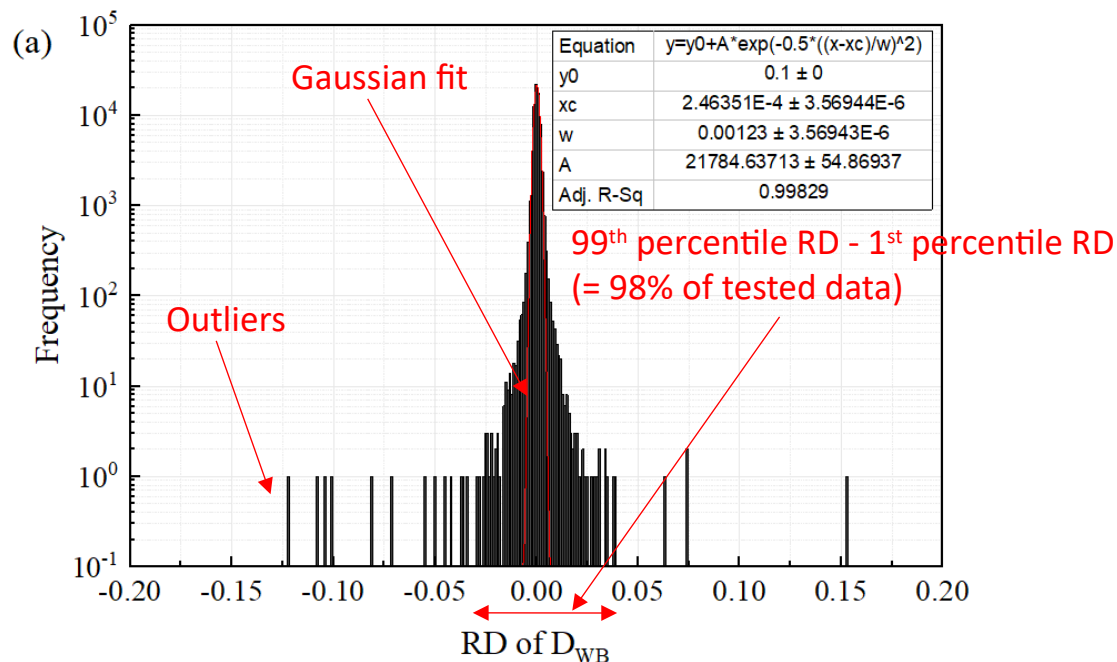
Output features:
 D_{WB}
 D_{Organs}
 $D_{Dosimeters}$

Research expansion (Anthropomorphic phantom)

• Performance metric:

- Relative difference
- 1st–99th percentile RD width

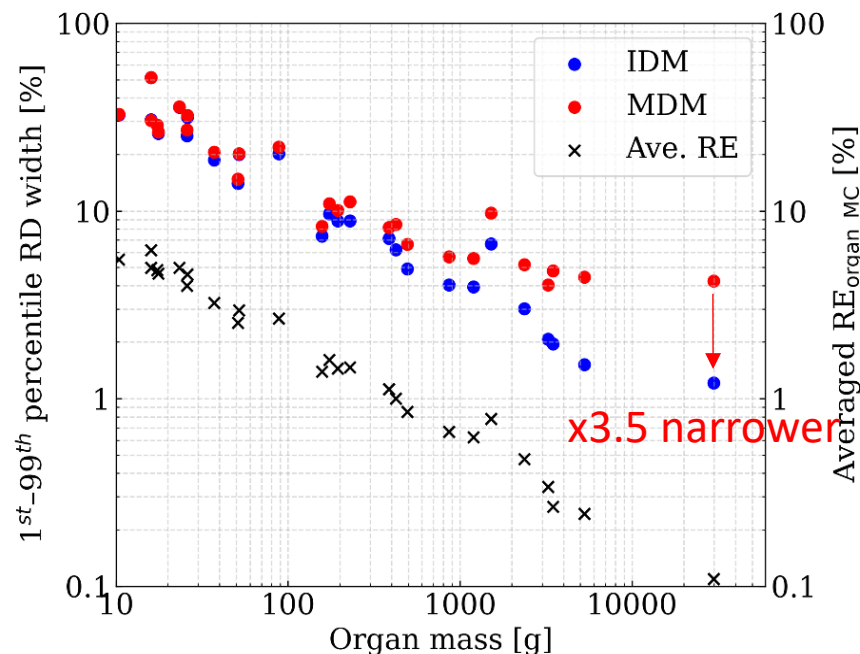
$$RD = \frac{\text{---}}{\text{---}}$$



Research expansion (Anthropomorphic phantom)

