Unit 1: Introduction to Nuclear Systems & Material Challenges

ME/ERS 5203 (4203) – Nuclear Materials

Prof. Sharma

Department of Mechanical Engineering
School of Energy Resources

Fall 2026

Outline

Course Introduction

Why Nuclear Materials Matter

Nuclear Reactor Systems

Material Selection Criteria

Material Degradation & Failure

Summary & Preview

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Course Description:

- Overview of materials in nuclear reactors
- Interactions of materials with radiation
- Atomic-level damage mechanisms
- Defect formation and transport
- Oxide, ceramic, and metallic materials
- Corrosion in nuclear environments

Course Format

- 12 weeks
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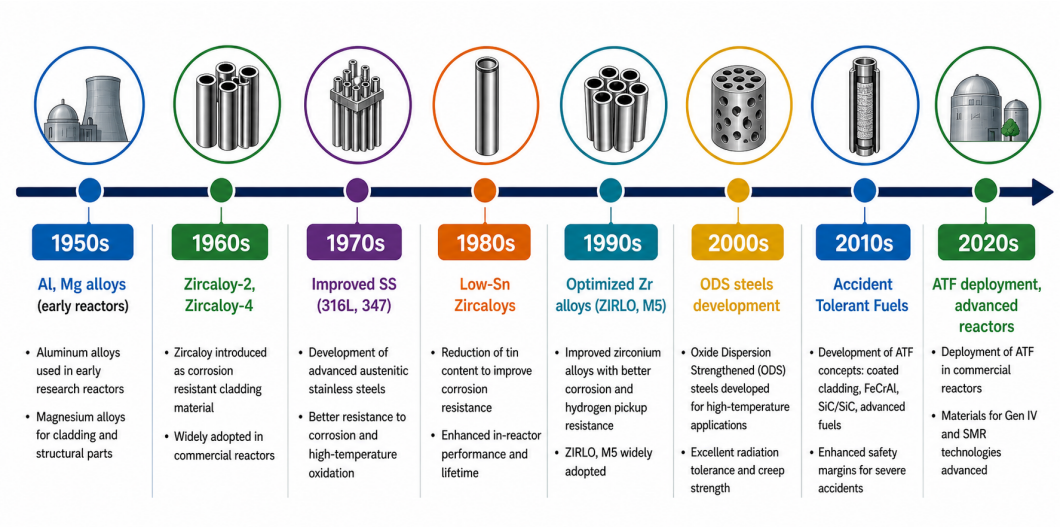
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Evolution of Nuclear Materials – *Seven Decades of Development*



Materials Evolution: Key Milestones – *Learning from Experience*

Era	Materials	Driver	Key Advance
1950s	Al, Mg alloys	Early research reactors	Low neutron absorption
1960s	Zircaloy-2, -4	Commercial LWRs	Corrosion resistance
1970s	316L SS, Alloy 600	Component reliability	Low-C grades (SCC)
1980s	Low-Sn Zircaloys	Extended burnup	Reduced corrosion
1990s	ZIRLO, M5, E110	High burnup (>50 GWd/t)	Nb-containing alloys
2000s	Alloy 690, ODS steels	Life extension, Gen-IV	PWSCC resistance
2010s	Cr-coated Zr, FeCrAl	Post-Fukushima ATF	Accident tolerance
2020s	SiC/SiC, U_3Si_2	Advanced deployment	Revolutionary concepts

Pattern Each generation of materials addressed limitations discovered in service.
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1. **Explain** why materials science is critical for nuclear energy safety and economics
2. **Identify** major nuclear reactor types and their operating environments
3. **Describe** key reactor components and map them to material classes
4. **List** material selection criteria for nuclear applications
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Unit 1 Roadmap – *3-Hour Journey Through Nuclear Materials*

Hour 1

- Why materials matter
- Nuclear energy context
- Safety & economics
- Historical perspective

Hour 2

- Reactor types
- Operating conditions
- PWR/BWR systems
- Advanced reactors

Hour 3

- Material selection
- Component mapping
- Degradation modes
- Course preview

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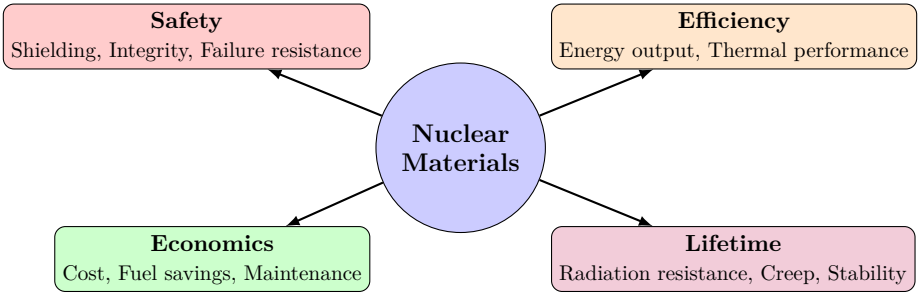
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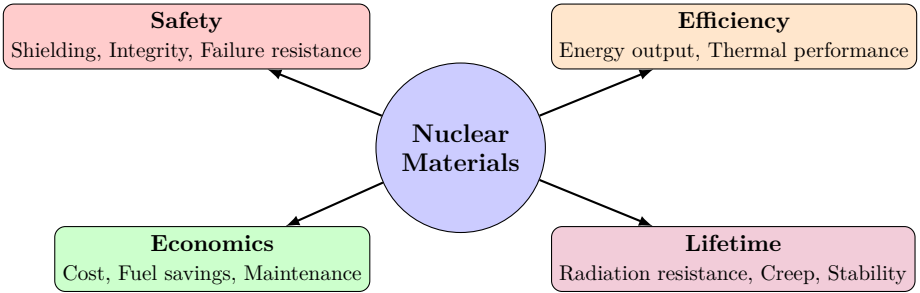
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Summary & Preview

The Central Role of Materials – *Materials: The Enabler and Limiter*



Materials play the **key role** in feasibility of nuclear energy system and are a key basis for classifying and comparing different reactor designs.



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Why Materials Matter – *The Four Pillars of Nuclear Materials Selection*

✓ Safety
- Containment of radioactivity
- Structural integrity
- Accident tolerance
- Predictable behavior

✓ Efficiency
- Thermal performance
- Neutron economy
- Power density
- Fuel utilization

✓ Economics
- Capital cost
- Operating cost
- Maintenance intervals
- Component replacement

✓ Lifetime
- 40–80 year operation
- Degradation prediction
- Life extension
- Aging management

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The Unique Nuclear Challenge – *What Makes Nuclear Different?*

Materials in nuclear systems face **simultaneous** loading from:

- Mechanical stress
- High temperature
- Chemical/corrosive environment
- Radiation damage

These factors often act in **synergy**.

