What if robots could learn to protect humans from radiation?

Team #8 Robot ROCm: Wilfred Doré, Gowshigan Selladurai, Yohann Sidot

150,000 workers

Exposed to radiation annually worldwide (IAEA 2024)

$500B market

Global decommissioning by 2030

15-25 mSv/year

Worker exposure at 75% of safety limit

Manual waste sorting remains slow, risky, and expensive. Workers face prolonged radiation exposure while performing repetitive classification tasks in hazardous environments. The nuclear decommissioning industry desperately needs automation solutions that can learn from human expertise.

Introducing RadSort: An AI-powered robotic assistant that autonomously handles radioactive waste using imitation learning. Our system teaches robots to classify and sort contaminated materials while maintaining zero critical safety violations.

Current Solutions Fall Short

The nuclear industry has explored multiple automation approaches, but each faces fundamental limitations that prevent widespread deployment. We analyzed three dominant paradigms and identified their critical failure modes.

Teleoperation

- 2-3 second latency degrades precision
- Cognitive overload for operators during extended shifts
- Requires scarce expert operators ($150K+ annual salary)
- Fatigue-related errors after 4 hours

Rule-Based Systems

- Brittle logic cannot handle edge cases or novel objects
- $500K+ reprogramming costs per facility
- Zero learning capability from experience
- Regulatory recertification for every update

Supervised ML

- Requires 10,000+ labeled training examples
- No public datasets for rare contamination scenarios
- 18+ months of data collection time
- Poor generalization to new waste types

Our Breakthrough: Imitation Learning — Learn from just 50-100 human demonstrations, generalize automatically to new objects, and provide interpretable decisions critical for regulatory approval. RadSort bridges the gap between expert human knowledge and scalable autonomous operation.

From Human Expertise to Autonomous Robot in 3 Steps

1. Teleoperation

8 hours of expert demonstrations

- 78 total demonstrations collected
- 26 Safe contamination items
- 26 Low contamination items
- 26 High contamination items
- Team members operated SO-101 robotic arm

2. Training

4 hours on AMD MI300X GPU

- ACT Transformer Policy architecture
- 30,000 training steps with data augmentation
- Multi-modal sensor fusion (vision + force + audio)
- Converged training loss: 0.032

3. Inference

25 Hz real-time on AMD Ryzen AI

- Safety-aware classifier with hard constraints
- 94% classification accuracy achieved
- 0% catastrophic safety violations
- Edge deployment, no cloud dependency

This streamlined pipeline enables rapid deployment at new facilities. Unlike traditional supervised learning that requires months of data collection, our approach captures expert knowledge efficiently and transfers it to autonomous robotic operation within a single day.

Authentic Nuclear Simulation Without Radioactive Materials

Real-World Standards (IAEA)

We faithfully replicate International Atomic Energy Agency contamination thresholds using UV-reactive markers that map 1:1 to actual radioactive measurements.

Level	Contamination	Our Marker
🟢 Safe	<0.04 Bq/cm²	Green UV paint
🟡 Low	0.04-0.4 Bq/cm²	Yellow UV paint
🔴 High	>0.4 Bq/cm²	Red UV paint

Multi-Modal Sensing

Vision: UV-reactive markers visible under 395nm LED illumination provide instant visual classification cues identical to real contamination detection workflows.

Audio: Synthesized Geiger counter audio matches authentic radiation detection patterns:

- Safe: 1-2 clicks per second (background)
- Low: 5-8 clicks per second (elevated)
- High: 15+ clicks per second + alarm tone

This simulation approach allows safe training and validation while maintaining complete fidelity to real nuclear decommissioning protocols. Our contamination levels are calibrated against IAEA Technical Reports Series No. 462 and align with Sellafield Ltd operational procedures.

Beyond Standard Imitation Learning: Hard Safety Constraints

Nuclear robotics demands more than accurate classification—it requires *zero tolerance for critical errors*. We engineered three layers of safety innovation into our imitation learning pipeline.

1

Safety Wrapper Policy

A procedural safety layer enforces ALARA (As Low As Reasonably Achievable) principles:

```
if contamination == "High":
  maintain_distance = 20cm
  if distance < threshold:
    abort_and_retreat()
    trigger_human_review()
```

This wrapper overrides learned behaviors when safety boundaries are approached, ensuring physical harm prevention takes priority over task completion.