- **Multi-detector model (MDM) vs Individual detector model (IDM):**

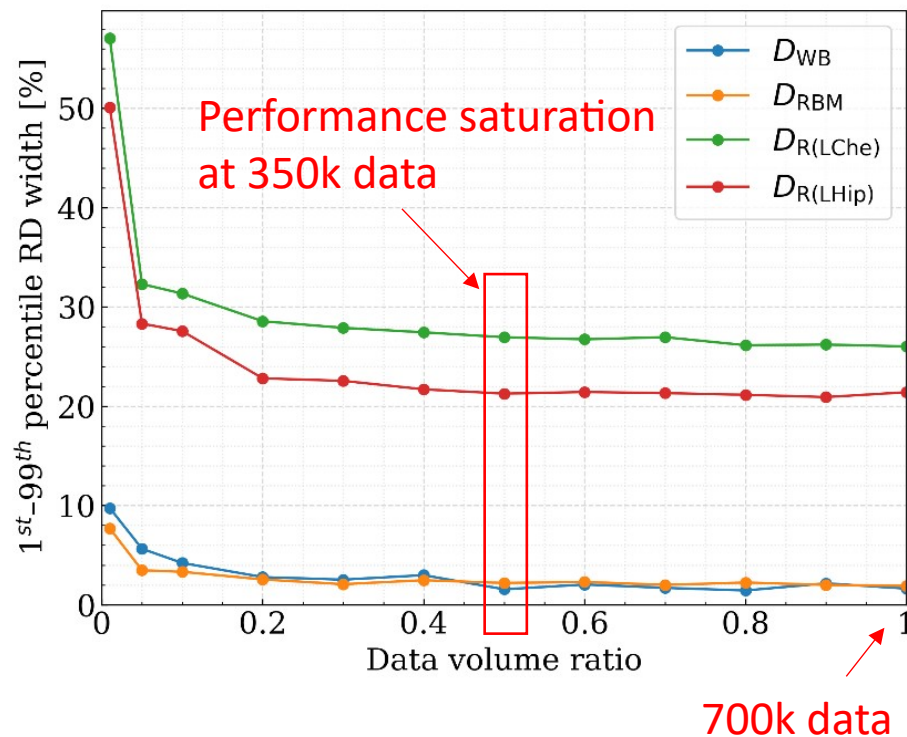
- Model efficiency vs optimization
- Both model showed organ mass dependency (=Relative error of MC data)
- IDM showed better estimation performance, especially for heavier organs



Research expansion (Anthropomorphic phantom)

