1. **Industrial context**

Within the manufacturing route of zirconium alloy cladding tubes, each process can have an influence on the chemistry, microstructure and properties of the intermediate and final products. An overall vision of the manufacturing processes is therefore necessary for a global optimization of the manufacturing route.

2. **VAR melting**

   - **VAR process modeling**
     - SOLAR software
     - Multi-physical coupling including thermic, hydraulic, magnetic stirring, solidification, segregation and volatilization
   - Ingot composition maps for alloying elements and impurities as a function of raw materials and melting parameters

3. **Quenching**

   - Beta quenching modeling
     - COMSOL software
     - Thermo-microstructural coupling
   - Microstructure after beta-quenching is a function of the local composition and the cooling rate

4. **Extrusion**

   - Hot extrusion modeling
     - FORGE software
     - Thermo-mechanical coupling
     - Recrystallization model
   - Optimization of hot extrusion to improve recrystallization of quenched microstructure (recrystallization is lower for parallel plates)

5. **Cold pilgering**

   - Cold pilgering modeling
     - FORGE software
     - Pseudo steady state
     - Ductile damage model
   - Optimization of cold pilgering tools geometry and parameters to reduce potential damage (higher with less recrystallized microstructure)

6. **Discussion and conclusion**

   - With the characterization of intermediate products, the numerical modeling of each manufacturing step is used for the optimization of the products quality through the mastering of the main process parameters.
   - **During all manufacturing steps Framatome ensures a high product quality with the right level of impurities.**

7. **Perspectives**

   - Improvement of models to increase the accuracy of the results: volatilization of impurities during VAR melting, dynamic recrystallization during hot extrusion and ductile damage during cold pilgering.
   - Modeling of upstream processes (Kroll and vacuum distillation processes) to get the full modeling picture of the manufacturing route and a more efficient optimization of downstream processes.