Conventional Engineering:

- Well-characterized materials
- Predictable degradation
- Accessible for inspection

Nuclear Engineering:

- Radiation-induced changes
- Complex synergistic effects
- Limited accessibility

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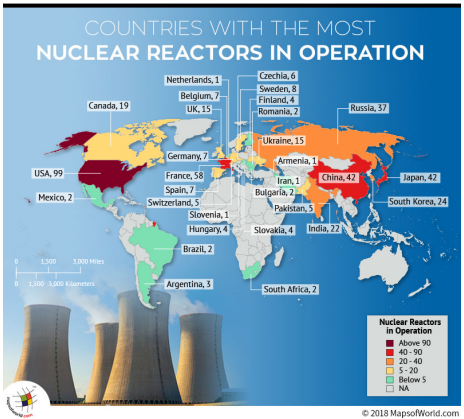
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Drivers for Nuclear Energy:

- Growing global electricity demand
- Energy security concerns
- Climate change – minimal GHG emissions
- Base-load power capability
- High energy density

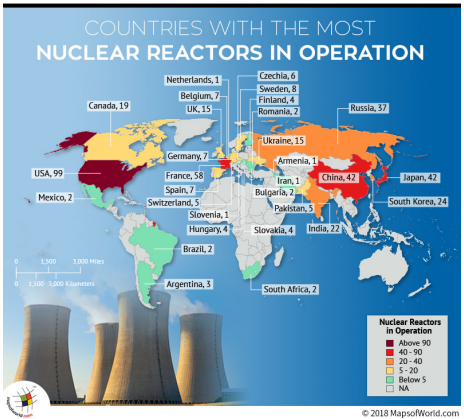


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~440 reactors operating worldwide, providing ~10% of global electricity.

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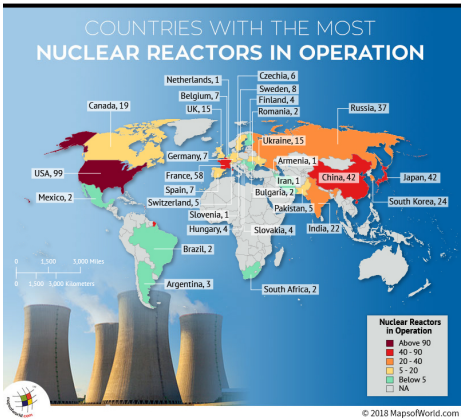


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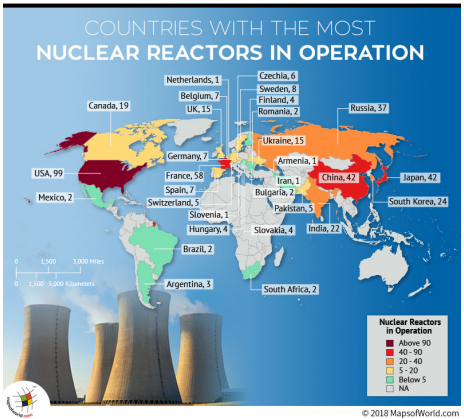


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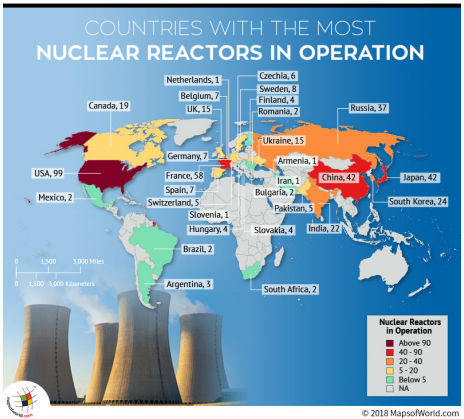


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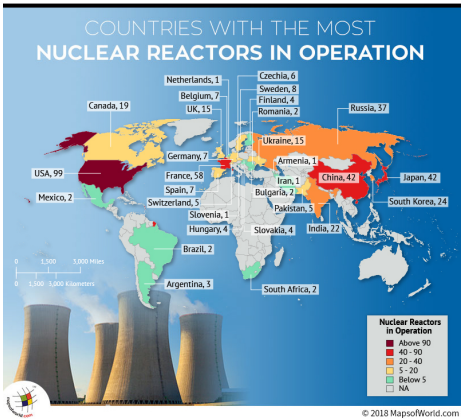


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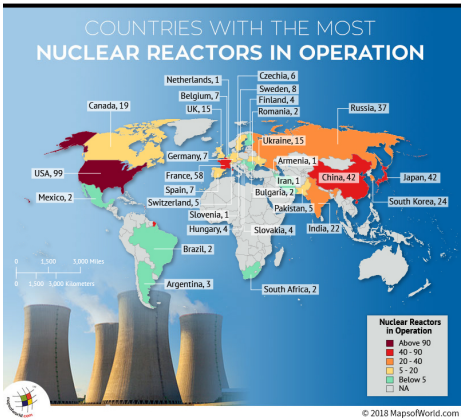


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- **Moderator type:** Light water, heavy water, graphite
- **Coolant type:** Water, sodium, lead, helium, molten salt
- **Fuel type:** Oxide, metal, carbide, nitride, TRISO
- **Structural materials:** Zr alloys, stainless steels, Ni alloys
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Many nuclear incidents have material degradation as a contributing factor.

Notable Examples:

- Bohunice A-1 (1977): Fuel cladding corrosion
- Davis-Besse (2002): RPV head corrosion
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Source: U.S. NRC Public Docs.

Remark

Understanding materials behavior is essential for preventing future incidents.

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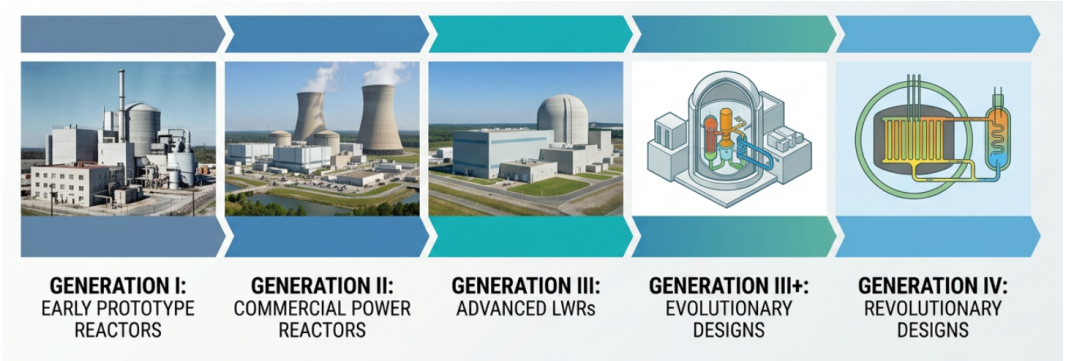
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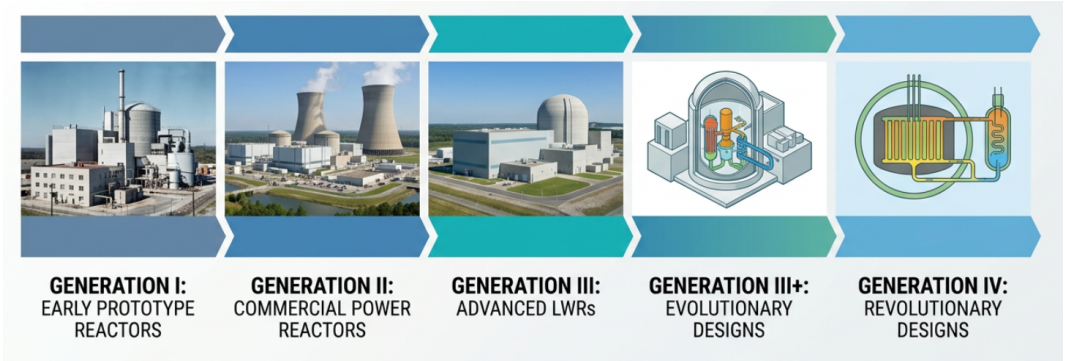
Nuclear Reactor Generations – *Evolution of Nuclear Technology*



