Transferability in Multisource Machine Learning for Nuclear Applications

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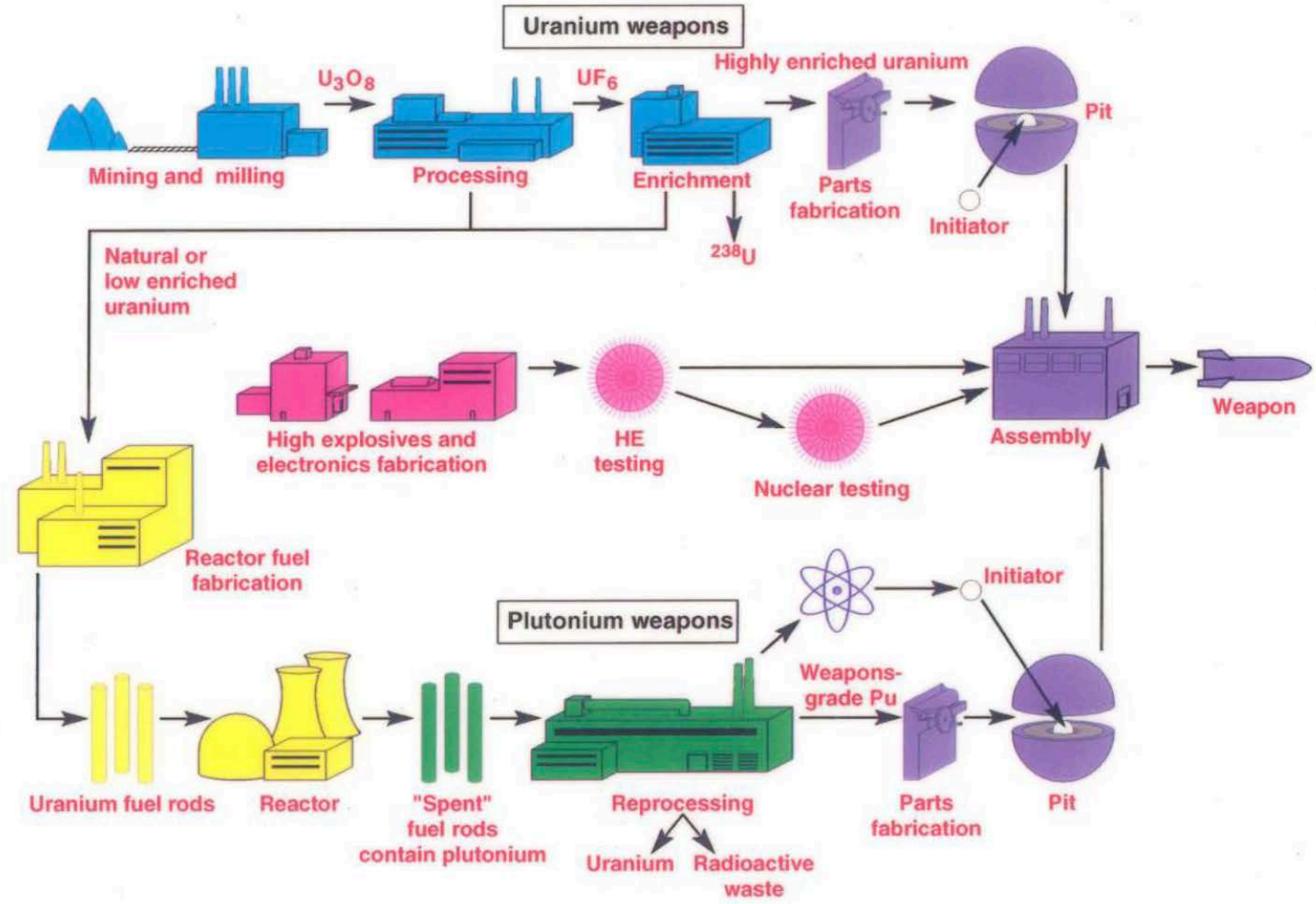
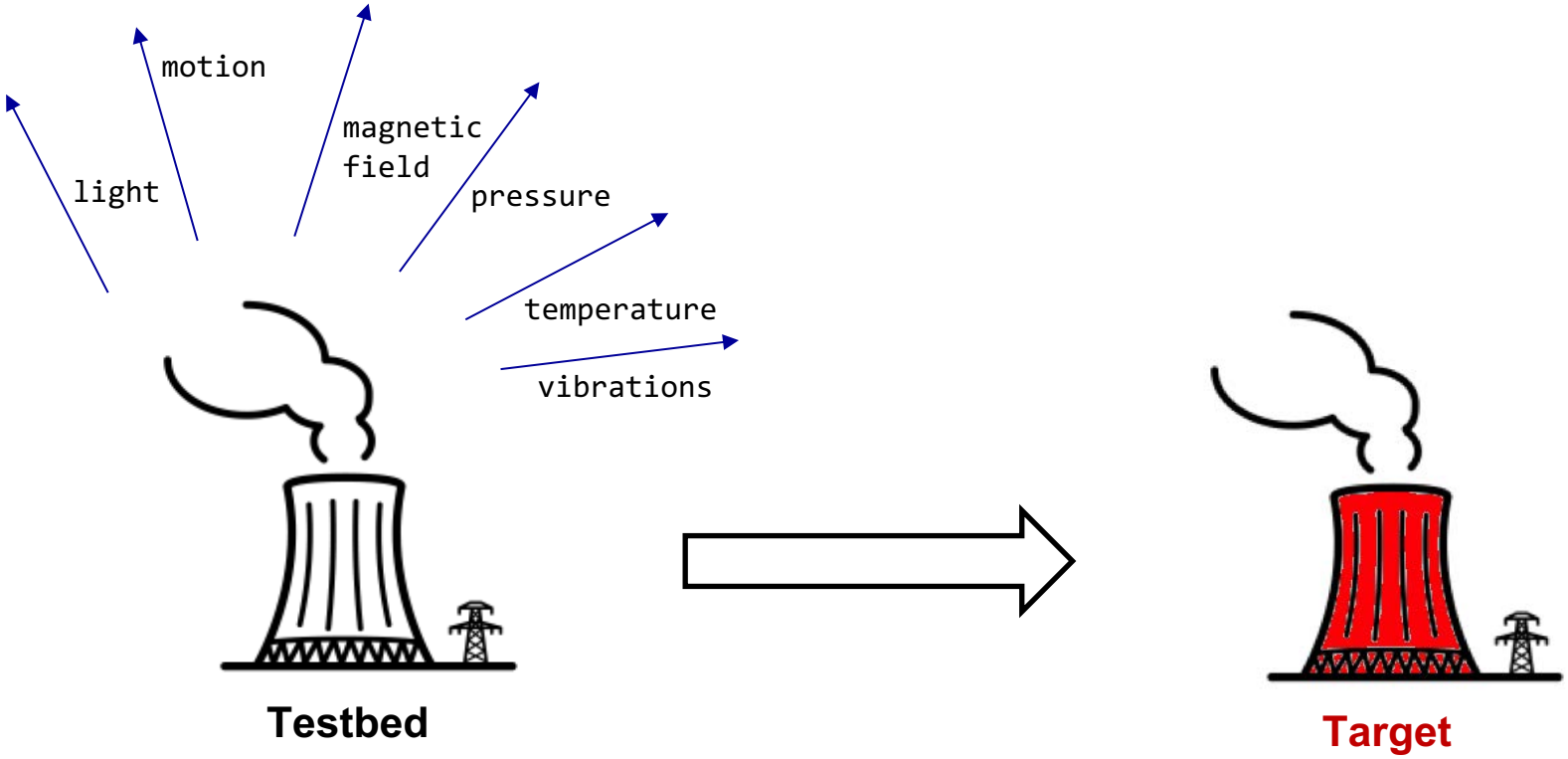
The Nuclear (Weapons) Fuel Cycle