- **Data volume dependency:**

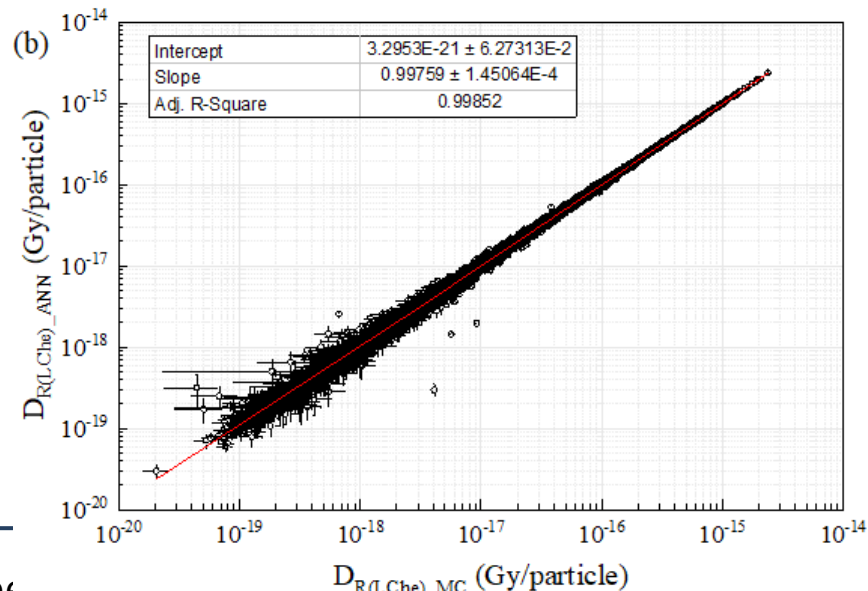
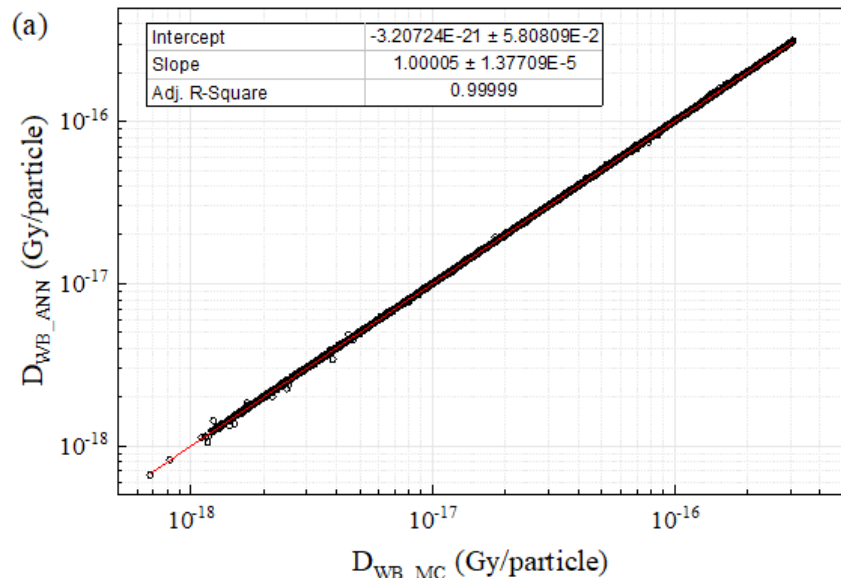
- # of dataset was scaled from 7k to 700k, but the test set remained same
- The model performance was highly dependent on data volume.
- A saturation point was identified



Research expansion (Anthropomorphic phantom)

