



# Several Aspects on Materials Problems for SCWR

---

Ning Dong ,Yao Weida

SNERDI

Oct,2009

International Conference on Opportunities and Challenges for  
Water Cooled Reactors in the 21st Century



# 1 Foreword

---

1/1

- The supercritical water cooled reactor is a Generation IV nuclear reactor concept
- Which builds on currently proven light water reactor technology and supercritical fossil plant technology to provide for high thermal efficiency and plant simplification
- The main features of SCWR opinion:
  - “coolant” is supercritical water that will be operated above the critical point of water(374 °C /22. 1MPa);the thermal efficiency can be increased more than that of present light water reactor because “supercritical water coolant” has typical characteristics of both liquid and gas.

- SCWR is operated in the environment of high temperature, high pressure and high irradiation, which design pressure is about 25MPa and reactor core outlet temperature is 510~550°C .
- The heat-transfer style is simplified so that the pressurizer, the steam generator and the recycle pump etc. in conventional light water reactor will be called off in SCWR.
- Even though many advantages of SCWR, these characteristics of increased temperature and pressure, radiation and supercritical water coolant bring into a more aggressive environment to candidate materials and multidiscipline interaction is also addressed for SCWR, such as material properties, water chemical and thermal-hydraulics, and etc.

# 1 Foreword

3/1

- The need to develop materials capable of performing in the severe operating environments expected in SCWR reactors represents a significant challenge in materials science because of the significant challenges associated with structural materials in this advanced nuclear energy systems

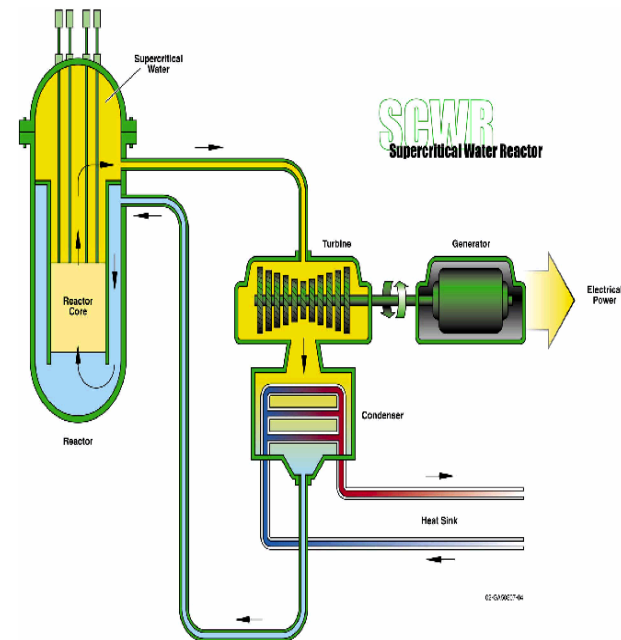


Figure 1 SCWR concept



# 1 Foreword

---

4/1

- The objective of this paper is to cover materials design requirements in ASME code section III subsection NH for elevated temperature components in NPP from the point of view at engineering design angle and to recount advanced computer material science in screening suitable materials and building in predicable performance in plant operating experience. In addition, establishment of new codes and standards and multidisciplinary cross research for SCWR development are proposed. At last, current situations in China of the candidate materials production are introduced.

# 2 Requirements in ASME code section III NH subsection 1/2

- ASME code section III subsection NH applies to Class 1 components serving as pressure boundaries at elevated temperatures in nuclear power plant. The recommended materials used under elevated temperatures are 304ss, 316ss, 21/4Cr-1Mo, 9Cr-1Mo-1V and 800H alloy, as following table, given corresponding maximum service temperature.