El-Mongy, Sayed. (2006). Recent Verification Techniques of Fissile Nuclear Content in Nuclear Fuel. National Center for Nuclear safety and Radiation Control.

complexity

Transferability is the application of models generated at one facility to other settings

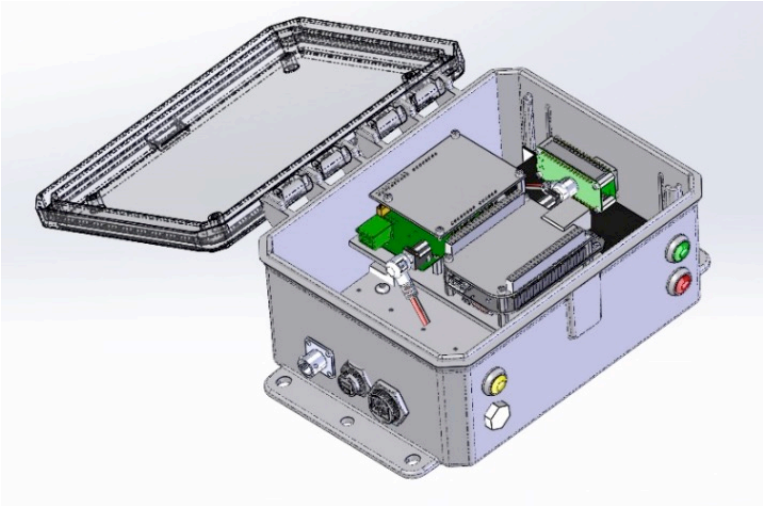


Indirect Physical Sensing with the MERLYN

MERLYN Sensor Suite

- Position (GPS)
- Magnetic field (3-axis)
- Acceleration (3-axis)
- Pressure
- Temperature
- Ambient Light + RGB
- Proximity

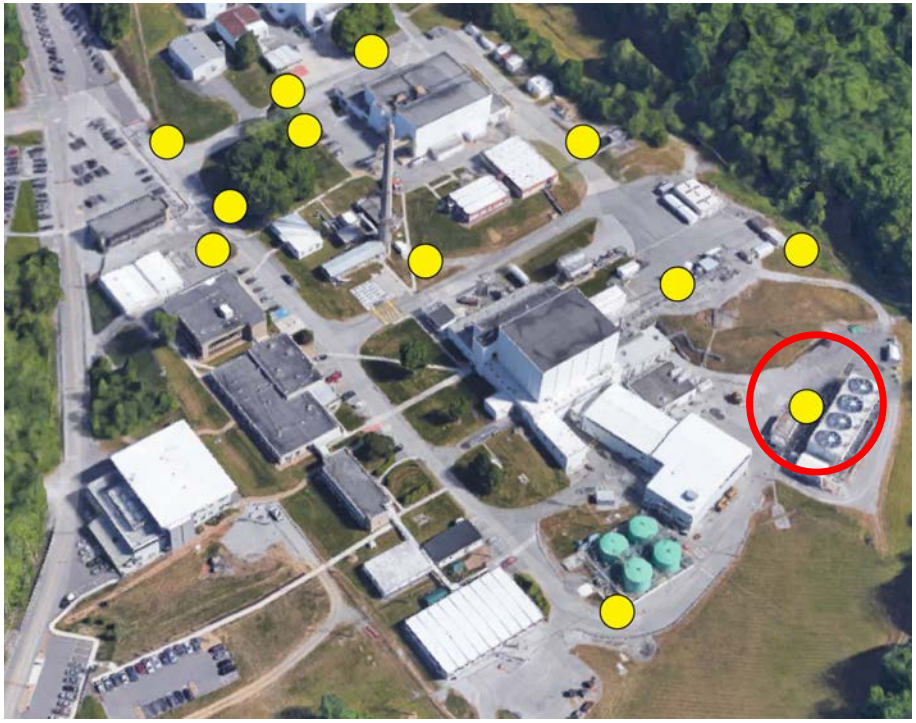
Sampling rate: 16 Hz



Testbed Facility: High Flux Isotope Reactor at Oak Ridge National Laboratory

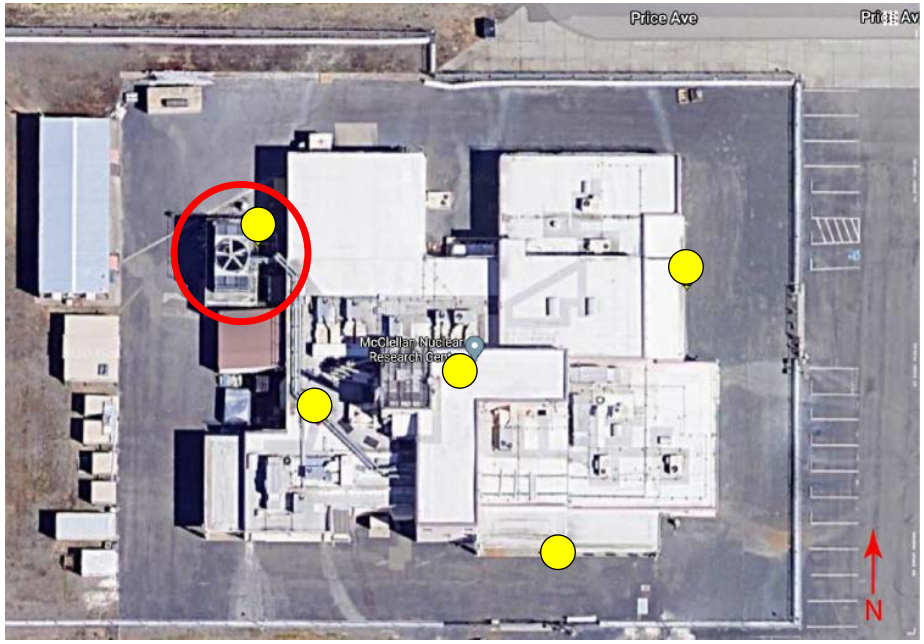
Fast facts:

- 85 MW testbed reactor, high steady-state neutron flux
- 12 MERLYN multisensors
- Deployed April 2019
- ~1 year of labeled data
- Ground Truth:
  - reactor on/off
  - 5-class power output
  - secondary loop pump speeds
  - target transfer
  - target irradiation



Merlyn array at the HFIR/REDC testbed at Oak Ridge National Laboratory. Overhead image from Google Earth.

