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# Genetic Algorithm Based Optimization for Nuclear Critical Experiment Design

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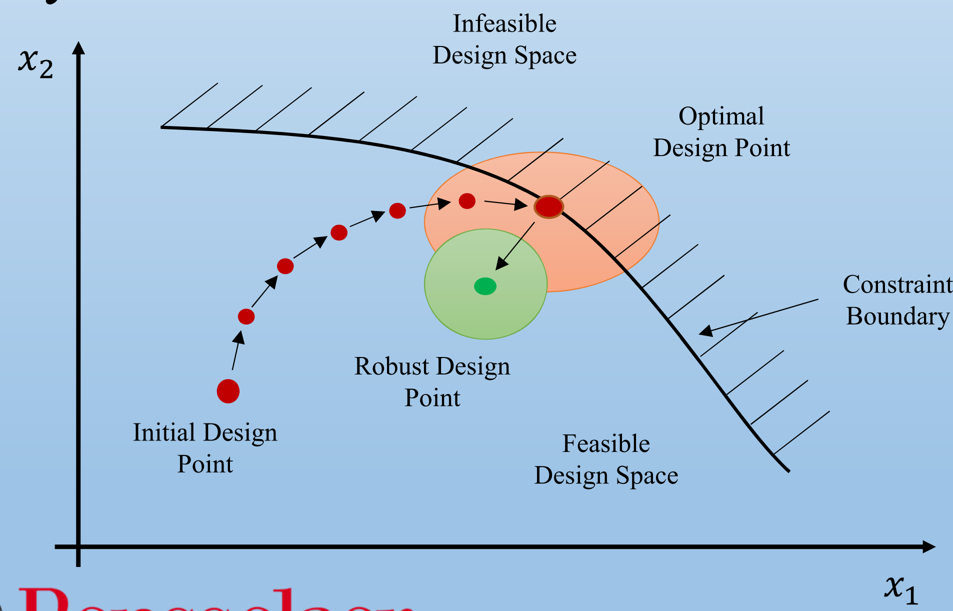
# Motivation

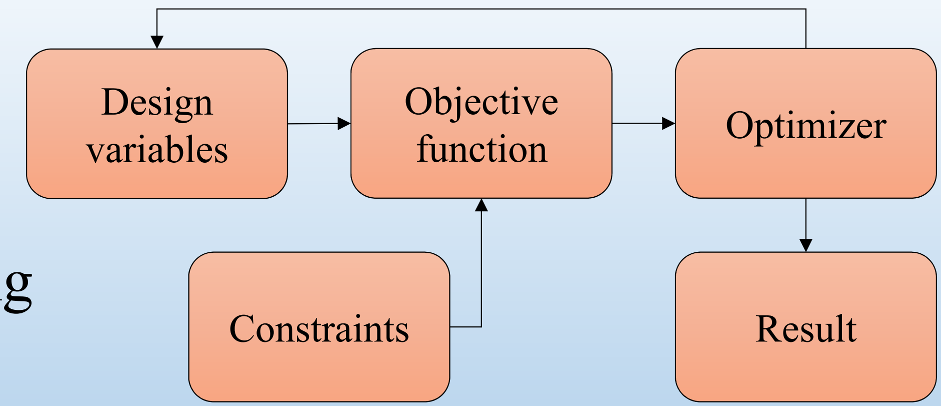
- Nuclear data is the foundation of Monte-Carlo and deterministic neutron transport calculations
  - Used across all disciplines – reactor physics, criticality safety, radiation detection etc.
- It is imperative that nuclear data is subject to rigorous verification and validation processes
  - Robust method is to design and operate critical experiments

Goal: Develop and implement a systematic methodology to design a critical experiment for cross section validation

# Optimization Methods

- Optimization algorithms provide a systematic basis for design of engineering systems