Table materials described in NH subsection

Materials	304SS	316SS	800H	2 1/4Cr-1Mo	9Cr-1Mo-1V
Max.temp.	800°C	800°C	800°C	650°C	650°C



# 2 Requirements in ASME code section III NH subsection 2/2

---

- Consideration with time-dependent materials property
  - The behavior of materials at elevated temperatures mainly puts up time-dependent properties. Consideration with time-dependent properties for materials serving above a specific elevated temperature is taken in NH subsection. Creep is one typical time-dependent material property, that is, the special case of inelasticity that relates to the stress-induced time-dependent deformation under load.
  - NH subsection pays attention to creep for class 1 components engineering analysis Where creep effects are presumed significant, inelastic analysis is generally required to provide a quantitative assessment of deformation and strains.

# 2 Requirements in ASME code section III NH subsection 3/2

- Design by analysis includes elastic analysis and inelastic analysis.
  - In subsection NH, the analysis for load controlled stress limits is elastic analysis while the analysis of strain, deformation and fatigue limits is inelastic analysis..

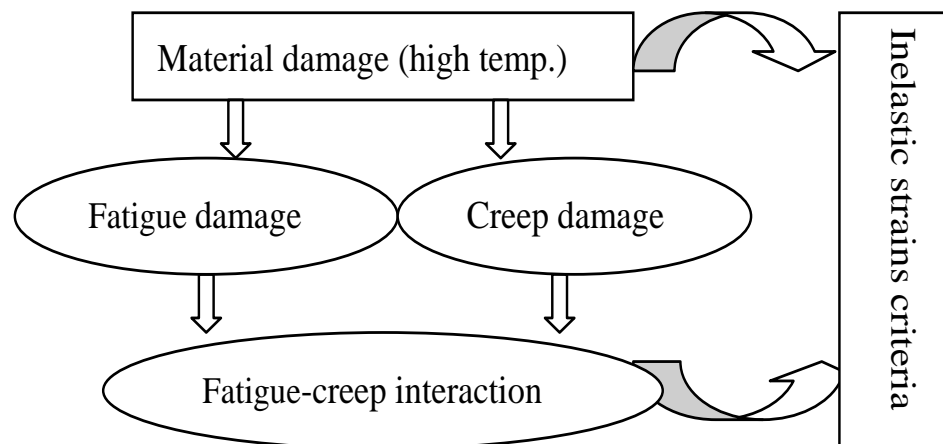
Table Design by Analysis

Category	Features	Requirements
Elastic analysis	No significant creep effects.	maximum shear theory → stress intensities for multiaxial stress states.
Inelastic analysis	Significant creep effects	Multiaxial stress-strain relationships + associated flow rules → combine multiaxial stresses and strains.



# 2 Requirements in ASME code section III NH subsection 4/2

- Structural integrity for class 1 components at elevated temperatures
  - Materials damage for structure integrity at elevated temperature includes fatigue damage, creep damage and creep-fatigue coupling effect in NH subsection as following figure. Creep-fatigue interaction is the effect of combined creep and fatigue on the total creep-fatigue damage accumulated at failure.