Target Facility: TRIGA reactor at the McClellan Nuclear Research Center



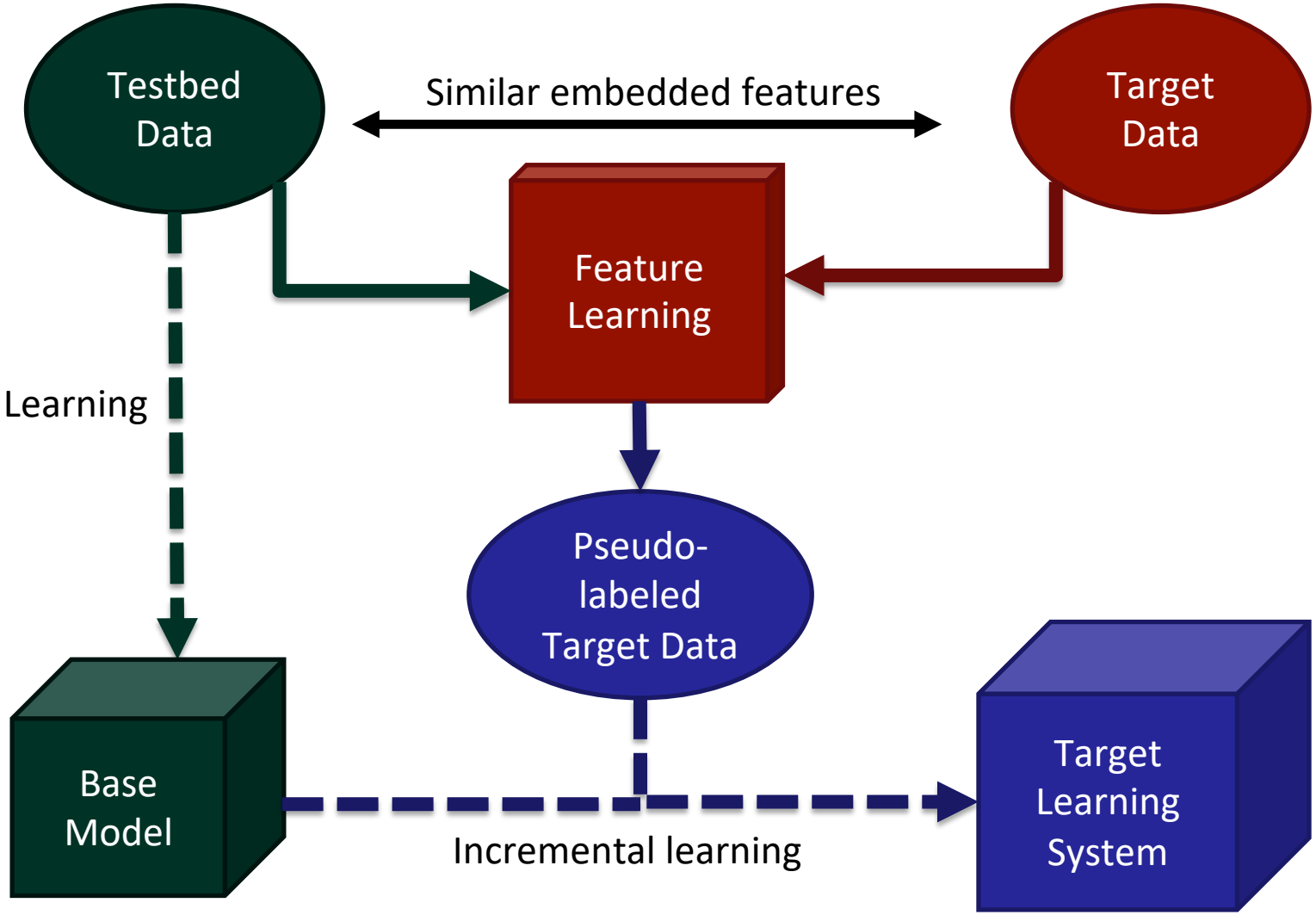
Merlyn array at the TRIGA target at the McClellan Nuclear Research Center. Overhead image from Google Earth.

Fast facts:

- 2 MW TRIGA reactor, 300 MW pulse
- 5 MERLYN multisensors
- Deployed July 2020
- ~2 months of labeled data
- Ground truth available:
  - Reactor operational history
  - Reactor power
  - Target production
  - Fuel movement

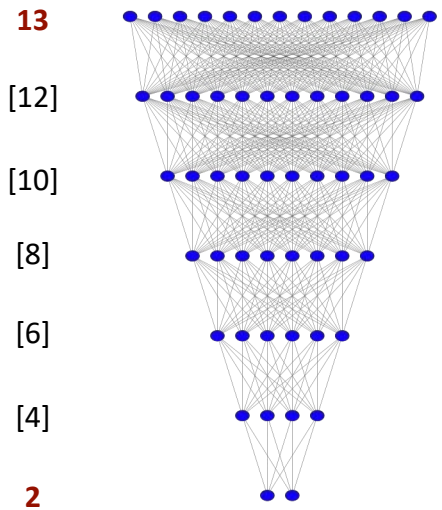
The same data products are measured at the target facility, but signatures may be different in different setting.