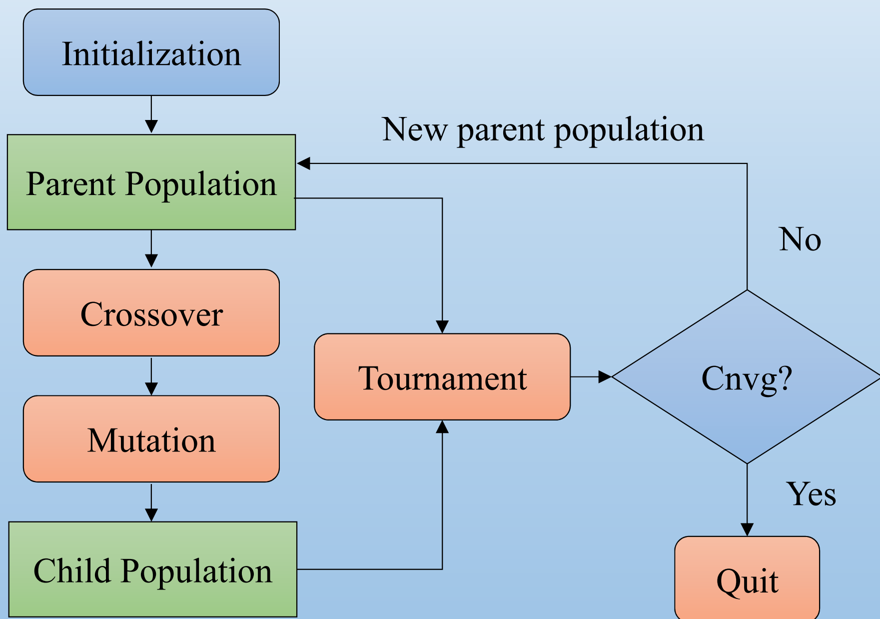



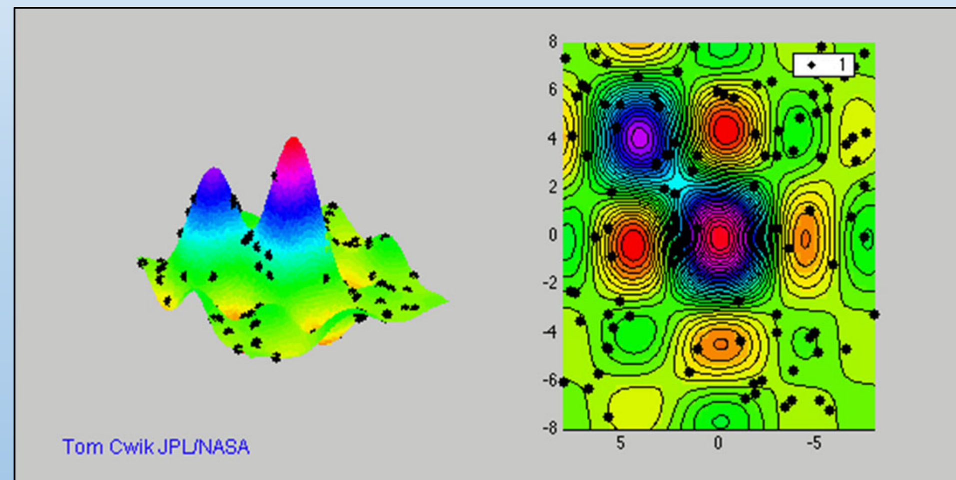

- Types:
  - Gradient-based
    - Neural networks
    - Quasi-Newton algorithms
  - Gradient-free
    - Genetic algorithms
    - Particle swarm algorithms

# Optimization of Critical Experiments

- The nature of neutron transport calculation methods makes gradient free optimization more suitable
  - Discourages the computation of objective function gradients, if even possible
- Genetic algorithms are a popular and versatile gradient free method
  - Use evolutionary theory to seek a function optimum
  - Pros:
    - Versatile
    - Search a wide range of candidate design space
  - Cons:
    - Typically more computationally expensive than gradient based methods
    - Unconstrained technique – require external constraint handling