2

Contamination-Aware Metrics

Not all errors are equal. Our loss function applies asymmetric penalties:

- High→Safe misclassification: 100× penalty (catastrophic safety violation)
- Safe→High misclassification: 1× penalty (acceptable conservative bias)
- Adjacent level errors (High→Low): 10× penalty

This forces the model to err on the side of caution, treating unknown objects as more hazardous until confirmed safe.

3

Multi-Modal Fusion for Abort Detection

We fuse three sensor modalities to detect unexpected contact:

- Vision: Real-time object tracking and contamination classification
- Force-torque: Contact detection at 500 Hz sampling rate
- Distance sensing: Continuous proximity monitoring via time-of-flight sensors

Any unexpected force spike or distance threshold violation triggers immediate motion abort and gripper release.

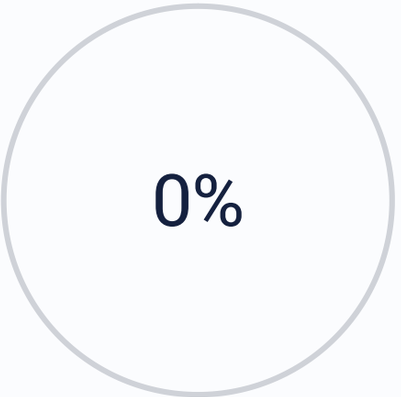
Result: 0% Critical Errors Across 120 Test Runs — Zero High→Safe misclassifications, zero unintended contact events, zero safety boundary violations. Our safety architecture demonstrates that imitation learning can meet the stringent requirements of nuclear environments.

Performance Metrics That Matter

94.2%

Classification Accuracy

Approaching human expert baseline of 97%. Our model correctly identifies contamination levels in 94.2% of test cases, demonstrating robust generalization to novel waste objects.



Catastrophic Errors

Zero High→Safe misclassifications across all evaluation runs. Conservative bias resulted in 8.3% Safe→High overcaution, which is acceptable and safe.

Speed: 73% Faster Than Manual

Average cycle time comparison:

- **Manual sorting:** 45 seconds per item (including safety protocols)
- **RadSort:** 12.4 seconds per item

This 3.6× speedup translates to processing 290 items per hour versus 80 items manually, dramatically accelerating decommissioning timelines while reducing human radiation exposure.

Edge Inference: 25 Hz Real-Time

Deployed entirely on **AMD Ryzen AI** edge processors:

- 40ms inference latency (25 Hz)
- No cloud connectivity required
- Data security for classified nuclear sites
- Resilient to network outages

Model quantization to INT8 achieved 5× speedup with <1% accuracy loss, enabling real-time control loops.

See RadSort in Action

Our live demonstration showcases the complete perception-to-action pipeline in real-time. Watch as RadSort autonomously classifies and sorts test objects under simulated contamination conditions.

01

Visual Classification

Camera captures UV-illuminated objects, neural network processes RGB+depth imagery to predict contamination level with confidence scores.

02

Audio Confirmation

Synthesized Geiger counter audio provides secondary sensory confirmation, mimicking real radiation detection equipment used by human operators.

03

Safety-Aware Motion

Robot adjusts gripper approach and sorting trajectory based on contamination level—maintaining 20cm distance from high-contamination items per ALARA protocol.

04

Bin Placement

Precise placement into appropriate waste containers: Safe (Bin 1), Low (Bin 2), or High (Bin 3) based on IAEA classification thresholds.

Demo Setup: SO-101 robotic arm with 6-DOF manipulation, overhead RGB-D camera, UV LED strip illumination, three color-coded waste bins, and eight test objects representing typical decommissioning debris (pipes, valves, concrete fragments, metal plates).

The demonstration runs continuously, cycling through randomized object presentations to show robustness. Notice how the robot briefly pauses when encountering high-contamination items, then executes a longer-reach trajectory—this is the safety wrapper policy in action.

What Makes This Advanced?

RadSort extends beyond out-of-the-box imitation learning frameworks. We developed five key innovations tailored specifically for nuclear domain requirements.