Transductive Transfer Learning Workflow



Base Supervised ML Model to Characterize Reactor Operations

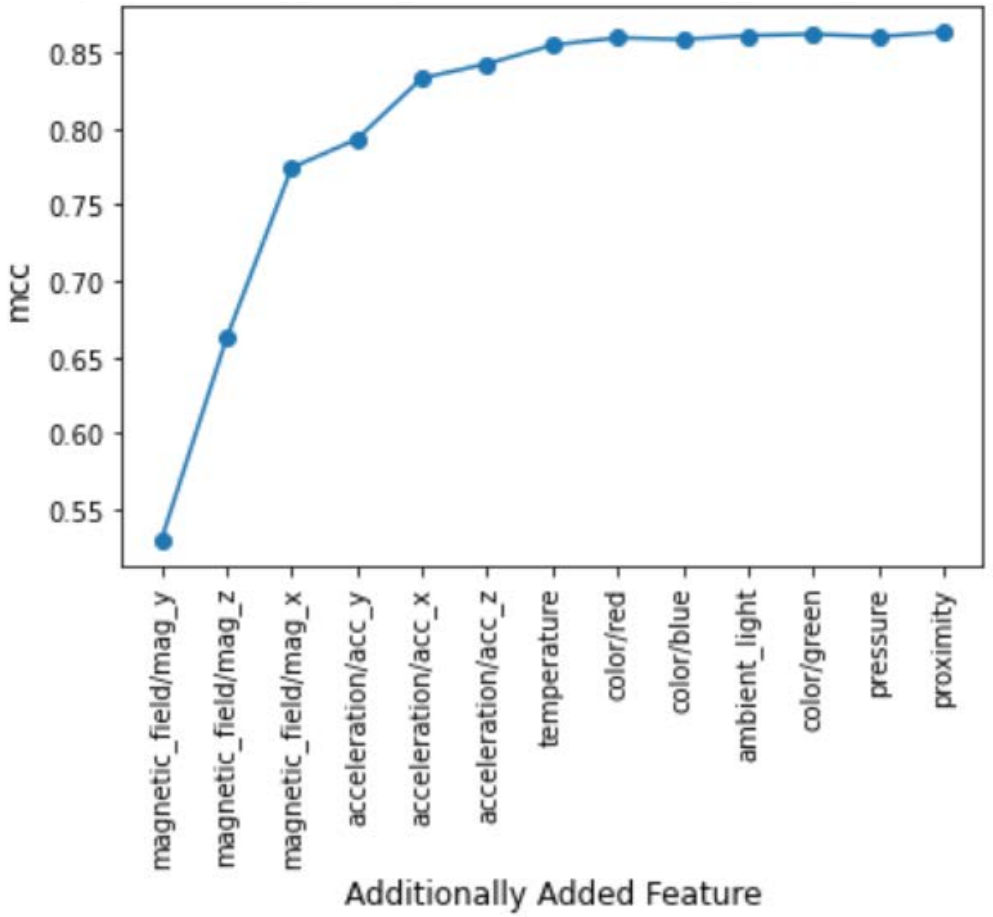
ARCHITECTURE



80/20 TRAIN/VALIDATE
Learning Rate: 10^{-3}
Training Batch Size: 2^{11}

	Vector
Prevalence	0.62
Accuracy	0.94
MCC	0.866

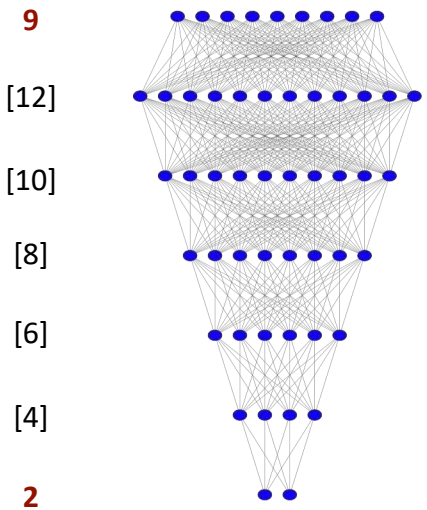
HFIR-109



https://complexity.berkeley.edu/mimosas/

Base Supervised ML Model to Characterize Reactor Operations

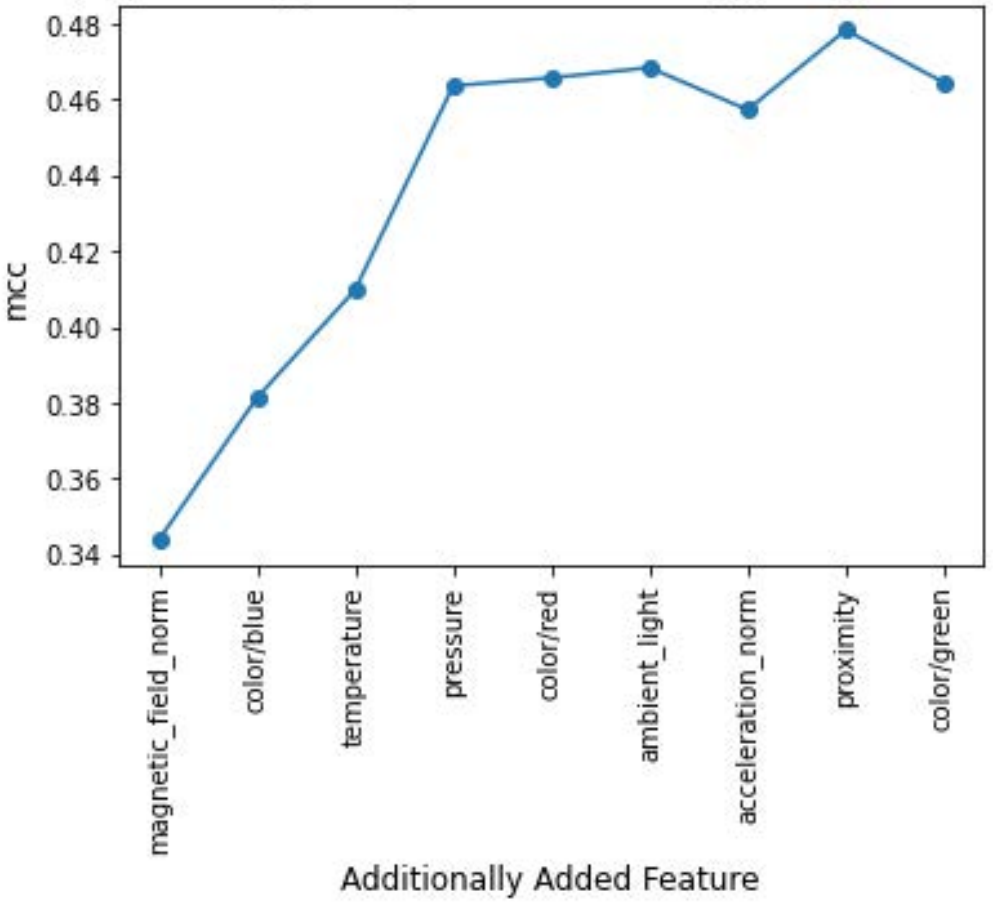
ARCHITECTURE



80/20 TRAIN/VALIDATE
Learning Rate: 10^{-3}
Training Batch Size: 4096

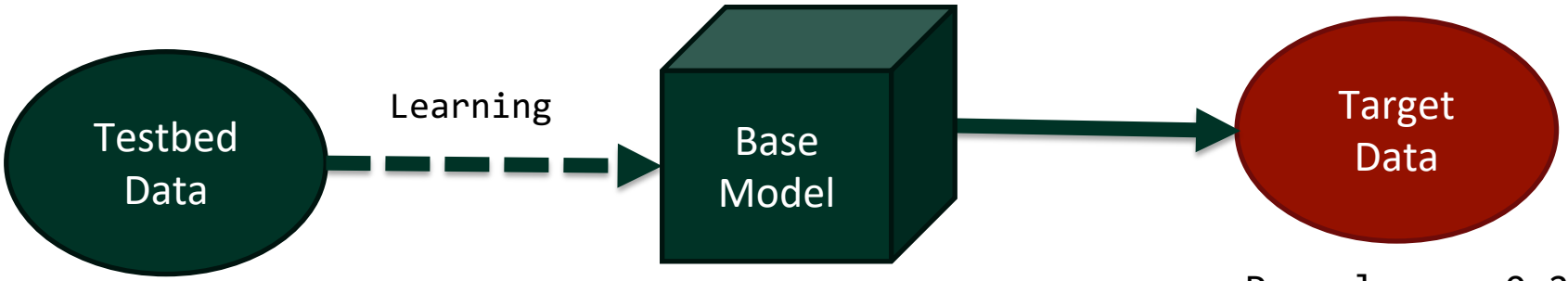
	Vector	Magnitude
Prevalence	0.62	0.62
Accuracy	0.94	0.75
MCC	0.866	0.456