Source: Adapted from United Nations Economic Commission for Europe

Gen I	Gen II	Gen III/III+	Gen IV
1950–60s	1970–90s	2000–now	2030+
Shippingport, Magnox	PWR, BWR – Most current	EPR, AP1000, ABWR	SFR, VHTR, MSR, GFR

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Light Water Reactors (LWRs) – *The Workhorses of Nuclear Power*

PWR – Pressurized Water Reactor

- Pressure: ~**15.5 MPa**
- Temperature: 290–330°C
- Separate primary/secondary loops
- No boiling in core
- Zircaloy-4 cladding

BWR – Boiling Water Reactor

- Pressure: ~**7 MPa**
- Temperature: ~290°C
- Direct cycle (steam in core)
- Boiling allowed in core
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Global Dominance LWRs constitute ~85% of operating reactors worldwide.

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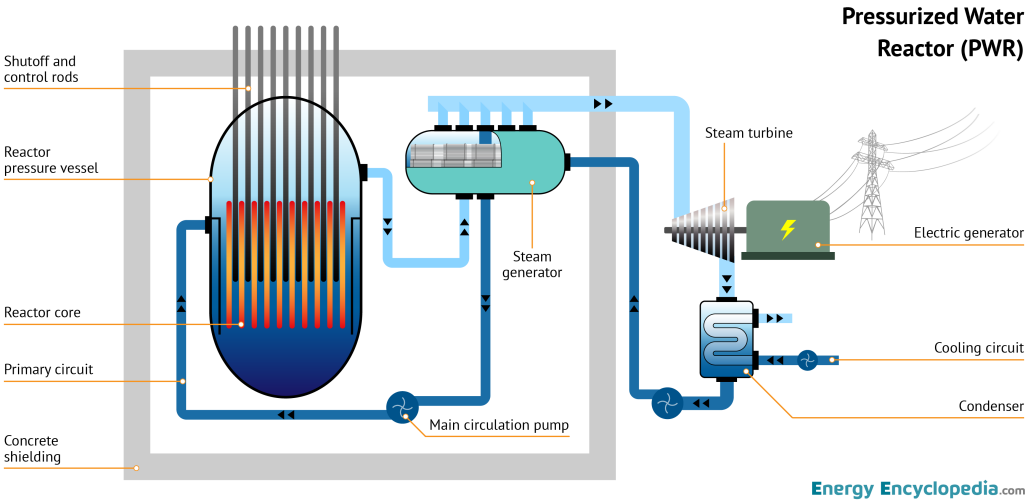
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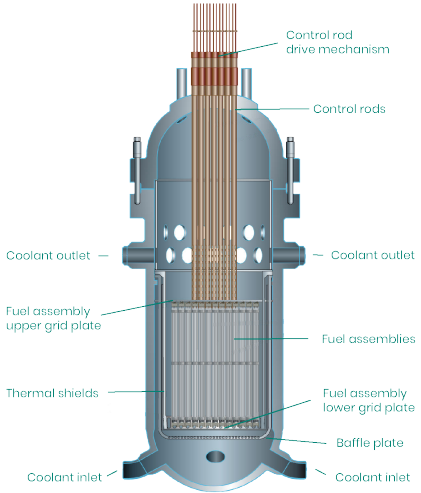
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PWR System Schematic – *Know Your Systems – Pressurized Water Reactor*



PWR Material Map – *Components and Their Materials*



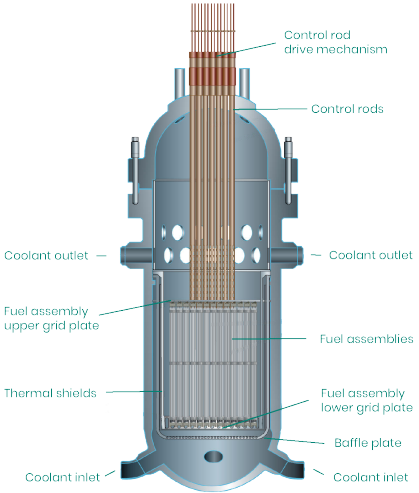
Component	Material
Fuel	UO_2 pellets
Cladding	Zircaloy-4, M5, ZIRLO
RPV	Low-alloy steel
RPV liner	308 SS, Inconel
Internals	304/316 SS
SG tubes	Alloy 600/690
Control rods	Ag-In-Cd, B_4C

Note

Each material chosen for specific nuclear and engineering properties.

Source: Frontier: Nuclear reactor shielding

PWR Material Map – *Components and Their Materials*



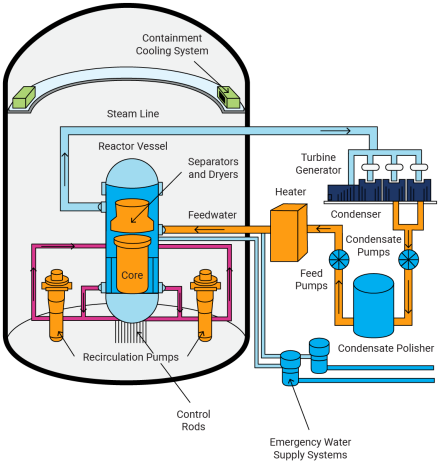
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BWR System Schematic – *Know Your Systems – Boiling Water Reactor*



Source: ECOLAB

PWR vs BWR Comparison – *Key Differences Affecting Materials*

Parameter	PWR	BWR
RPV Pressure	~15.5 MPa	~7 MPa
Coolant Temperature	290–330°C	~290°C
Steam Generation	In SG (secondary)	In RPV (primary)
Coolant Chemistry	**High H_2**	**High O_2**
Fuel Cladding	Zircaloy-4	Zircaloy-2
Control Rods	Top entry (clusters)	Bottom entry (blades)
Boiling in Core	No	Yes

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Different water chemistry ⇒ different corrosion mechanisms!

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PWR Operating Environment – *What Materials Must Endure*

Core Conditions

- Temperature: 290–330°C
- Pressure: 15.5 MPa
- Neutron flux: ~10^{14} n/cm^2·s
- Coolant: H_2O + H_2 + B + Li
- pH: 6.9–7.4 at 300°C

Lifetime Exposure

- Design life: 40–60 years
- Fuel cladding: 4–6 years
- RPV fluence: >10^{19} n/cm^2
- Internals: >50 dpa
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The Challenge Materials must maintain integrity under these extreme conditions for **decades** while being **inaccessible** for routine inspection.