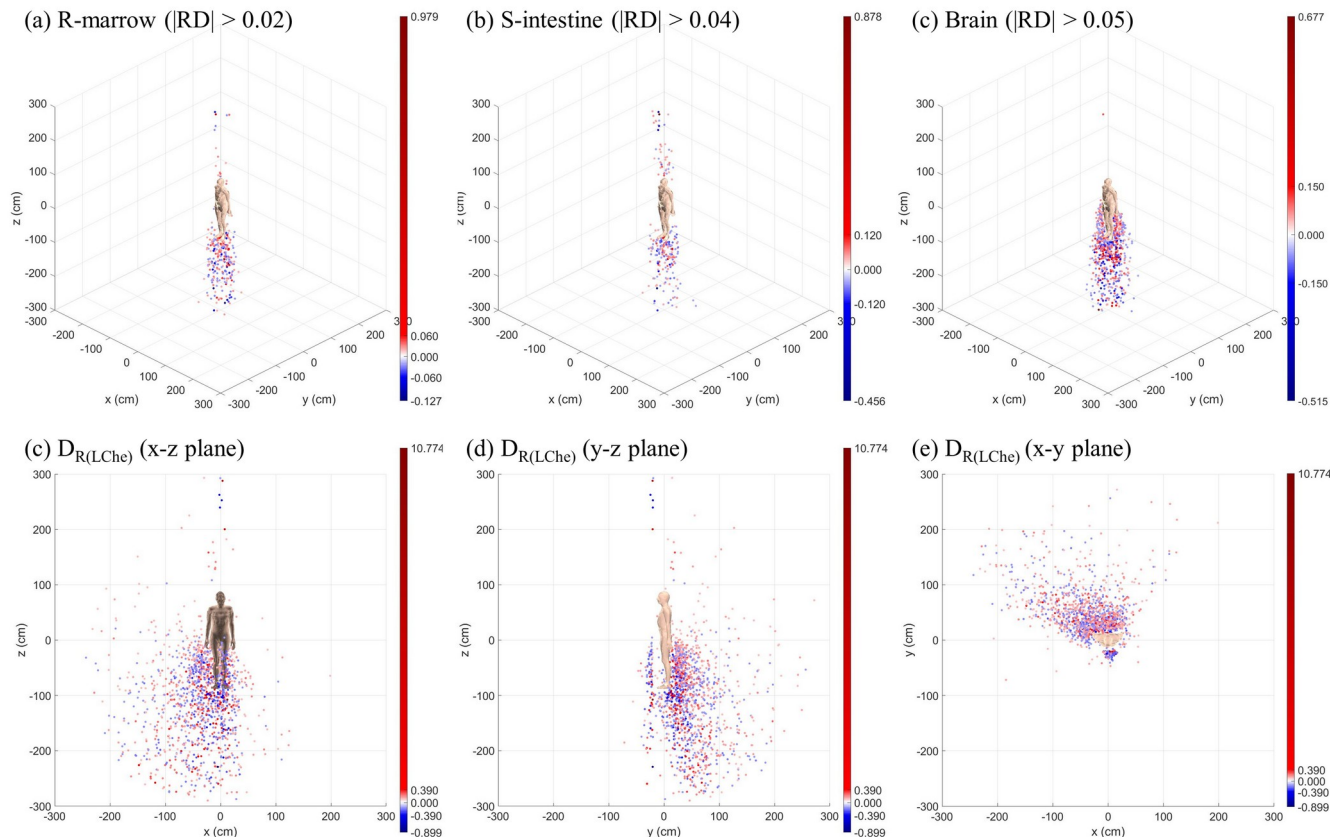
- **Dose linearity:**

- The D_{WB} model showed **high precision: the RD width 0.8%**
- The $D_{Dosimeter}$ models exhibited wider variability (RD width 28%) compared to the D_{WB} model due to higher noises (i.e. higher relative errors of MC data)



Research expansion (Anthropomorphic phantom)

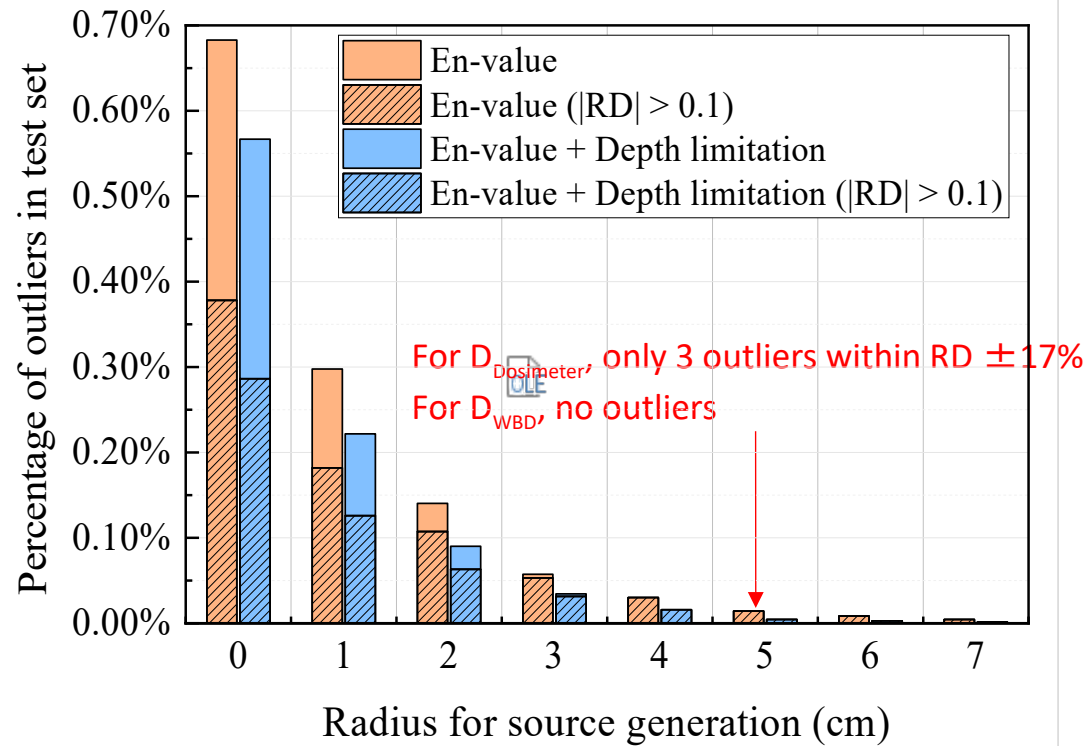
- **High RD positions:**
 - High attenuation and steep dose gradient positions
 - Noise in training data (i.e. relative error of MC data) is the major factor for model performance