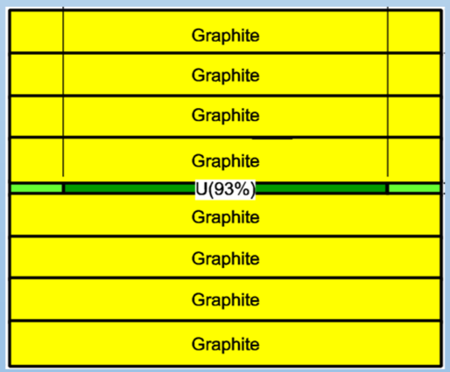
# Genetic Algorithms

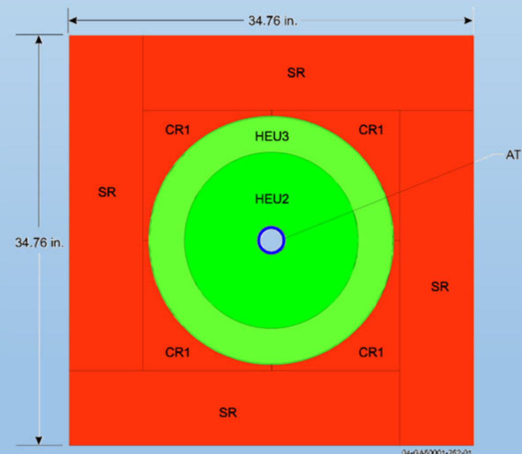


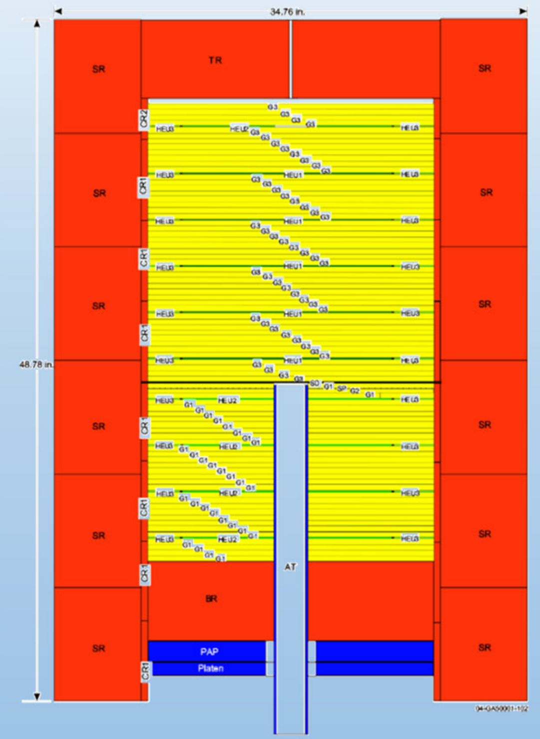



# Example: MOSES Critical Assembly

- Molybdenum Sensitive Eigenreactor System
  - Critical experiment designed using GA method
  - Purpose: Validation of molybdenum intermediate energy URR cross sections from 1 to 100 keV
  - Multiple operation configurations