PWR Operating Environment – *What Materials Must Endure*

Core Conditions

- Temperature: 290–330°C
- Pressure: 15.5 MPa
- Neutron flux: $\sim 10^{14}$ n/cm^2·s
- Coolant: $H_2O + H_2 + B + Li$
- pH: 6.9–7.4 at 300°C

Lifetime Exposure

- Design life: 40–60 years
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Problem: Compare neutron absorption in Zr vs. stainless steel cladding.

Given Data

- Thermal neutron absorption cross-sections:
  - Zr: $\sigma_a = 0.185$ barn
  - Fe: $\sigma_a = 2.56$ barn
  - Cr: $\sigma_a = 3.1$ barn
  - Ni: $\sigma_a = 4.5$ barn
- SS-304 composition: ~70% Fe, 19% Cr, 11% Ni

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Step 1: Calculate effective cross-section for SS-304

$$\sigma_a^{\text{SS}} = 0.70 \times \sigma_a^{\text{Fe}} + 0.19 \times \sigma_a^{\text{Cr}} + 0.11 \times \sigma_a^{\text{Ni}}$$
$$= 0.70 \times 2.56 + 0.19 \times 3.1 + 0.11 \times 4.5$$
$$= 1.79 + 0.59 + 0.50$$
$$= \boxed{2.88 \text{ barn}}$$

Step 2: Calculate ratio

$$\frac{\sigma_a^{\text{SS}}}{\sigma_a^{\text{Zr}}} = \frac{2.88}{0.185} = \boxed{15.6\times}$$

Conclusion Stainless steel absorbs **~16 times more neutrons** than Zr! This would require ~0.2% higher enrichment, significantly increasing fuel costs.

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Worked Example: Solution – *Neutron Economy Calculation (continued)*

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Worked Example: Practical Implications – *Why This Matters*

Economic Impact:

- Each 0.1% enrichment increase costs millions per reload
- A typical PWR has ~50,000 fuel rods
- Cladding mass per rod ≈ 0.5 kg
- Total cladding: ~25,000 kg
- Neutron losses compound over fuel cycle

The Trade-off

- Zr: Low σ_a, but oxidizes in steam at high T
- SS: Higher σ_a, but better high-T strength
- **ATF concept:** FeCrAl cladding accepts higher σ_a for better accident tolerance

Remark

Key Takeaway Material selection always involves trade-offs. Zr wins on neutronics; other materials may win on other criteria.

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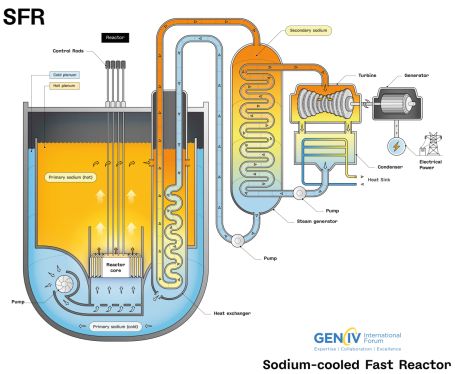
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Key Characteristics:

- Fast neutron spectrum (no moderator)
- Liquid sodium coolant
- Temperature: ~550°C outlet
- Can breed fuel (Pu-239 from U-238)
- Higher neutron flux ⇒ more damage

Material Challenges

- High dpa rates (>100 dpa)
- Void swelling
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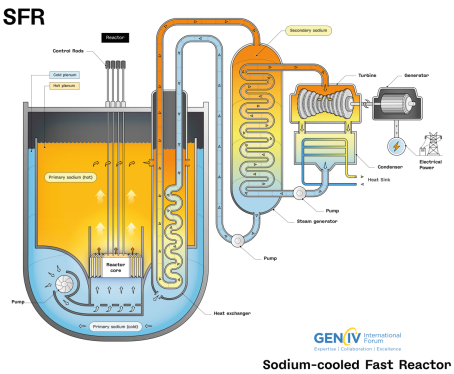


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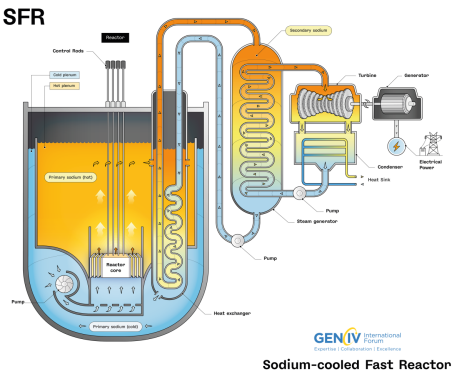


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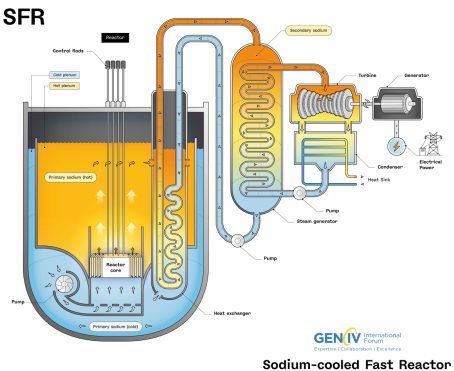


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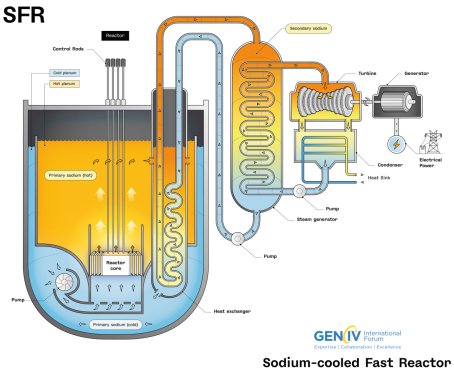


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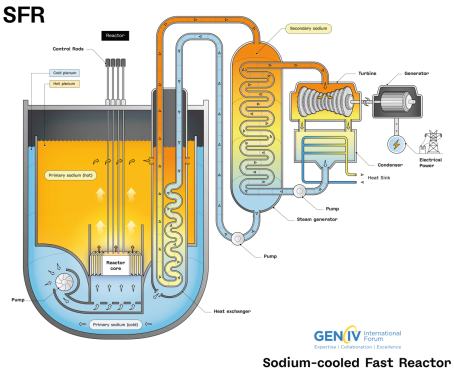


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⚠ Warning

Material Challenges for Gen-IV Higher temperatures, higher doses, new coolant environments ⇒ Current LWR materials often unsuitable!

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Demanding Service Conditions:

- Higher neutron doses (>100 dpa)
- Higher temperatures (550–1000°C)
- New corrosive environments
- 60+ year design life
- Proliferation resistance requirements

Candidate Materials

- F-M steels (HT9, T91)
- ODS steels
- Ni-based superalloys
- SiC/SiC composites
- Refractory metals (Mo, W)

Remark

Example Zirconium alloys unsuitable for Gen-IV due to: H embrittlement at high T, phase changes (α–β), poor creep resistance, rapid oxidation.