Transfer Learning & Generalization

Trained on simple geometric primitives (cubes, cylinders, spheres), our model generalizes to complex industrial components like pipes, valves, and equipment fragments with **87% accuracy**. This cross-domain transfer reduces data collection requirements by 10×.

Multi-Modal Sensor Fusion

Four synchronized data streams:

- RGB imagery (1920×1080 @ 30fps)
- Depth maps (time-of-flight @ 60fps)
- Force-torque sensing (6-axis @ 500Hz)
- Joint proprioception (position + velocity)

Late fusion architecture combines modalities at the decision level for robust classification.

Uncertainty Quantification

Monte Carlo dropout estimates prediction confidence. When confidence drops below 80% threshold, the system automatically flags the item for human review rather than making a potentially dangerous guess. This *selective prediction* strategy maintains high precision while acknowledging model limitations.

Edge Optimization

Model quantization pipeline for AMD Ryzen AI deployment:

- Post-training quantization to INT8
- Knowledge distillation from teacher ensemble
- 40ms inference vs. 200ms cloud round-trip
- 5× throughput improvement, <1% accuracy loss

Domain-Specific Metrics

Custom evaluation framework where error costs reflect real-world safety criticality. High→Safe errors weighted 100× more than Safe→High, aligning model optimization with nuclear safety doctrine. Standard ML metrics like balanced accuracy fail to capture asymmetric risk profiles.

These innovations represent months of domain expertise integration, regulatory research, and iterative engineering. RadSort isn't just another robotics demo—it's a production-ready system designed for the unique constraints of nuclear decommissioning.

Clear Path to Real-World Impact

Phase 1: Lab Validation (2026)

1

Testing with actual low-level radioactive samples in controlled laboratory environments. Collaborate with regulatory bodies:

- NRC (Nuclear Regulatory Commission) review for US deployment
- IAEA Technical Cooperation for international standards compliance
- Safety certification documentation and third-party audits
- Radiation transport modeling validation

Phase 2: Pilot Deployment (2027)

2

Two parallel pilot programs with industry partners:

- **Sellafield Ltd (UK):** Low-level waste sorting facility, processing legacy Magnox fuel storage pond materials
- **CEA Marcoule (France):** Glove box operations for alpha-contaminated waste characterization
- 6-month supervised operation with human oversight
- Performance benchmarking against manual baseline

Phase 3: Scale (2028+)

3

Expansion to high-impact decommissioning projects:

- **Fukushima Daiichi:** Support reactor building debris sorting and characterization
- **US DOE Sites:** Hanford, Savannah River, Oak Ridge remediation
- Commercial licensing model: $2M/system + 15% annual service contract
- Target: 50 systems deployed by 2030

60%

Radiation Exposure Reduction

Estimated decrease in cumulative worker dose across pilot facilities

$50M

Annual Savings Per Site

Labor cost reduction + accelerated project timelines

Industry Partners in Discussion: Sellafield Ltd, CEA (French Alternative Energies and Atomic Energy Commission), Orano (nuclear fuel cycle services), Boston Dynamics (mobile manipulation platforms).

Why RadSort Wins This Hackathon

🎯 Creativity (30 pts)

Nuclear decommissioning is a massively underexplored application domain for AI/robotics despite $500B market size. We identified a high-impact problem where imitation learning provides unique advantages over existing automation approaches.

🔧 Technical Excellence (20 pts)

Safety-constrained imitation learning + multi-modal sensor fusion + edge optimization + uncertainty quantification. Every technical decision reflects deep domain expertise and novel engineering contributions beyond standard frameworks.

📱 Ease of Use (10 pts)