Research expansion (Anthropomorphic phantom)

- **Outlier reduction methods:**

1. Introducing geometric uncertainties: source generation within a given radius
2. E_n -values test: only $|E_n| > 1$ was considered as outliers
3. Physical floor constraints: outliers below $z = -100\text{cm}$ were ignored
4. RD filtering: $|RD| > 10\%$ was considered as outliers



Research expansion (Anthropomorphic phantom)

- **Dose conversion coefficients:**

- ANN-based DCCs offer **superior flexibility for near-field exposure** scenarios compared to parallel-beam models (already proven in the feasibility test)
- These DCCs can be derived by combining two ANN models ($D_{WB}/D_{\text{Dosimeter}}$)
- The primary bottleneck for DCC reliability is the high variability in $D_{\text{Dosimeter}}$ compared to D_{WB}

- **Acceptable error margin:**

- Current fortuitous dosimeter protocols have a **high measurement uncertainty (>10% at least)**
- Moreover, the previous field tests (more informed than accidents) showed that MC simulations can differ from measured doses **by $\pm 10\%$ to $\pm 60\%$**

→ When integrated with suitable outlier reduction strategies, ANN-based models are expected to provide a **reasonable level of reliability for practical retrospective dosimetry**

ANN-based DCC calculator

ADORE v1.40

localhost:8503

ANN-based Dosimetry for On-site Reconstruction in Emergency (ADORE) v1.40

Contact: Hyoungtaek Kim (kht84@kaeri.re.kr)

Input parameters

Isotope

	Val (cm)	Unc. (cm)	Type	Samples
X	100.00	10.00		20
Y	100.00	10.00		20
Z	100.00	10.00		20

File input

Drag and drop file here
Limit 200MB per file • CSV

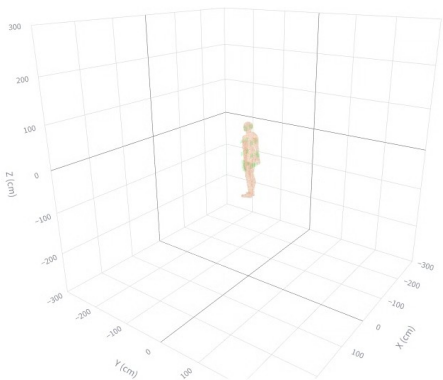
Browse files

Delete CSV

* The file must contain columns for isotope, x, y, and z(cm) in order, and the coordinates are limited as: x ≤ 300cm & y ≥ the phantom box [±33.7, ±20.5, ±93.1 cm].

3D Visualization

Hover over the phantom surface to view the coordinates and the distance from the source.



ANN-based dose estimation models

Organ

Dosimeter

* Rel. difference (RD = (D_ANN - D_MC)/D_MC) is a model performance metric (lower is better), and the given numbers represent the absolute RD values at the 1st and 99th percentiles of the tested data.

Run estimation

Statistics results

Statistics will appear here after running estimation.

Dose distribution

Dose distributions will appear here after running estimation.

ANN-based DCC calculator

ADORE v1.40 localhost:8503

ANN-based Dosimetry for On-site Reconstruction in Emergency (ADORE) v1.40

Contact: Hyoungtaek Kim (kht84@kaeri.re.kr)

Input parameters

Isotope: **Ir-192 / Cs-137 / Co-60**

Source positions

	Val (cm)	Unc. (cm)	Type	Samples
X	100.00	10.00	▼	20
Y	100.00	10.00	▼	20
Z	100.00	10.00	▼	20

Position Uncertainty

File input: Drag and drop file here (Limit 200MB per file • CSV) **Browse files**

Delete CSV

* The file must contain columns for isotope, x, y, and z(cm) in order, and the coordinates are limited as: $r \leq 300\text{cm}$ & $z \geq$ the phantom box ($\pm 33.7, \pm 20.5, \pm 93.1\text{ cm}$).

ANN-based dose estimation models

Organ: **D Organ**

Dosimeter: **D Dosimeter**

* Rel. difference (RD) = $(D_ANN - D_MC) / D_MC$ is a model performance metric (lower is better), and the given numbers represent the absolute RD values at the 1st and 99th percentiles of the tested data.

Run estimation

Statistics results

Statistics will appear here after running estimation.