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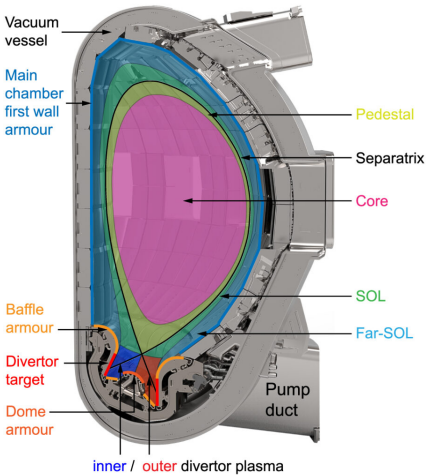
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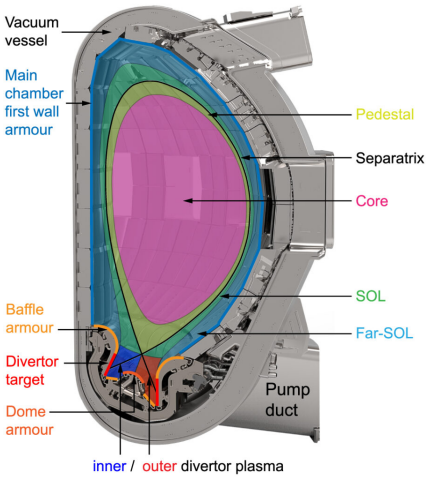
Source: K. Krieger et al 2025 Nucl. Fusion 65 043001

Extreme Conditions:

- Plasma temperature: 150 million °C
- 14.1 MeV neutrons (vs 2 MeV fission)
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- Plasma-material interaction
- Tritium breeding required

⚠ Warning

Key Challenge He/dpa ratio much higher than fission ⇒ severe helium embrittlement



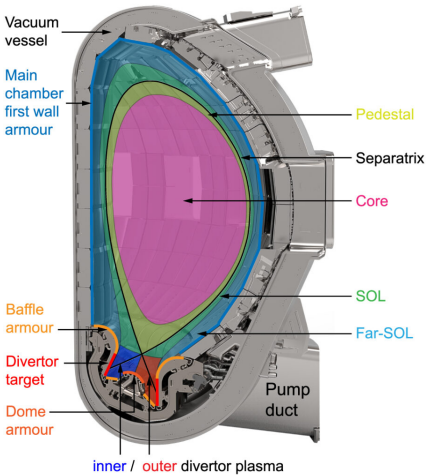
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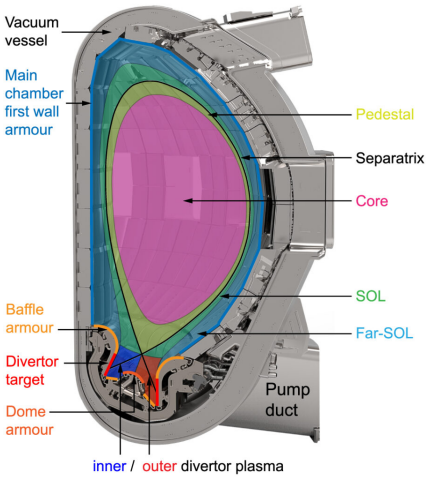
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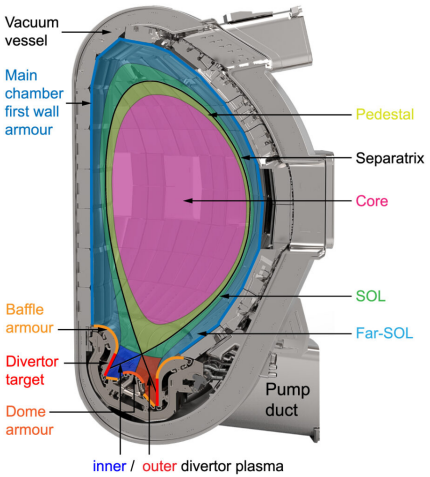
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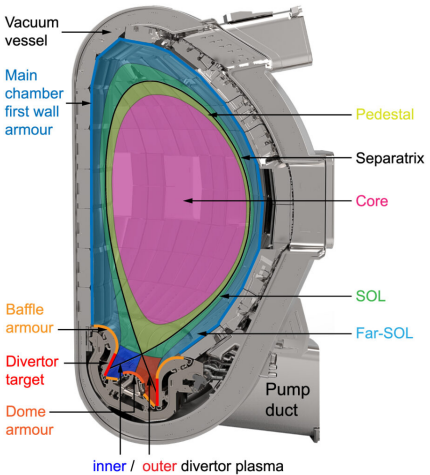
Source: K. Krieger et al 2025 Nucl. Fusion 65 043001

Extreme Conditions:

- Plasma temperature: 150 million °C
- 14.1 MeV neutrons (vs 2 MeV fission)
- Very high He production
- Plasma-material interaction
- Tritium breeding required

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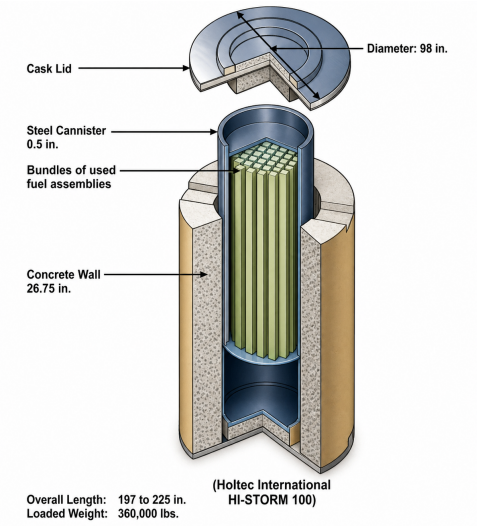
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Nuclear Waste Storage – *Long-Term Material Performance*



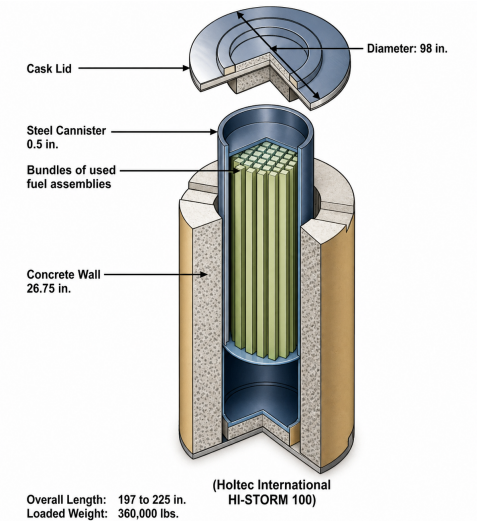
Design Requirements:

- Containment for **10,000+ years**
- Corrosion resistance (groundwater)
- Radiation damage tolerance
- Mechanical integrity
- Heat dissipation

Candidate Materials

- Copper (Sweden/Finland)
- Stainless steel
- Alloy 22 (Ni-Cr-Mo)
- Carbon steel (salt formations)

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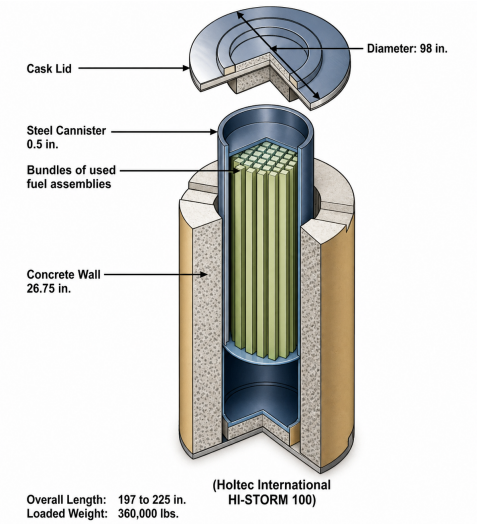
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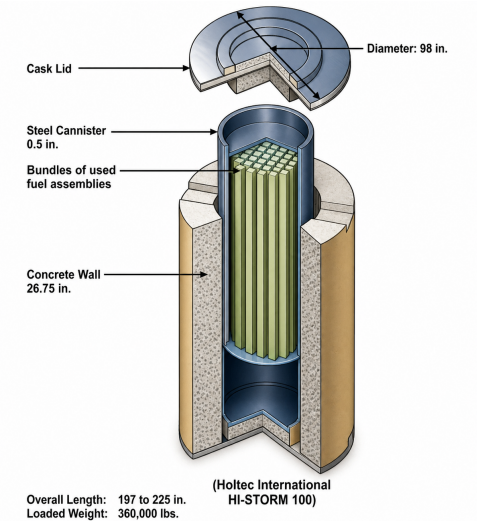
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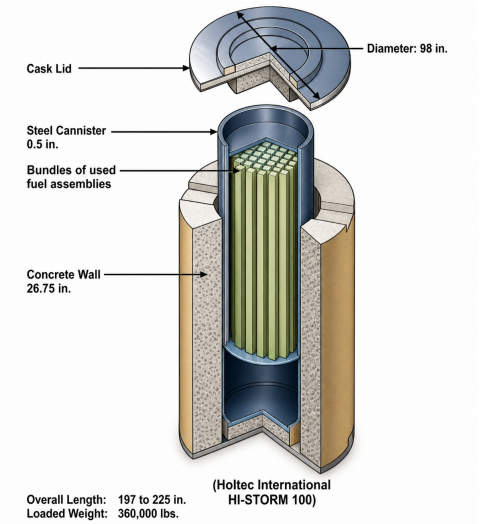
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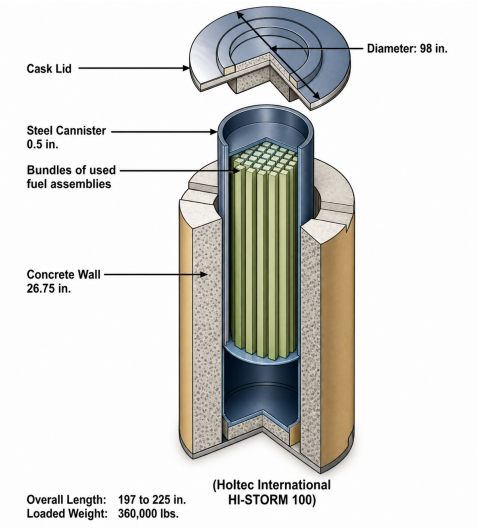
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Outline

Course Introduction

Why Nuclear Materials Matter

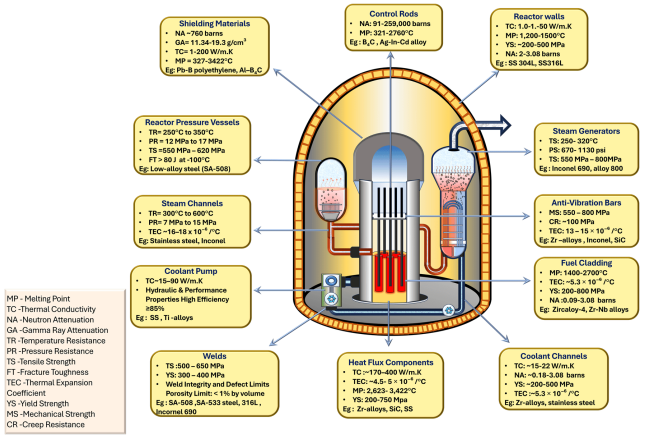
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Material Selection Criteria

Material Degradation & Failure

Summary & Preview

Material Selection Overview – *The Decision Framework*

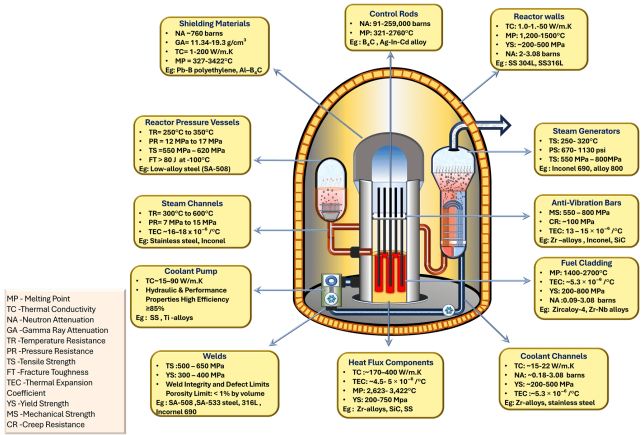


Source: Sasi et al. 2025

Remark

Neutronic and radiation criteria define feasibility. Engineering properties determine final selection.

Material Selection Overview – *The Decision Framework*



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Key Nuclear Properties

1. **Neutron absorption cross-section** (σ_a)
   - Low for structural materials (preserve neutron economy)
   - High for control materials (absorb neutrons)
2. **Induced radioactivity**
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3. **Radiation damage resistance**
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Nuclear Property Requirements – *The First Filter*

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Neutron Absorption Cross-Sections – *Why Zirconium for Cladding?*

Element	σ_a (barns)
Zr	**0.18**
Mg	0.063
Al	0.23
Fe	2.55
Ni	4.43
Cr	3.1
Hf	105
B-10	3840
Cd	2450

Remark

Note Values for thermal neutrons (0.025 eV).

Cladding Selection Zirconium: Low σ_a + adequate high-T strength + corrosion resistance

Control Rod Materials B_4C, Ag-In-Cd, Hf: Very high σ_a to absorb neutrons effectively

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Caution Hf must be removed from Zr for nuclear use (naturally occurs together)!