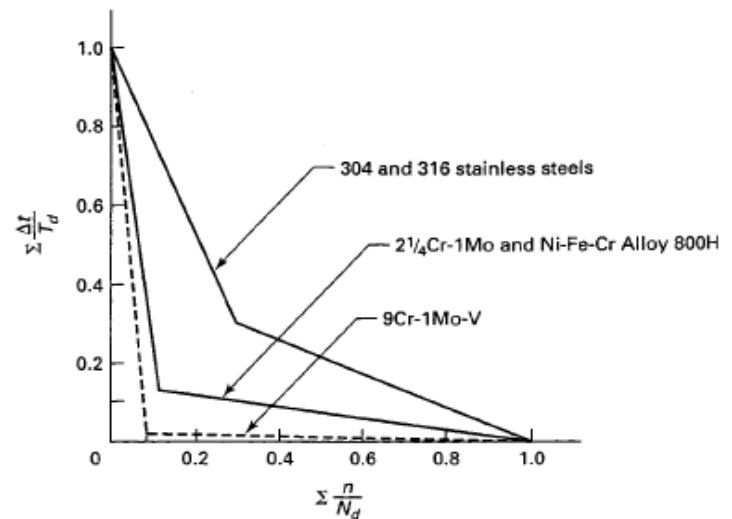
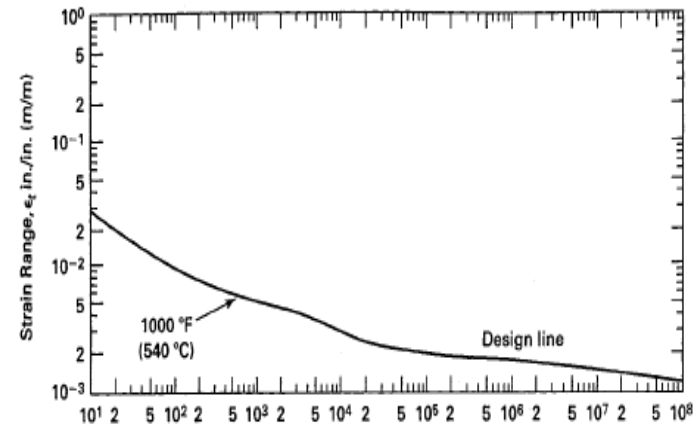
# 2 Requirements in ASME code section III NH subsection 5/2

---

- Example of 9Cr-1Mo-1V material
  - The candidate materials for SCWR comprise austenitic stainless steel, martensite-ferritic steel and nickel-base alloy while 9 Cr steels are one of recommended candidate material. however, 9Cr-1Mo-1V is defined in NH subsection, which is specially mentioned.
  - 9Cr-1Mo-1V has several unique characteristics accounted for below that material design and structure analysis for high temperature components shall be greatly given notice to.

# 2 Requirements in ASME code section III NH subsection 6/2

- Especially for 9Cr-1Mo-1V, the design fatigue curve at elevated temperatures is shown as figure at right side (the upper) and the creep-fatigue damage envelop is shown as figure at right side (the lower), which are used for fatigue damage and creep-fatigue interaction analysis and evaluation.





# 3 Advanced computational material science in research on SCWR 1/3

---

- Significance of advanced computational material science for SCWR
  - Computational material science extends and supplements the traditional material science and has a significant impact on the development of material science.
  - Can be taken as an effective assistant tool for solving related materials problems for development of SCWR and for future engineering application.
  - An aggressive theory and modeling effort will not only reduce the time and experiments but also the quantity of design data for candidate materials in severe conditions in SCWR.
  - Objective is to develop predictive property models that account for the highly synergistic combinations of candidate materials and environmental variables under SCWR conditions. Another is to interpret materials property changes in engineering assessment of structure integrity in practical service conditions in NPP.