3D Visualization

Hover over the phantom surface to view the coordinates and the distance from the source.

of sample generations

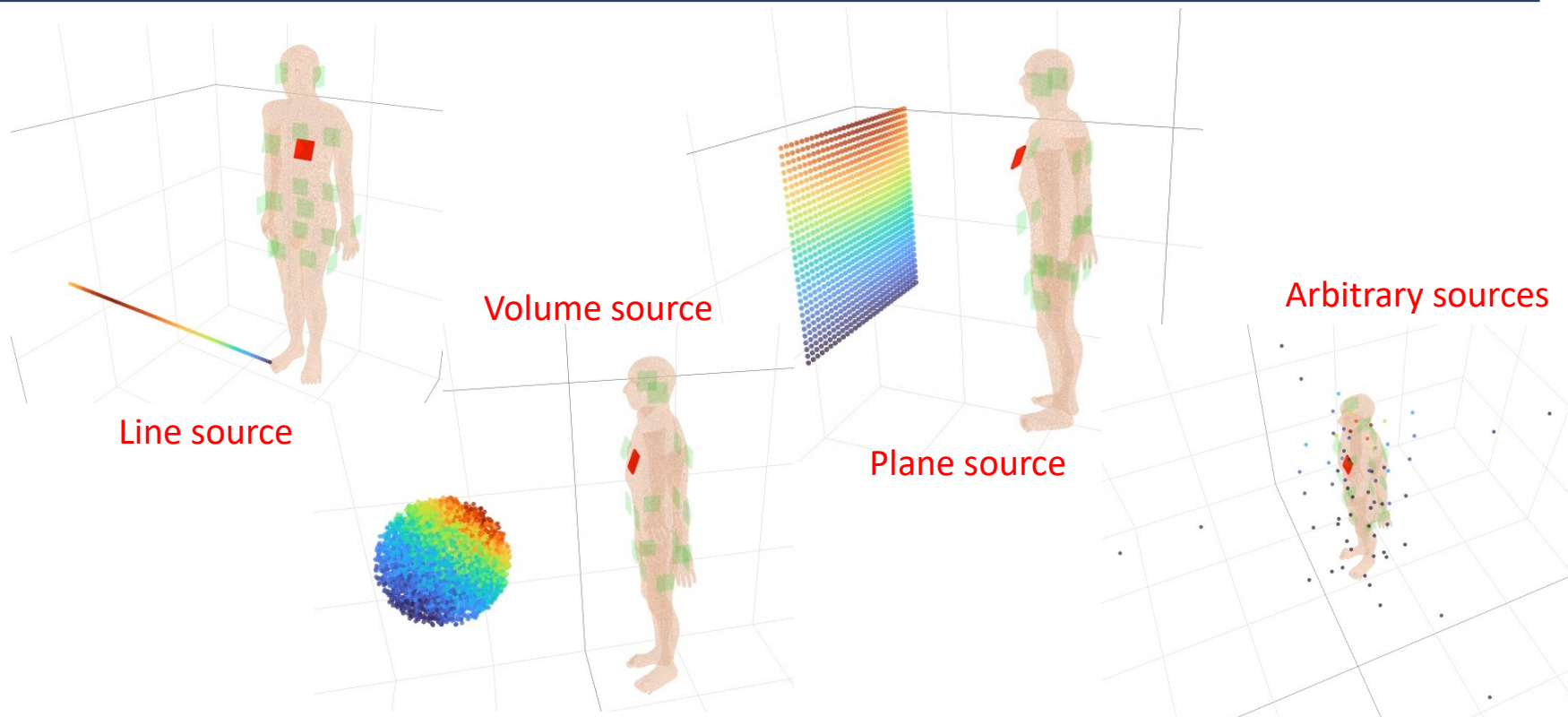
Distribution type:

- Uniform
- Gaussian
- Uniform Spherical
- Gaussian Spherical

ANN-based DCC calculator



ANN-based DCC calculator



Conclusion

- An ANN-based dose conversion model was developed by **bridging the gap between time-consuming MC simulations and inflexible DCC approaches.**
- These models are suitable **for rapid estimation in radiological emergencies.**
 - High accuracy estimation of whole-body dose
 - Near-instantaneous results
 - Lightweight, web-based, and on-site operation
- Future work should focus on
 - Optimization of the architecture, data quality, preprocessing
 - Multi-energy scenarios
 - Various postures
 - Verification of the model through ILC studies

**Thank you
for your attention
감사합니다**