# Yarden - Visualization

- Java application - Cyclist
    - Original Cyclus output visualization
    - Focus on Cyclus database tables
    - Drag and drop based interaction - fully interactive graphs
    - Different style graphs; charts, bars, flows, etc.
    - Table or Simulation level filtering
- Moving to Cyclus.JS (javascript)
    - Moves to distributed services
    - And web based interactions
    - Provides management for Cyclus services
    - Data storages services
    - Post-processing services
- Jupyter Notebook used as a model for this service.
    - JupyterLab : In Beta (https://github.com/jupyterlab/jupyterlab)
    - Release will probably be announced at the JupyterCon conference (late august)
- Plans are to provide extensive fuel cycle metric pre-calculations.
- Views
    - Table visualization of cyclus output tables.
    - Geo-spatial location finding
    - Notebook for more powerful python based scripting
    - Material flows, energy, economics, political

# Ross Hayes - Fuel composition transition modeling

- VISION
- Tracks fuel mass through various stages
- Isotopics can be calculated either implicitly or explicitly
- Fuel Vintage
    - Can now change reactor recipe without reactor restart
- Changing fuel recipe without restart
    - VISION can now shift reactors from one type of fuel to another.
    - This is done over a period of several batches
- Improved discharge calculations
    - Surplus fuels
    - Shutdown discharges - can be burnup dependent

# Kathryn Huff – Discussion on driving deployment with demand

- Driving Deployment with Demand
- Meet varying power demand ( Growth, decline etc)
    - Regional
    - Replacing decommissioned capacity
- Supporting fuel cycle facilities (prop. To reactors' fuel demand)
    - Mining, Enrichment, reprocessing, fuel fab etc
- 3 strategies
    - No automatic (manual)

            - Deploy according to demand
            - Infinite capacity
            - Run
            - Back-calculate demand
            - This is easy to implement and you can back out the amount used or required after the simulation is completed.
            - This technique can't capture dynamic economics, or intermediate mass flows.
        - Look ahead - deterministic forecasting
            - Deploy reactors according to demand
            - Estimate demand (fuel, rep, enr, natl u needs)
            - Run simulation
            - Pro: can capture market economics / realistic matl flows
            - Cons: under-supply
        - Something cleverer.
            - Deploy reactors according to demand
            - Dynamic response to fuel cycle needs
                - Facility deployment (just in time)
                - Market interrogation
                - Response to unexpected shutdowns
            - Con: complicated to implement, but should solve most issues, if done correctly.
        - Stochastics - Also clever ish
            - Running lots of simulations and choosing the one that works.
- Questions:
    - Meta question: What is the purpose of our simulations?
        - What kind of questions are we trying to answer?
            - Minimize Pu stockpile?
            - Minimize radiotoxicity?
            - Minimize Natl U?
            - These should depend on market situations (Minimizing Natl U usage would be less important if prices are cheap)
        - Why do we even need to predict the past?
    - Capacity - Demand - Constraints
    - Optimizing / Debugging / Back- calculation / Tuning 'ON THE FLY'
        - We are not sure how sensitive and impactful to your objective function.
    - Economy of scale / Deployment criteria
        - Complex design / facility specifications questions
    - As fuel cycles become more advanced, more things are intertwined
        - eg01- > just natl U supply and enrichment
        - Eg29 -> Mox / SFR Fuel reprocessing / fabrication along with natl U

## Discussion 1 (Wed @ 10:15)

- Supply issues are not unheard of, for example uranium imports to India (driving the thorium deal).
- Batch size changes?
    - Change breeding ratio of same reactor
        - By replacing blanket -> reflector (lower the BR)

        - Changes in core / batch size
        - Single core envelope that can have ‘interchangeable’ core design
    - Flexible fuel switching
    - Various parameters that gives BR
        - Driver size, enrichment, blend
        - Blanket size, blend, etc.
- `Better` approximation of reactor depletion / batch
- PPHW: Add more layers to complication -> more difficult to do it right
    - Stochastics may be the way to go?
    - Human time savings comes from computer time wastage
- EH: importantly, all levels of simulation have a place and value

## Léa Tillard – Preliminary studies for ASTRID-like SFR implementation in the CLASS code

- Preliminary Studies for ASTRID-LIKE SFR implementation in the CLASS code
- CLASS code depletion calculation -> Full core
- Uses
    - MORET - Monte Carlo
    - VESTA 2.2 Beta - Depletion
    - JEFF 3.1 Nuclear data
    -
- Investigated the error induced by varying time step sizes and random seed for the monte carlo runs.
- Random seed is dominate over time step error for 10 time steps.