# 3 Advanced computational material science in research on SCWR 2/3

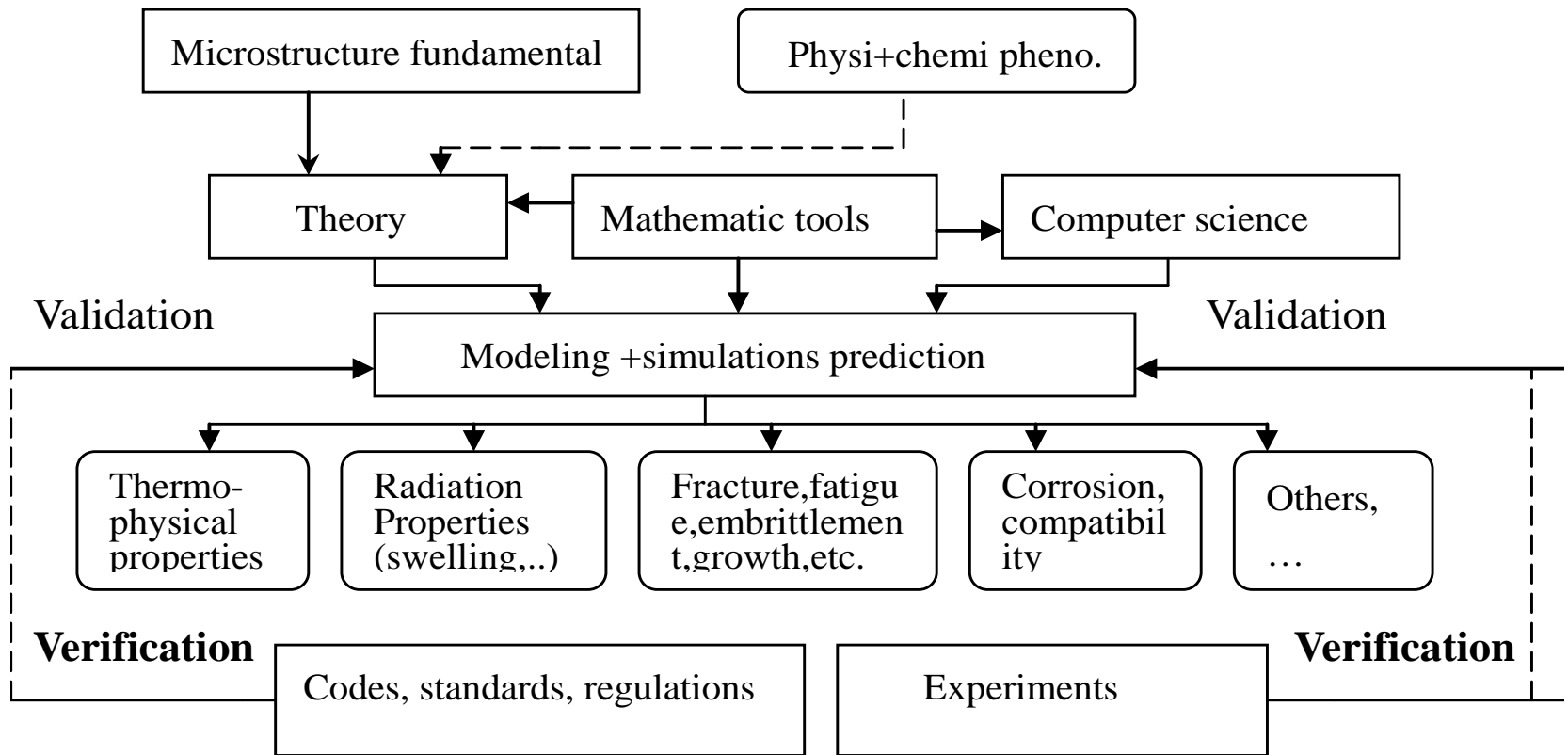


Figure 5 Configuration on advanced computational material science

# 3 Advanced computational material science in research on SCWR 3/3

- Configuration on advanced computational material science
  - Theory and modeling are helpful to be used as resultful description of materials phenomena and mechanism and assistant for structure analysis together with alloy design.
  - The fully and profound understanding of microstructure evolution and activities of defects in alloy are the basis on building theory and modeling.
  - Further ,models of microstructure evolution and defects activities form fundamentals of description and understanding of many materials properties varying with aggressive environment conditions in NPP.
  - Progress of Computer science is a second conditional factor. Mathematics knowledge is also an useful measure. In addition, a wide variety of experiments are to understand mechanism, measure parameters and validate models prediction.
  - Codes, standards, regulations are also used for verification and validation of reasonableness of models and simulations prediction.

# 3 Advanced computational material science in research on SCWR 4/3



---

- Problems needed to solve for SCWR by advanced computational material science
  - Coolant inlet/outlet temperature 280/510 °C : creep, fatigue/thermal fatigue, creep-fatigue interaction, toughness, corrosion/SCC, thermal-hydraulics effects
  - High irradiation dose: void swelling, irradiation creep, creep rupture, stress relaxation, embrittlement and irradiation accelerating SCC(IASCC)
  - Unique chemical environment of supercritical water : corrosion, oxidation, compatibility, IASCC, EAC, and coupling combination effects of chemical parameters and irradiation.