HFIR-109

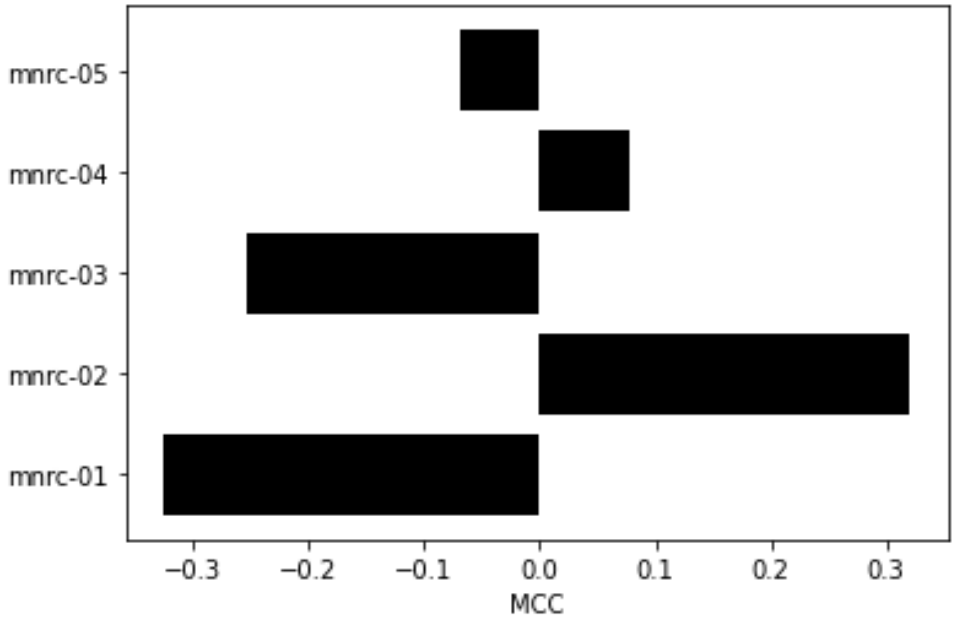


https://complexity.berkeley.edu/mimosas/

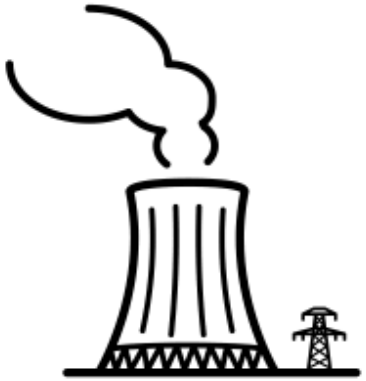
Baseline Transferability



MRNC-ID	Accuracy
101	0.28
102	0.64
103	0.32
104	0.51
105	0.54

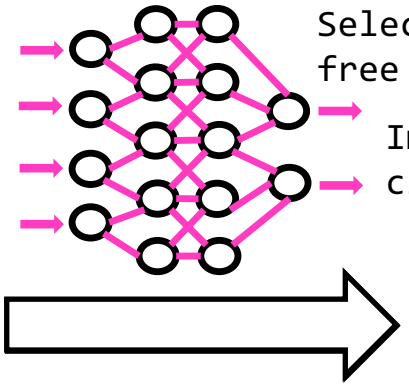


Transductive Transfer Learning



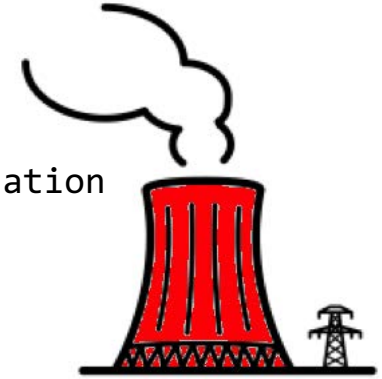
Testbed

Feed target data