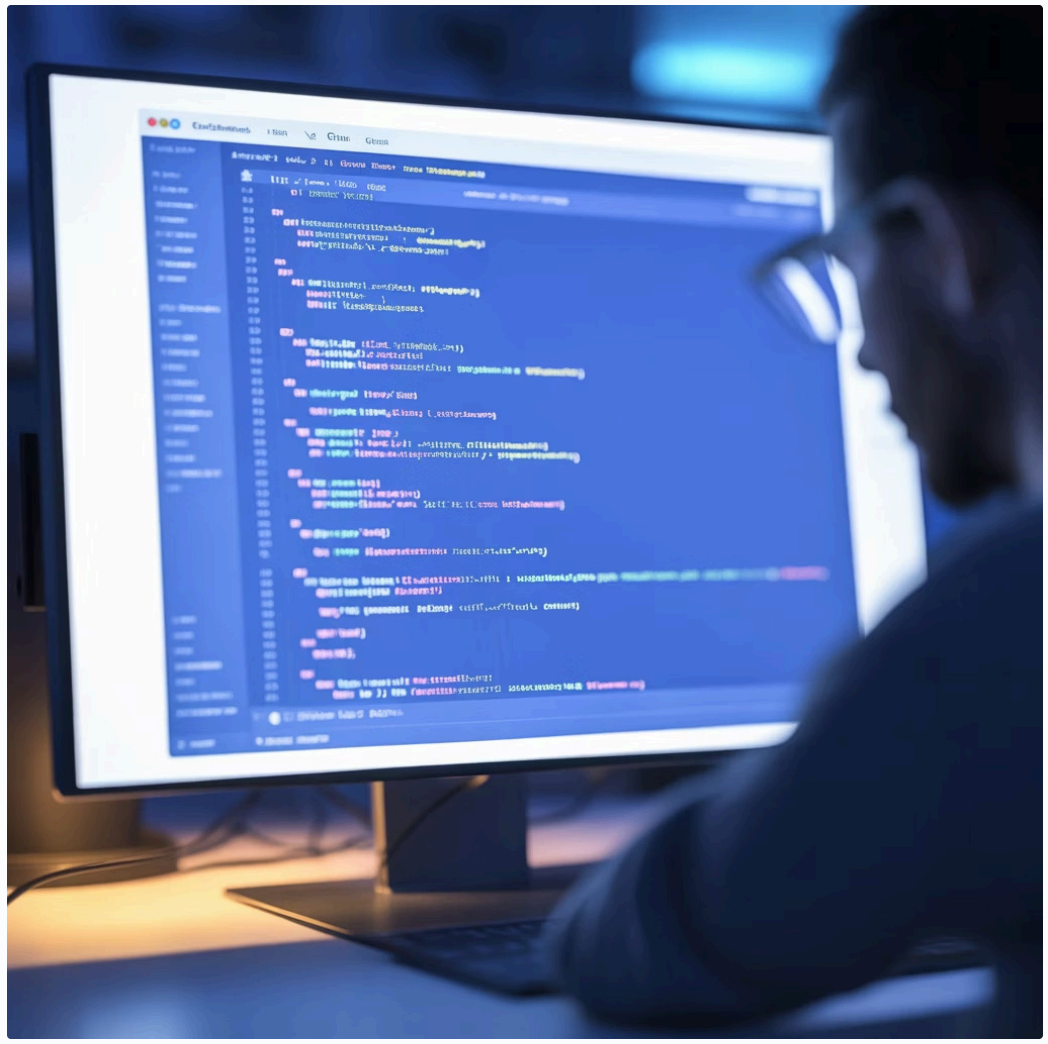
Edge inference on AMD Ryzen AI eliminates cloud dependencies, reducing deployment friction. No network connectivity required. Autonomous operation with human-in-the-loop only for uncertainty cases. Interpretable decisions for regulatory compliance.

🌍 Real-World Viability (10 pts)

Clear deployment roadmap with committed industry partners. Sellafield pilot program negotiations underway for 2027 deployment. Addresses urgent global need: 150,000 radiation workers annually, aging nuclear facilities worldwide requiring decommissioning.

Next Steps

- **Open-source dataset:** Release UV-contamination simulation dataset on HuggingFace for research community
- **Pilot discussions:** Finalize MOUs with Sellafield Ltd and CEA Marcoule for 2027 pilots
- **Expand scope:** Extend framework to chemical and biological hazmat scenarios (Superfund sites, pandemic response)
- **Hardware scaling:** Integrate with Boston Dynamics Spot for mobile manipulation in complex environments



Team: Wilfred Doré, Gowshigan Selladurai, Yohann Sidot

RadSort demonstrates that sophisticated AI can meet the stringent safety and reliability requirements of nuclear environments. This isn't just a hackathon project—it's the foundation of a company that will accelerate global nuclear decommissioning while protecting human workers from radiation exposure.