# 3 Advanced computational material science in research on SCWR 5/3

---

- Major progress of computational material science for nuclear application
  - A typical example is development of physically-based models of reactor pressure vessel irradiation-induced embrittlement and other irradiation damage effects including void swelling in traditional light water reactor (LWR)
  - 3-dimensional dislocation dynamics involving in dislocation climb models are encouraged to quantitatively apply to investigations of microstructural evolution of irradiated materials.
  - It is reported(ORNL,2004) a further challenge is how to develop the appropriate linkages of 3-dimensional dislocation dynamics to atomic scale and mesoscale regimes so that multiscale phenomena such as fracture toughness can be appropriately modeled.



# 4 Development of new codes and multidisciplinary cross research 1/4



- Necessity on development of new codes for SCWR
  - Codes ,regulations and standards that can successfully predict experiments results before the experiments are performed provide the most reliable predictions on engineering applications.
  - During development of advanced nuclear reactor system, ASME code NH subsection for class 1 components at elevated temperatures does not fully consider with other environment variables except temperature, stress, time and SCWR is also a new concept for nuclear components suppliers (responsible for nuclear components design and manufacture)
  - Because brand-new concept of reactor system and aggressive environment conditions and advanced materials development, new codes, regulations and standards are urgently needed to be brewed, drawn up and developed for engineering design along with gradual progress of innovation of SCWR techniques and for licensing by USNRC.
  - The demands for new codes ,regulations and standards are driven by ultimate engineering purpose.



# 4 Development of new codes and multidisciplinary cross research 2/4

---

- Necessity on development of multidisciplinary cross research
  - The thermal-hydraulics (fluid field and temperature field) in reactor core of SCWR has been closely coupling relationship with behaviors of various reactor materials.
  - It is a problem needed to probe into that coupling relationship between water chemistry of coolant in SCWR and anti-corrosion properties of candidate materials.
  - Multidisciplinary cross research is called out in screening materials and evaluating materials properties during the development of SCWR.

# 5 Current Situations in China of the Candidate Materials Production 1/5

---

- China began to develop and manufacture steels serving with elevated temperature properties by ourselves because the introduction and development of techniques of (ultra) supercritical fossile power units, including pipes, forgings and castings.
- In many cases, design techniques have been mastered by our country but manufacture industries still exit a big gap from famous enterprises in the world, which one problem is materials manufacture



# 6 Conclusions

---

1/8

- SCWR concept is set up on the basis of currently proven technology of light water reactor and supercritical fossil plant with supercritical water coolant, high thermal efficiency and plant simplification.
- ASME code NH subsection applies to class 1 components serving as pressure boundaries at elevated temperatures in NPP and considers with time-dependent materials properties for design by analysis which includes elastic analysis and inelastic analysis. 9Cr steels are recommended for SCWR concept design, which 9Cr-1Mo-1V steels is specially mentioned and needed to take notice on because they have unique characteristics influence on design by analysis.
- Advanced computational materials science has great impact on material screening, material development and material research to helpfully apply to design of advanced reactor system and has made quite progress in irradiated materials, which link microstructure evolution and materials performance under environment variables. Many problems is needed to solve by computational material science in future for SCWR, including embrittlement, creep, swelling, irradiation creep, corrosion, etc..



# 6 Conclusions

---

2/8

- New codes, standards and regulations needed to develop because they are safety assurance of engineering application of SCWR. In addition, necessity of multidisciplinary cross research is required in whole research works for SCWR.
- In China, manufacture capacity of candidate materials for SCWR is needed to strengthen and acceleratory development of materials production industry is an urgent problem currently faced by the field of industries in China.