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+ Low cross-section for absorption of thermal neutrons
+ Higher melting point with adequate strength and ductility
+ Adequate thermal conductivity
+ Compatibility with fuel (no chemical reaction)
+ Corrosion resistance to high-temperature water

Rejected Candidates

- Be: Expensive, toxic
- Mg: Low melting (650°C)
- Al: Low melting (660°C)
- SS: High σ_a

Winner: Zr Alloys Zircaloy-4, M5, ZIRLO meet all requirements for LWR service.

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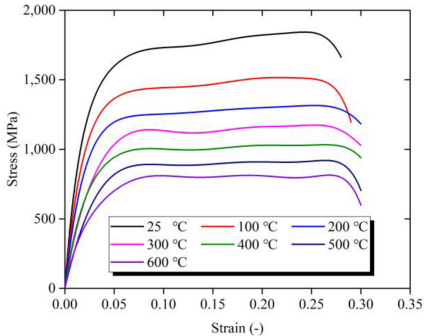
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Required Properties:

- Adequate strength at temperature
- Sufficient ductility (>1% elongation)
- Creep resistance
- Fatigue resistance
- High fracture toughness
- Low DBTT (for ferritic steels)



Source: doi:10.3390/ma11060938

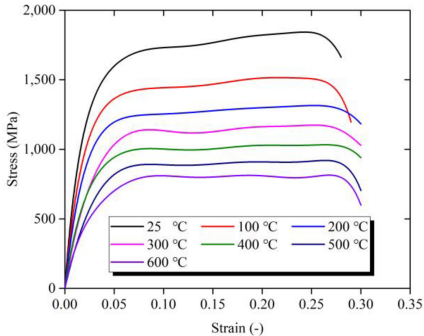
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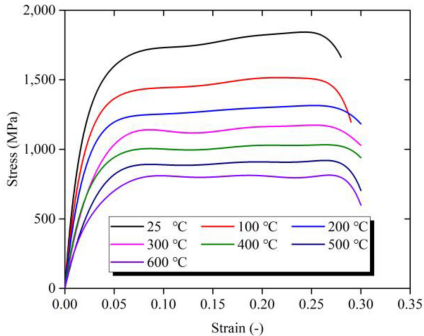
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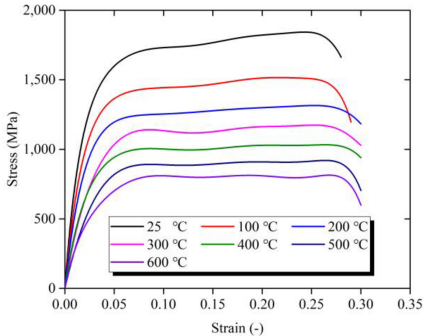
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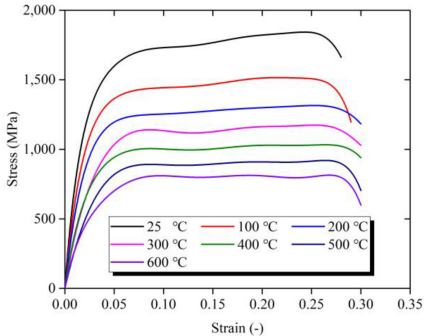
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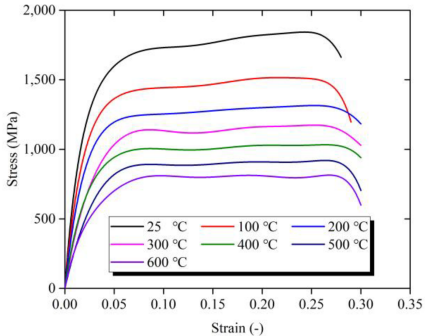
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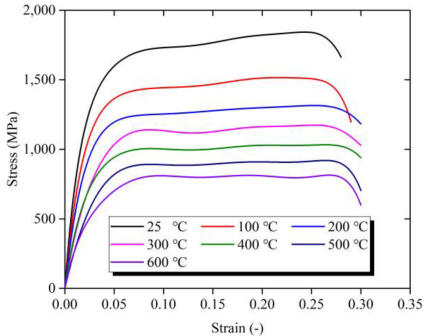
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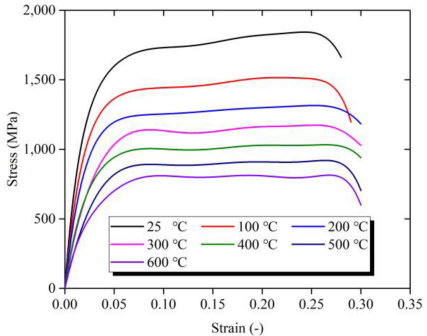
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- High thermal conductivity
- Low thermal expansion
- High melting point
- Thermal shock resistance
- Stable phases at temperature

Chemical Properties

- Corrosion resistance to coolant
- Compatibility with fuel
- Resistance to SCC
- Resistance to hydrogen pickup
- Stable oxide formation

Example

UO_2 has low thermal conductivity (~3 W/m·K) that decreases with burnup
$\Rightarrow$ high centerline temperatures, fuel restructuring.

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Component	Material Class	Key Requirement
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Core internals	Austenitic SS	Strength, corrosion resistance
RPV	Low-alloy steel	Fracture toughness
RPV liner	SS/Inconel	Corrosion resistance
SG tubes	Ni alloys (600/690)	SCC resistance, heat transfer
Control rods	B_4C, Ag-In-Cd	High σ_a
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2. Creep rupture
3. Fatigue (cyclic loading)
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5. Corrosion (various forms)

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1. **Radiation damage**
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   - Helium embrittlement
   - Irradiation creep
   - Hardening/embrittlement
2. **Radiation-environment synergy**
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Failure Mechanisms in Nuclear Systems – *Comprehensive Classification*

Mechanical

- Overload
- Creep rupture
- Fatigue
- Brittle fracture
- Fretting wear

Environmental

- General corrosion
- SCC (IGSCC, TGSCC)
- H embrittlement
- Corrosion fatigue
- Pitting/crevice

Radiation-Induced

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- Hardening
- Embrittlement
- RIS
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This course focuses on radiation-induced mechanisms and their synergy with environmental effects.

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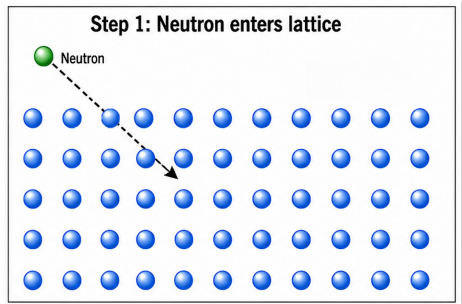
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Radiation Damage: A Preview – *What Happens When Neutrons Hit Atoms?*



doi:10.1007/978-3-642-15439-3_2

Cascade Sequence

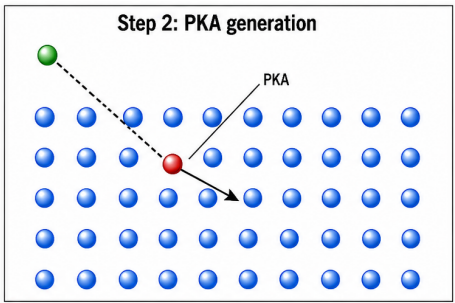
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Time Scale Entire cascade: $\sim 10^{-11}$ seconds!