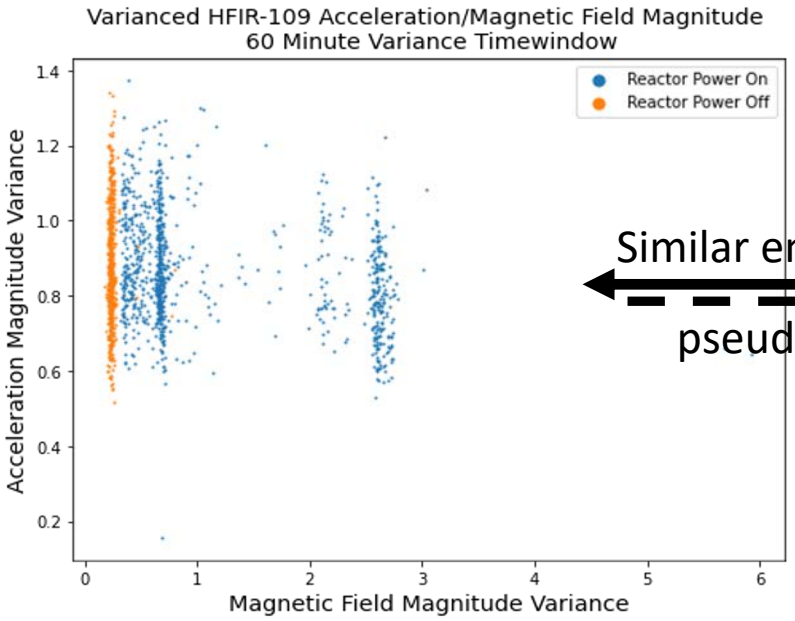


Selectively free layers

Improved classification

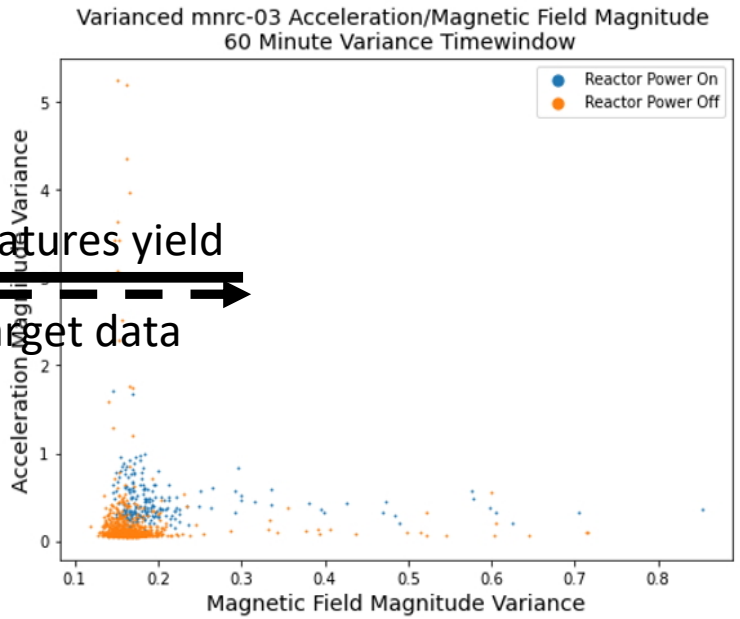


Target

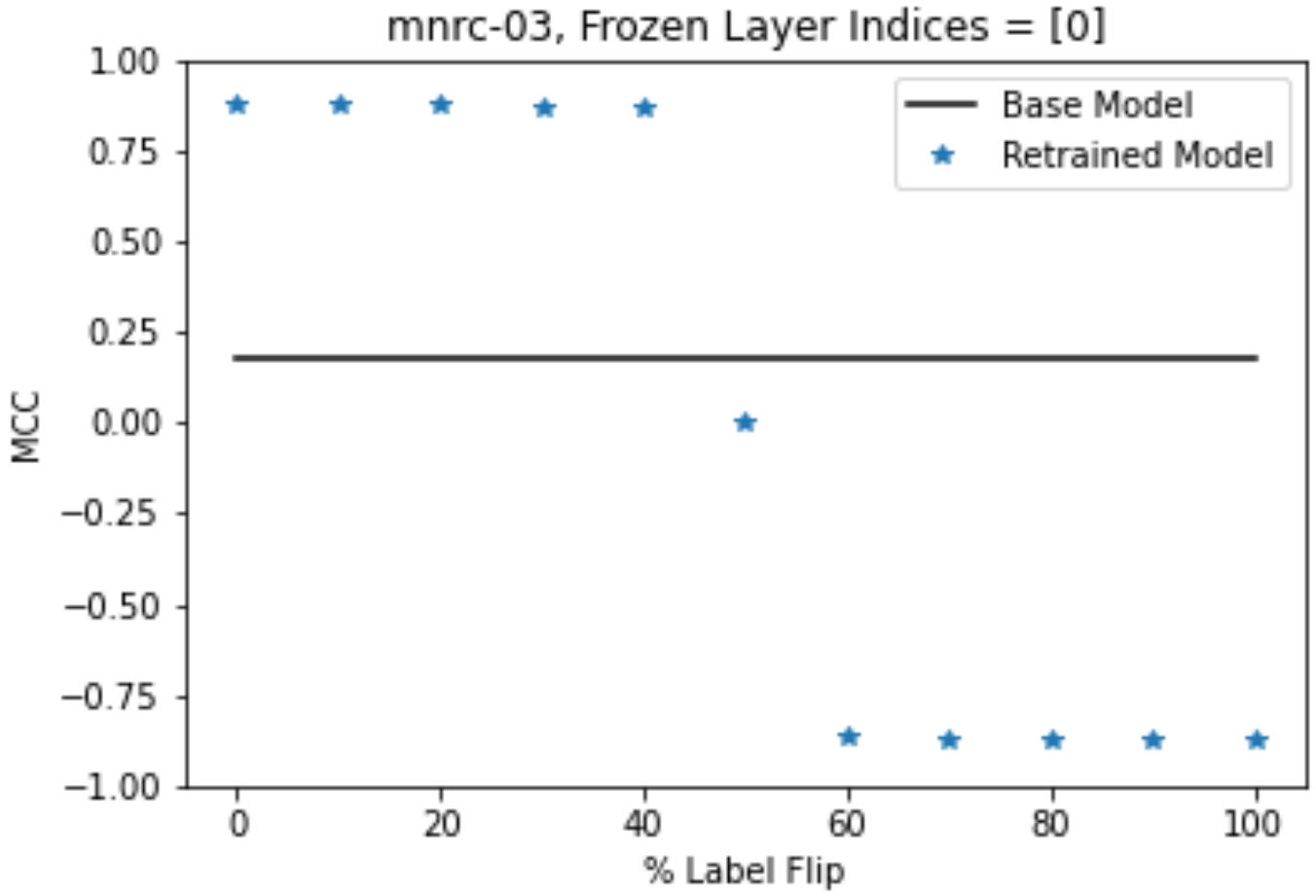


Similar embedded features yield

pseudo-labeled target data

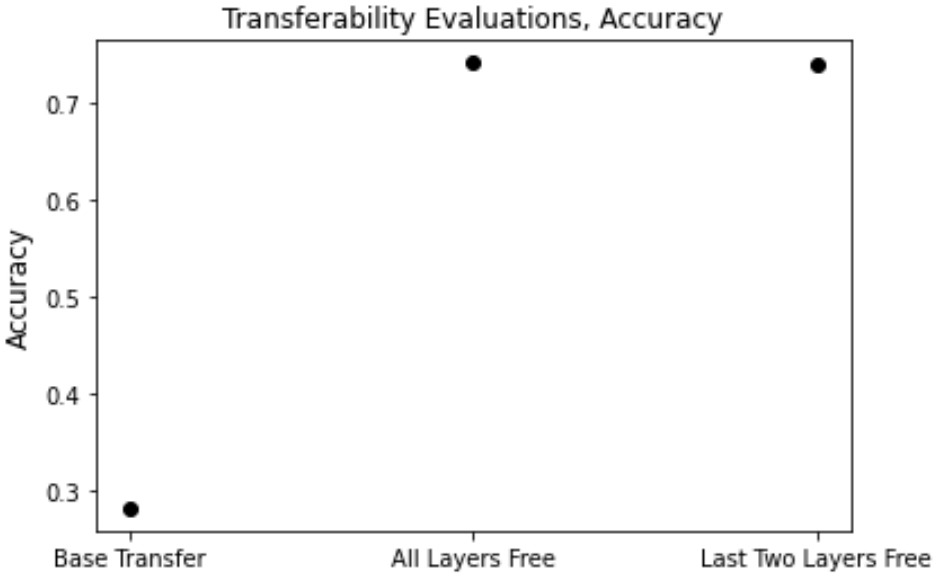


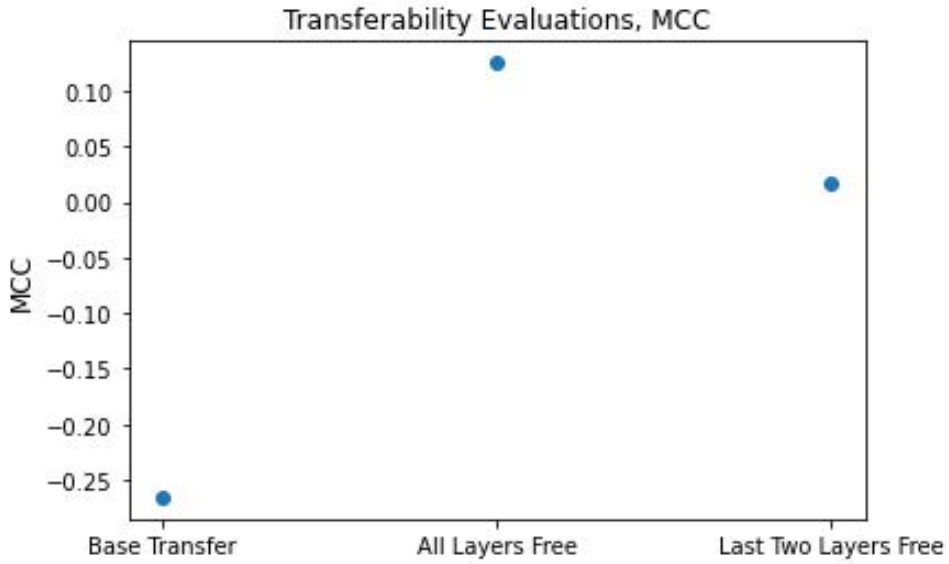
What accuracy is needed in the pseudo-labeling process?