## Baptiste Mouginot – Model Performance Analysis

- Neural network model performance analysis
    - Prediction of neutronics metrics evolution during irradiation
        - Xs, multiplication factor
- Fuel types:
    - (PWR) Mox- pu
    - (PWR) mox-pu/am
    - (PWR) mox-pu/LEU
    - (SFR) mox-pu
- When moved to Cyclus, started tracking other minor actinides - Cm, Am, etc.
- Testing - used 1000 depletion codes inside sample space and 500 outside sample space
- Nears MCNP error using ~ 1000 simulations.
- When outside of training space, the precision drops very quickly
- When doing fuel cycle, the ultimate goal is the end composition.
    - Keff, xs is needed for composition.
-
- Used to predict the concentration of PU239 to higher accuracy.

## Discussion 2 (Wed @ 11:30)

- Baptiste uses 750 neural network files as the basis for these models - does not know how long it takes to load them all.
- What is a comfortable error for fuel cycle calculations?
  - Not 50%
  - Maybe 10%?
  - Compare the model uncertainty with the cross section uncertainty. Therefore assuming the cross section is the dominant error.
- New modelling choices that are driven by unhappiness with uncertainty in old models should probably be better than older models.
- Necessity for a reference: uncertainty and error
- Low fidelity to find preferable fuel cycle -> high fidelity for more careful analysis
- Again: What problem are we trying to solve?
  - assumptions
    - Cooling time
    - Power demand growth rate etc
- CYCLUS: module swap-ability
  - Low fidelity -> high fidelity module are interchangeable.
  - Sophistication (fidelity) is variable.
- Automation to find optimal solution:
  - Low fidelity to find the 'solution space' -> high fidelity to fine-tune answer.
- Uncertainty in the amount of nuclear in the future in the US is an order of magnitude error. How can you predict the behavior of nuclear with that much base uncertainty.
- Instead of predicting the exact future, predict possible futures.
- There can exist more error in storage time, feed stocks etc, than there is in isotopic compositions. Sophistication in one area only makes sense if the problem is balanced.
  - Losing the field in the roses.
- Availability of fissile material / under-supply of fuel
  - Fuel composition only needs to be 'within that range' to be 'fuel'
  - But the errors might accumulate throughout time..?
- How much can errors accumulate in batches over the span of several years?
- You need to know the acceptable range of for a value, as long as your error is within that range, it's probably okay.
- The DoE transition studies don't really include error bars, why is that?
  - The transition studies are more about finding the problems that will arise,
- Are error bars on reactor operation much bigger than we expect.
  - Errors in operating power density, thermal efficiency, etc.
- We simplify reactor design to reduce error bars.
- What happens when we need to flip conservative on numbers. How much dose will workers take vs how self-protecting is a material. You want the high end of dose protecting the workers, but the low end for protecting the material.
- Difference between what Europeans are investigating vs what the Americans are investigating.

## Aris Villacorta Skarbeli – Analysis of reprocessing options for medium sized nuclear fleets

- Video of presentation - https://youtu.be/-YQSCdQXjK0
- Uses EVOLCODE for irradiation calculations
- Uses a levelized cost of electricity.
- Overnight and financial costs for investments

- Fuel costs were calculated at creation and included future reprocessing / separation if applicable.
- Simulated the Spanish nuclear fleet, which is a mixture of PWRs and BWRs.
- Spain could not support the PU requirements for a 60-year future of MOX. It needed to borrow 39 tons of the 110 required.
-
- Assumed fixed costs for all the facilities and operations.
- The question brought up is the cost of facilities and operations will increase if the facilities are ramped up faster than not.
    - Yes, as part of the investment cost there are included interest rates and payback periods

## Dan Wojtaszek – Scenario analysis of PT-HWR used fuel management for once-through thorium fuel cycles

- Looks at deploying thorium fuel in Heavy water reactors in Canada.
- SEU (Slightly Enrinched Uranium) - 1.2% U235 + Th (2%)
- Med-SEU+Th - middle line thorium
- Second concept LEU - centerline graphite, mixed thorium / uranium pellets
- Uses MACSTOR for the dry storage assumptions, and plans to shift from dry storage to a deep geological repository.
- Future work includes doing recycle of Thorium - well the uranium 233 - into the candu reactors.
- Transition from dry storage to DGR is mostly triggered by decay of the fission products.

## Brent Dixon – Next generation FCS missions and use cases

- Retrospective on the last 7 years (after the NGFCS reqs doc):
    - K. Huff and B. Dixon, “Next Generation Fuel Cycle Simulator Functions and Requirements Document,” Idaho National Laboratory, fcrd-sysa-2010-000110, Jul. 2010.
- Facility Studies
    - Low level users - build models with building blocks, restricted to prevent ‘illegal’ actions.
    - High level users - making the blocks to be used by other people. Restrictions are removed.
- Strategic Studies
    - Preconfigured strategies vs manually creating your own strategies
    - We were looking at repository, but no long
    - New ideas, does nuclear need to go to load following due to wind and solar?
- Multi-regional studies
    - How do advanced countries in nuclear technology help or utilize developing nuclear countries?

## Discussion 3 (Wed @ 14:00)

- Did Dan look at errors or sensitivity for his CANDU work.
    - He did not look into it closely.