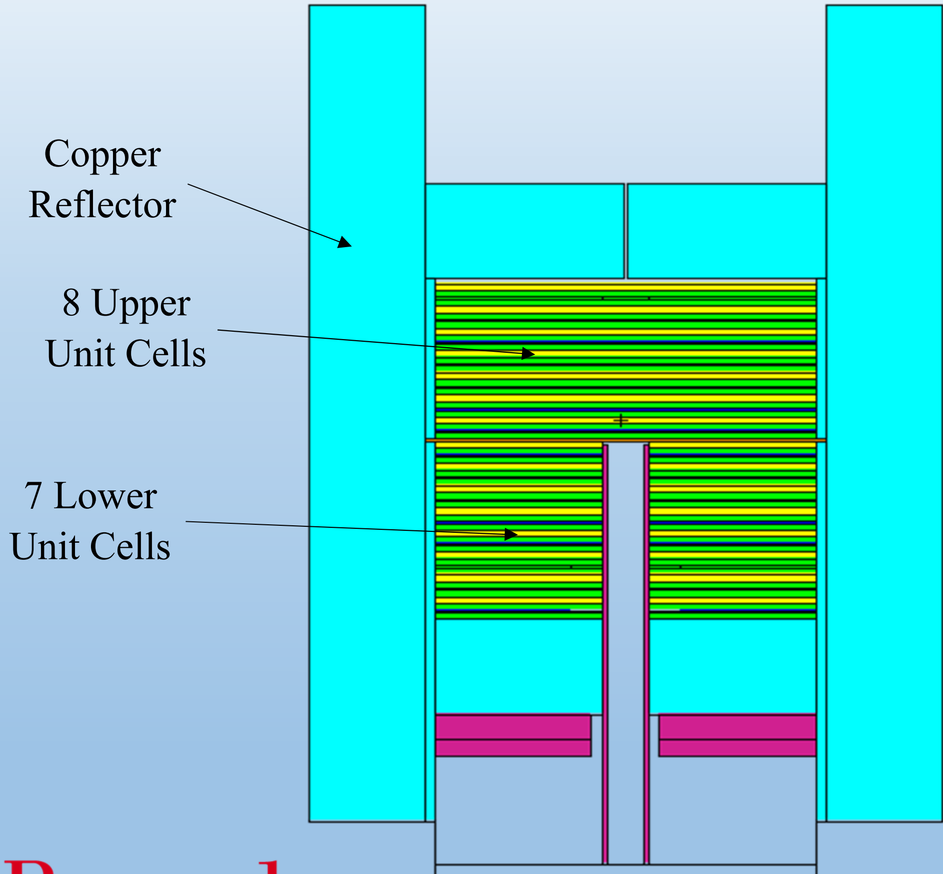



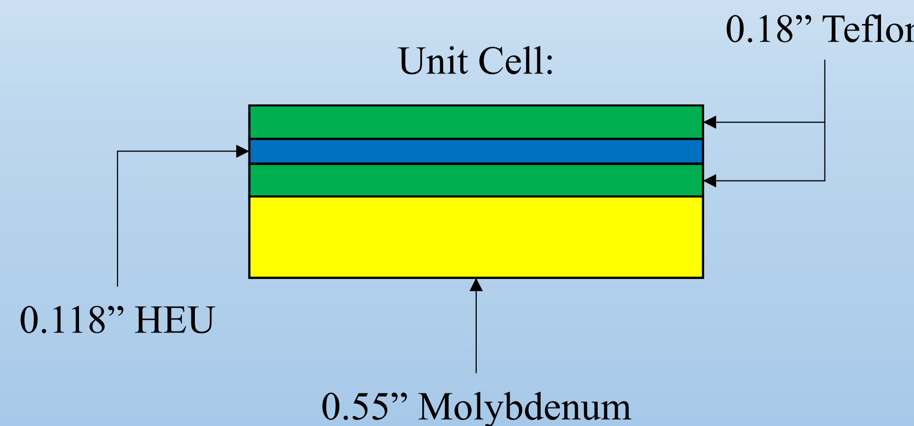



# Example: MOSES Optimization

- Optimization Components:
  - Objective function: Peak Mo capture cross section sensitivity magnitude between 1 and 100 keV
  - Design variables (4):
    - Plate thickness of moderator and Mo plates
    - Number of unit cells in each reactor unit
  - Constraints:
    - Experiment must be critical within $0.80 excess reactivity
    - Upper unit weight less than 20,000 lbs., lower unit weight less than 2,000 lbs.
    - Fuel inventory
    - Comet vertical assembly machine geometric constraints
  - Mathematical model: MCNP® 6.1.1 Beta Monte-Carlo model

