USE OF INTENSIVE SIMULATION SUPPORTING SFR UNCERTAINTY DRIVEN CORE DESIGN PROCESS: PRESENTATION OF MULTI-PHYSICS TRIAD PACKAGE

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CONTENT

- Context
- Examples of core patterns
- TRIAD specifications
- Core optimization rationale:
  - Evaluation of core performance / uncertainties
  - Visualization of core viability zone
  - Display compromise & Select core configurations
- Conclusion
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Early stage development of ASTRID prototype
- Preliminary specifications are underway in parallel with design studies

Criteria and constraints are subject to regular changes

At each stage, core designers should be able to provide:
- An optimal solution panel
- With transversal macroscopic indicators (for comparison sake)
- Clear visualization of compromises to be made

Within a reasonable time frame…
BUT!

Core Design is an iterative process between core physics disciplines… (Neutronics, fuel mechanics, hydraulics etc.) …often performed by separate teams of experts
- Possibly a lengthy process especially in the early stage of design
- Sources of errors are increasing with interface number

Design space can be very large (8-10 dimensions with millions of possible configurations) …and design constraints very numerous

Finding best compromises?

Possibility to miss non-intuitive solutions?
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EXAMPLE OF CORE DESIGN PROBLEM (SFR)

- Geometrical parameters
  - Inner radius
  - Spacing wire diameter
  - Cladding width
  - Smearing ration

- Plutonium content
  - Zone 1 content
  - Ratio Z1/Z2

- Operating conditions
  - Sodium inlet/outlet temperature

- Reflectors and shielding
  - Inner radius
  - Space
  - Spacing wire
  - Cladding
  - Pellet

Zone 1

Zone 2
A MORE COMPLEX EXAMPLE…

<table>
<thead>
<tr>
<th>Rotation symmetry around this axis</th>
<th>PNS (3 H1+H2)</th>
<th>Control rod follower</th>
<th>PNS (3 H1+H2)</th>
<th>Control rod follower</th>
<th>PNS (3 H1+H2)</th>
<th>Steel shielding (7)</th>
<th>PNL (8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PNL (8)</td>
<td>Internal blanket (1)</td>
<td>LCP (4)</td>
<td>B4C (3 H0)</td>
<td>Na-plenum (2)</td>
<td>LCP (4)</td>
<td>Steel shielding (7)</td>
<td>PNL (8)</td>
</tr>
<tr>
<td></td>
<td>Internal fissile core (1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Internal fertile plate (1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>Lower axial blanket (1)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head (9)</td>
<td>Upper Na (10)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Foot (5)
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Inter-disciplinary design tools allowing « systematic » exploration of design parameter space

Based on performing data processing software (URANIE, ROOT…)
- Allowing super-computing application
- With advanced sampling / optimizing tools
- With complex problem visualization capabilities

Possibility to access either reference codes OR simple models
- The objective is to evaluate one core performance within less than 1 second of CPU time!
- Calculation Time vs precision trade-off is the key
- Adapting meta-model type (polynomials, neural networks, kriging)

With sufficient user-friendliness for all designers use
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Core performance evaluation
- Create large data base using High Performance Computing (once and for all)
- Use interpolation techniques (spline functions) or elaborate meta-models (Neural networks) to replace whole codes or fit complex phenomena (pellet – cladding heat transfret coefficient for example)
- Define simplified models using data base as reference

Visualization of feasibility zones
- 3D mapping

Selecting core configurations
- Applying optimization algorithms using uncertainties
- Use iso-values representation

Display compromise
- Multi-1D cobweb
OPTIMISATION RATIONALE

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Evaluation of core performance
- With « direct » indicators (Void coefficient, fusion margin)
- With indirect indicators « Safety estimators »
- Accounting for transient core configuration

With various modeling accuracies:
- With fine tools (long but accurate, coupling codes requires dedicated platform)
- With correlations *(calculated once and for all)*
- With mixed accuracy (for certain disciplines or certain cores only)
Core performance evaluation
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Possible to visualize feasibility space reduction by adding design constraints.

Once sub-set is defined; optimisation of core performance within this space can be performed.
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Effet de l'annularité du cœur et du décalage diabolo

« Chosen » optimal configuration
Advantages: Excellent exploring capacity on multi-criteria optimisation problems

Drawback: Requires many core performance evaluation

Principle:
Approach optimal configuration with a natural selection process
Core performance evaluation
- Create large data base using High Performance Computing (once and for all)
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Linking core performance and characteristics

- One core (individual) = one broken line running from left to right
- Each Vertical bar represents either a data (left) or a performance (right) with statistical dispersion

Blue lines represent cores fulfilling similar constraints (Void coefficient and Margin to fuel melting)

2 possible technological paths with similar performance are showing:

- Core with low pressure drop (light blue)
- Core with low diameter (purple)
DISPLAY COMPROMISE (2)
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CONCLUSIONS (1)

- TRIAD is an optimisation package for complex core design
  - Making the most of High Performance Computing
  - Using softwares dedicated to Large data Flow management (ROOT)
  - Using advanced visualization techniques for data mining
  - Implementing advanced algorithms accounting for uncertainties

- Defining best compromise (precision vs CPU time) for core performance evaluation is still a key issue

- Efficient Use of developed tools requires a thorough understanding of core design disciplines
CONCLUSIONS (2)

- Progressive implementation of proper code chaining/coupling (via SALOME tool for example) of best estimate codes for data base creation (and optimizing?)

- Implementation of new performance « estimators » are under development (robustness to Loss of Flow transients etc.)

- Efforts to make these tools available to a wider core designer community is underway (GUI for TRIAD)
Result of multi-criteria optimization is the so-called Pareto front. When an «individual» (a core) is located on the Pareto front, designer cannot improve one of its performance without downgrading another.

Pareto front individuals are considered as the best individual of their generation. Other individuals have less chance to breed…

Exemple of 2D Pareto front, C1 et C2 criteria are antagonists.
**OPTIMISATION WITH UNCERTAINTIES**

- « Smartly » accounting for uncertainties within optimisation processes is still a hot R&D field

- A prerequisite, of course, is to have a first estimation of uncertainties for each core design discipline

- Then those uncertainties can be used with PareBRO method (V. Baudouin) for example: generalization of ranking process

\[ A \text{ dominate } B \Leftrightarrow BS(A) < BI(B) \]
Démarche de TRIAD :

- Jeux de paramètres
- Chaine de calcul
- Jeux de critères
- Plan d’expérience
- Formation réseaux de neurones
- Optimisation
II. UTILISATION D’URANIE

- Lanceur local et batch
  - Utilisation de la fonction de mise en donnée xml

- Analyse de sensibilité / Statistique
  - Morris
  - Sobol
  - Krigage (via longueur de corrélation)

- Méta-modèles :
  - Réseau de neurones
  - Krigage (en cours)

- Algorithmes génétiques

- Qt-Root pour IHM d’optimisation
Méthode de Leave One Out :

1. On retire un point de la base support
2. On compare la prédiction du Krigeage avec la valeur du code
3. Si le delta code / krigeage > 5sigma on vas voir si le code à correctement fonctionné

Courbe :
si \( Y_{\text{code}} - Y_{\text{krigeage}} < 5\sigma_{\text{krigeage}} \)
\[ f(y) = 0 \]
Sinon :
\[ f(y) = \sigma(Y_{\text{code}} - Y_{\text{krigeage}}) - 5\sigma_{\text{krigeage}} \]

Probabilité d’avoir une erreur dépassant 5 sigma :
1 individu pour 1,744,278

Erreur de code :
- Porosité négative
- Matrice singulière
- Maillage dégénéré....