Courtesy of 2d Lt. M. Brinker, Maj J. Bevins

Transfer Learning Performance Evaluation



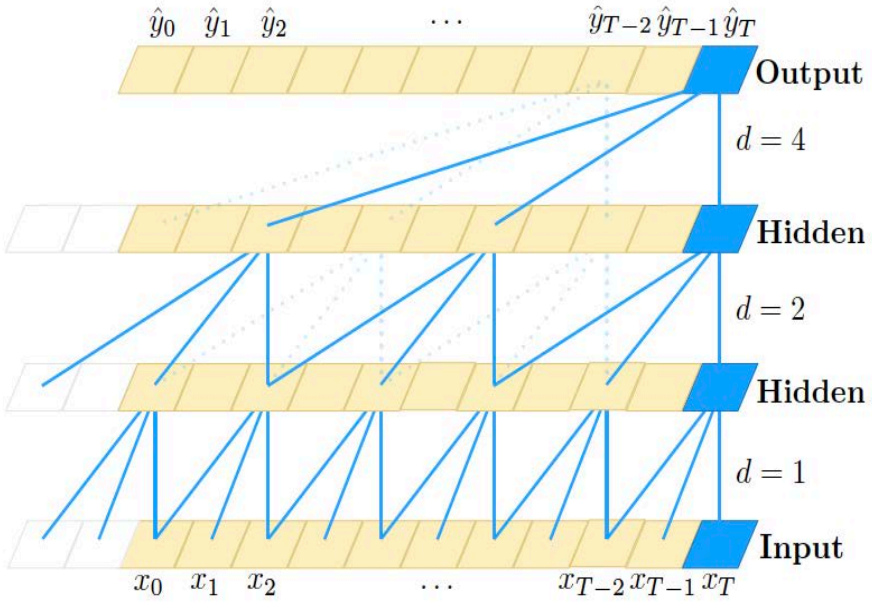


- Remarkable improvement in transfer accuracy using transductive cluster-then-label approach
- MCC results suggest room for improvement

Next Steps with SNITCHES

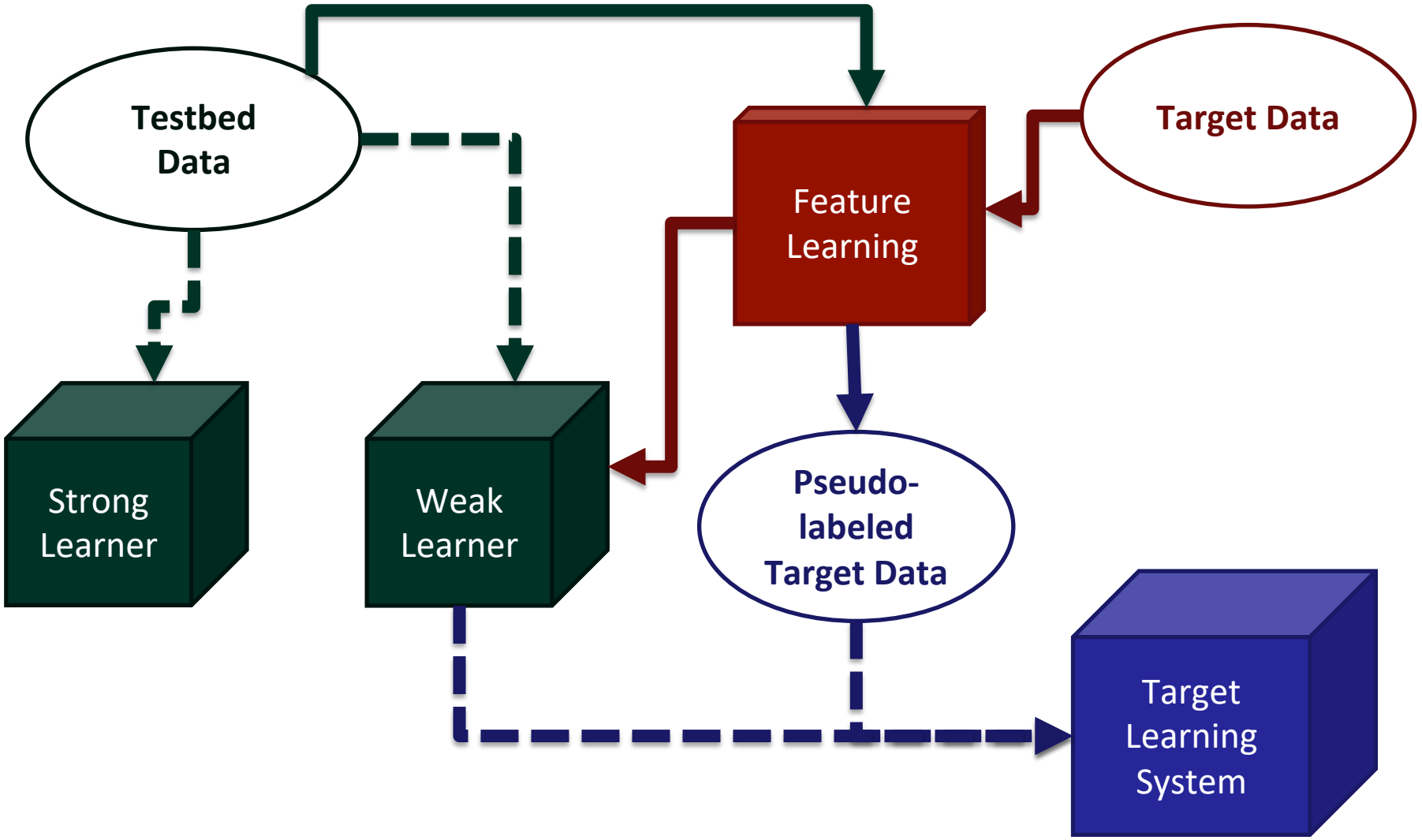
New Start for FY21
Sensor Networks to Identify Transferable Classification Heuristics for Enhanced Security

1. ***Why* do our ML models yield the given predictions?**
2. ***How* do we develop interpretable, transferable ML models?**