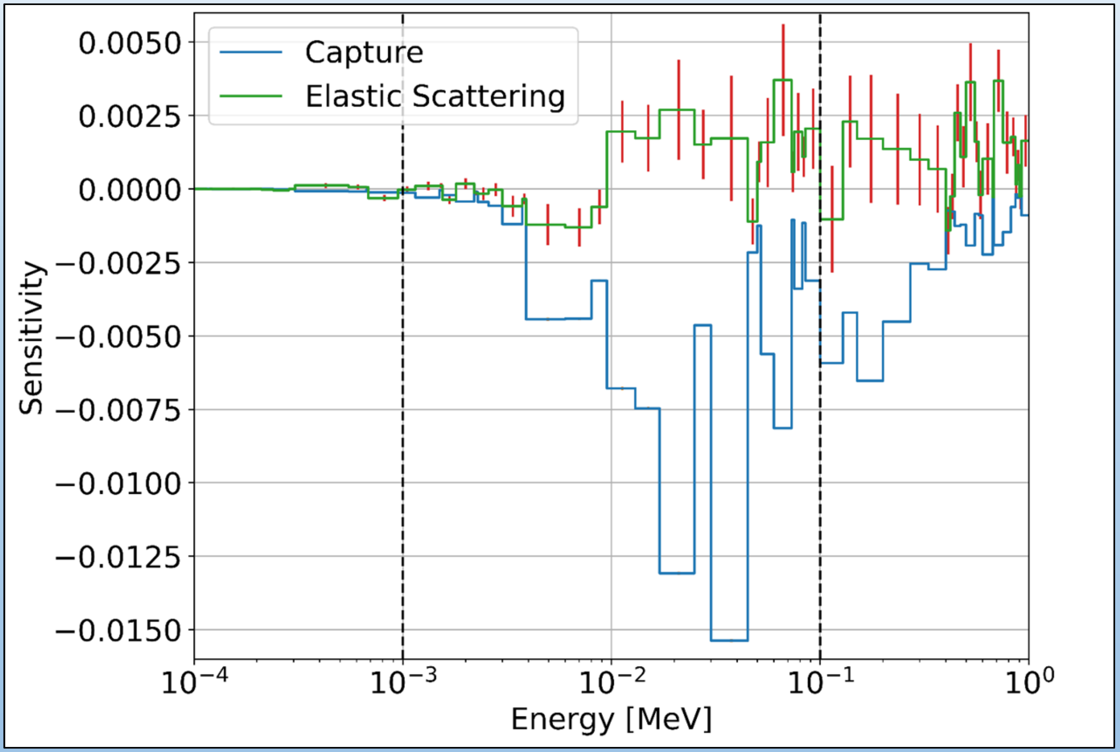
# Example: MOSES Optimal Geometry



# Example: MOSES Optimization Results

| MOSES Configuration 3 Parameters | |
|---|---|
| **System Parameter** | **Value** |
| Molybdenum Plate Thickness | 0.55 in. / 1.3970 cm. |
| Teflon Plate Thickness | 0.18 in. / 0.4572 cm. |
| Number of Upper/Lower Unit Cells | 8 / 7 |
| $k_{eff}$ | 1.00229 ± 0.00012 |
| $\beta_{eff}$ | 0.00681 ± 0.00020 |
| Excess Reactivity | $0.34 ± 0.02 |
| Stationary Weight | 17211 lbs. |
| Mobile Weight | 1183 lbs. |
| Intermediate Flux Fraction | 0.455 |
| Intermediate Fission Fraction | 0.498 |
| Max (n,γ) Sensitivity Magnitude | 0.01537 |
| Max (n,n) Sensitivity Magnitude | 0.00371 |
| Total Max Sensitivity Magnitude | **0.01908** |



# Conclusion and Future Work

- Genetic algorithms show good performance for autonomous design of critical experiments
  - Up-front cost of developing the autonomously-modifiable MCNP model but easy to extend to additional critical assemblies
  - GAs parallelize well, so computational cost can be decreased significantly using HPCs
- Future work:
  - Consideration of surrogate model optimization methods to increase efficiency
  - Tailor genetic algorithm to specifically handle critical experiments

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