    - He also did not look at non thorium fuel

## Mark Ernoult – A Global and flexible model for sodium-cooled fast reactors in electro-nuclear scenarios

- SFR are common in most advanced nuclear fuel cycles.
    - However, there are a huge number of possible reactor models. To simulate each model would be difficult.
    - Creating a standardized model that can be flexibly changed could help solve this problem.
- What are the important approximations do we use.
    - Assemble model, homogenous, multigroup, etc.
- Which fuel parameters have an impact on the reactor?
    - Pu content, blanket rings, control rods, etc.
- Very high errors in Pu, which is odd for a fast reactor.
- Currently this model has a higher error than the used models, but they are not sure where these errors are coming from.

## Ondrej Chvala – Fuel cycle of LEU-fueled denatured molten salt reactor

- First look at LEU molten salt reactors
- Start reactor on 2% LEU and add 20% LEU fuel salt into primary vessel bucket.
- Control the burn by adjusting material flows
    - Criticality using fuel or absorbers
    - Reduction chemistry to maintain chemical balance
- Mostly 72% LiF - 12% $UF_4$
- 4x4m core, 300 MWth for 10 years
- What happens to the spent salt?
    - Drop the gases.
    - Glass and dump it
    - Reprocess it?
    - Assume that it is possible to remove all but 10% of the FP.
    - Reporting 251GWd/MT burnup. This is 'ridiculously' high.

## Ed Hoffman – Fuel cycle options campaign transition analysis

- Overview of FCO work
- List of metrics to consider,
    - For example, uranium utilization, is there an issue for not?
- Consider what matters to different countries as well as what matters to the US.
- There are so many metrics and things to track that it becomes an accounting exercise to keep track of them all
- Discounting is very difficult for this because of the huge time scales, because the time periods seem arbitrary.
- FCS is an integrated engineering challenge.
    - Feasibility, sensitivity analysis.

- FCS aims to use all the tools that are available to look at the problem. From simple spreadsheet simulation to equivalence simulation. Each offer something important to the job.

## Discussion w (Wed @ 15:15)

- Higher fidelity treatment of enrichment would be good (see PyNE for multicomponent enrichment)
- Cem Bagdatlioglu - building data sets to minimize errors.
- Meta-question: What is the purpose, even of these transition scenarios, given that we know we will not have an orderly transition from one fuel cycle to another. The real question is what are the sizes of error (choice error) that we won't be able to adapt to in the future. (restated: how path-dependent are our future technologies)

# Breakout Session Topics

- Use Cases - Katy
    - Short term vs. long term studies (varied time scales)
        - In multi-physics, this is called "multi-scale" when you have small time scales (milliseconds) and very large time scales (minutes)
        - For us, we have something more like minutes/hours/days to years/hundreds of years
    - Hybrid energy systems are inherently tightly coupled to brief time scales
        - Diversion of thermal energy to other purposes complicates the simulation (and you have, then, an analogy to multiphysics)
        - Hybrid energy systems, notably, not mentioned explicitly in the reqs. Document
    - Load following
        - Fuel constraints in the plants constrain the ability of these plants to load follow often
        - Grey rods are the current strategy
        - Forced outages in the summer (France)
    - Market floating
        - The peak price in most places is in the afternoon, but as there is more injection of renewables into the system, then we see peak price times move away from peak load times…. We see solar penetrate the early afternoon.
        - Duck curve
    - Should these hybrid energy systems (and their Economics) be part of fuel cycle simulators?
        - Actual impact on the fuel is pretty minimal, so from a fuel cycle perspective -- it may be very interesting in the context of one reactor, but across the fleet, probably low impact.
        - Economics of load following may be sufficiently interesting, though.
    - Economics is a main constraint
        - Occasionally we formulate fuel cycle simulations as mass flow constraints
        - How do economics need to be modeled?
            - Micro

            - Macro
        - Find the "average day", determine key parameters to develop a reduced order model (e.g. RAVEN-simulated typical day)
    - We want to spend most of our compute time on least probable days (extreme production constraints, no baseload one day because too much solar/wind penetration)
    - Key question for right now: how do we determine the adaptability of nuclear energy to renewable penetration
    - Reality is very different from modeling
        - Enrichment
        - Use of DU
        - Long term contracts vs. spot pricing
        - Risk hedging within a company (uranium buyers are part owners of the mines) -- fixed plus variable
        - What parameters are the most important anyway?
            - Good example from waste: when the timescale changed due to policy, the actinides of interest all changed.
        - Talking to people outside of your immediate field are important for understanding what goals are.
    - It would be nice to have a metric for flexibility and robustness against political disruption
        - Disruption due to gas pipelines?
        - Disruption of supply of other energy is an interesting case for fuel cycle simulators to include market economics
        -
- Uncertainty - Ed
- Visualization - Yarden
- Use Cases - Paul