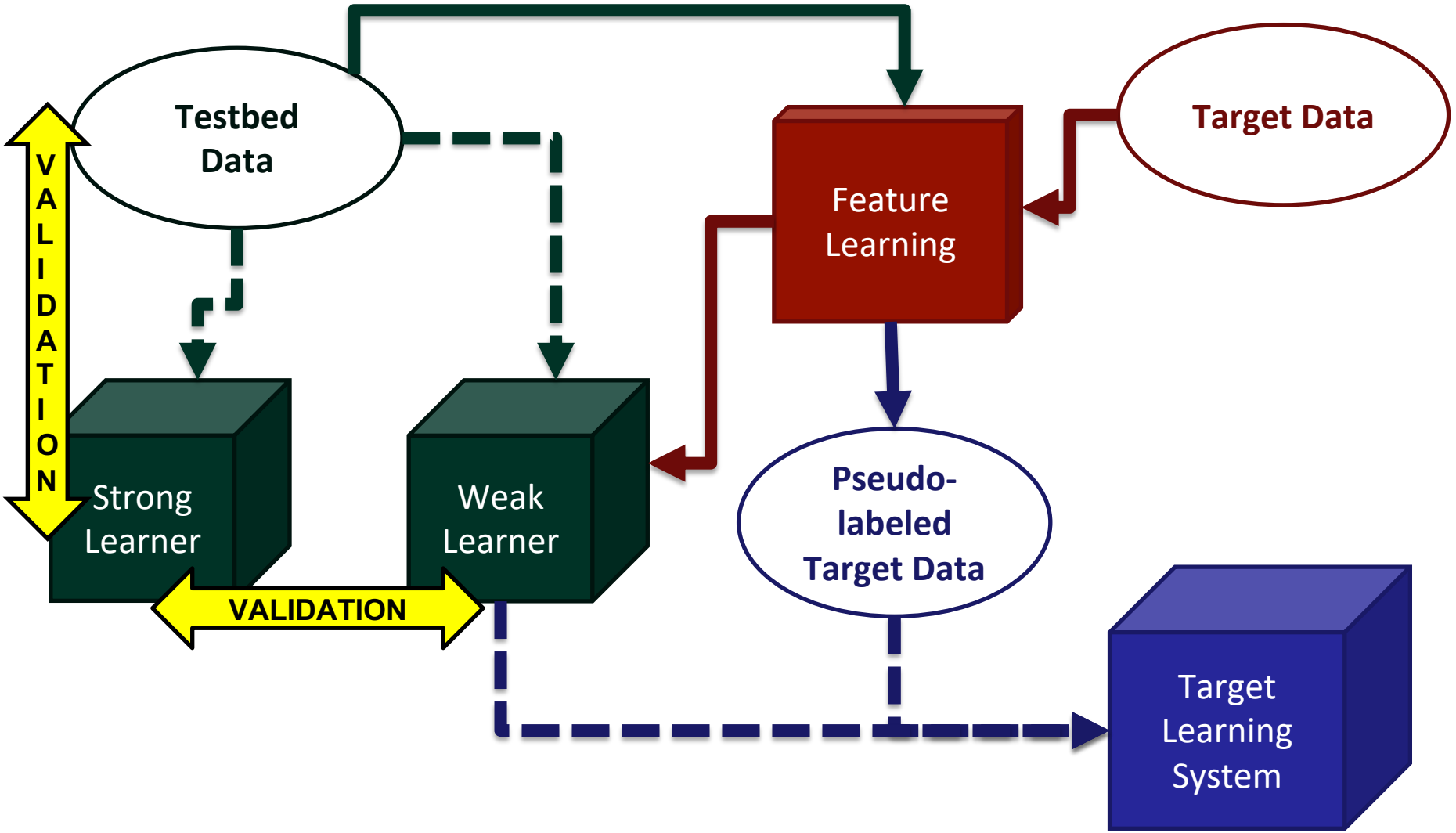


S. Bai, J.Z. Kolter, V. Koltun, "An Empitical Evaluation of Generic Convolutional and Recurrent Networks for Sequence Modeling," *ArXiv* abs/1803.01271 (2018).

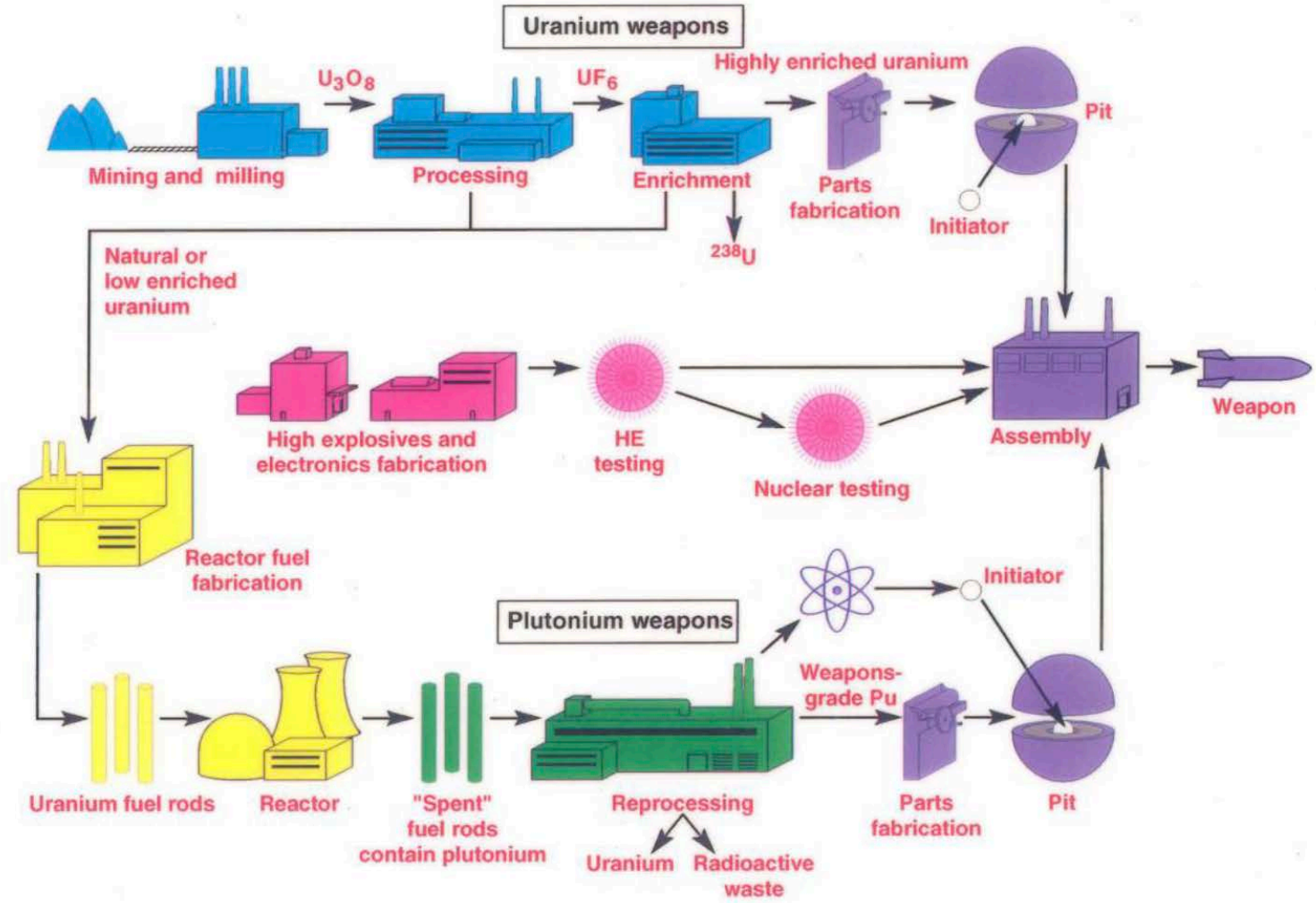
SNITCHES Workflow



SNITCHES Workflow



Applications across the Nuclear (Weapons) Fuel Cycle



El-Mongy, Sayed. (2006). Recent Verification Techniques of Fissile Nuclear Content in Nuclear Fuel. National Center for Nuclear safety and Radiation Control.

Acknowledgments

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