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Radiation Damage: A Preview – *What Happens When Neutrons Hit Atoms?*



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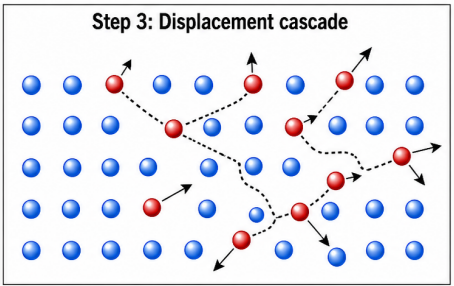
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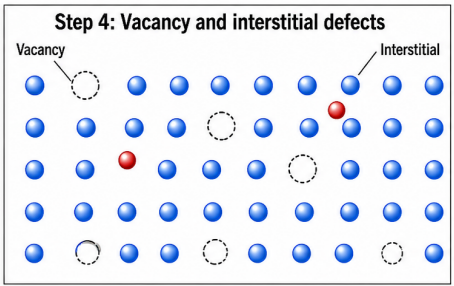
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Microstructural Changes

- Point defect accumulation
- Dislocation loop formation
- Void nucleation & growth
- Precipitate evolution
- Segregation at boundaries

Property Changes

- **Hardening** ↑
- Ductility ↓
- Fracture toughness ↓
- Creep rate changes
- **Swelling** (volume ↑)
- DBTT shift ↑

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We will study the mechanisms behind each of these effects in Units 3–4.

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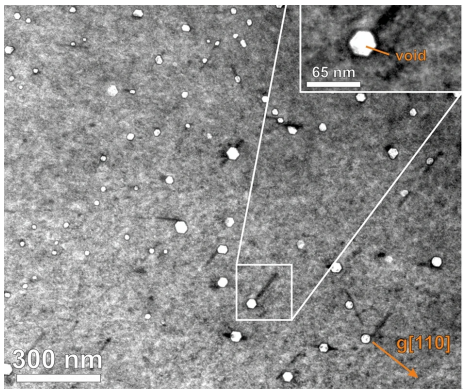
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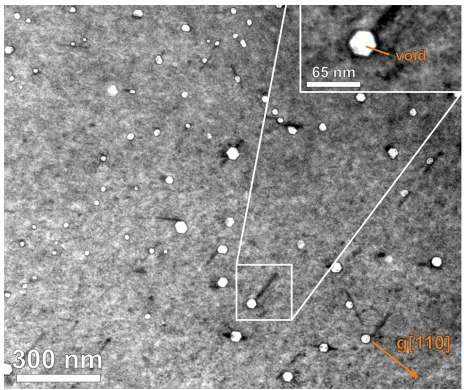
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Void Swelling:

- Volume increase due to void formation
- Can exceed **20% volume change**
- Severe in austenitic steels
- Peak at ~500°C for SS
- Major concern for fast reactors

Consequence: Dimensional changes ⇒ bowing, interference, stuck assemblies

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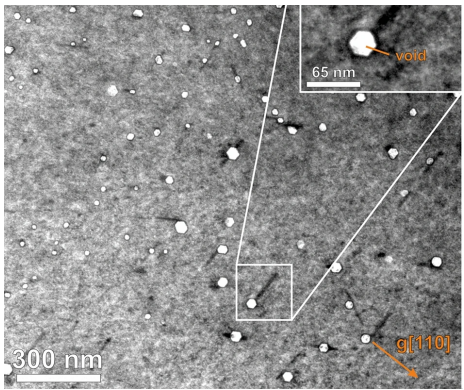
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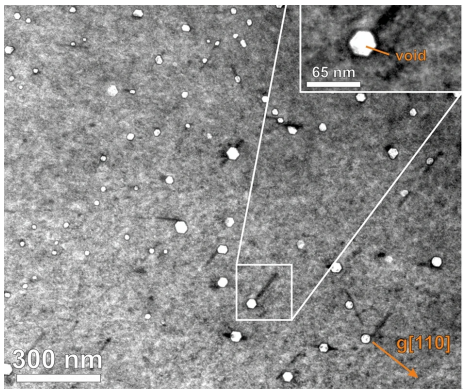
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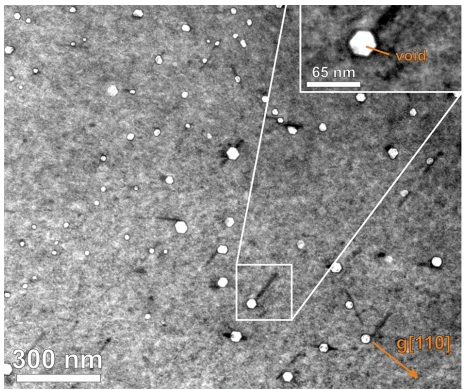
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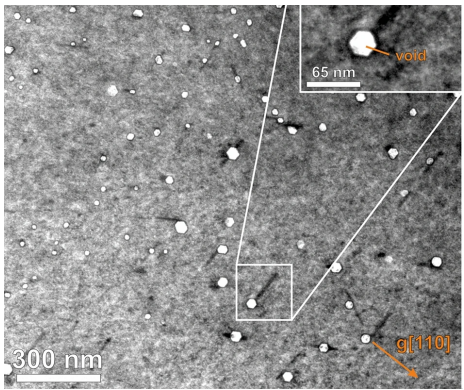
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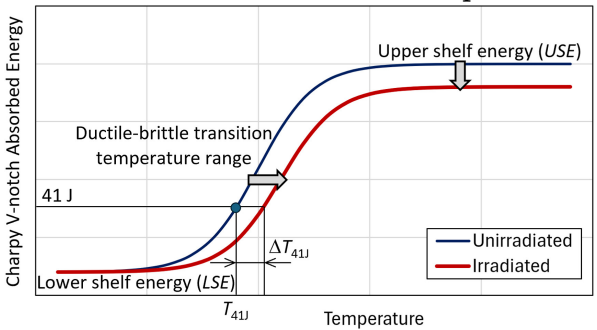
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Ductile-to-Brittle Transition Temperature:



Source: doi:10.1016/j.ijpvp.2025.105495

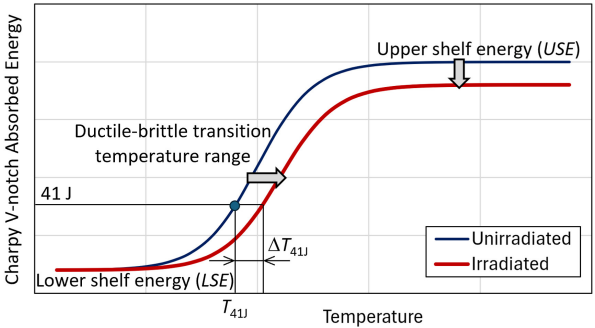
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- DBTT shifts to higher T
- Reduces safety margin
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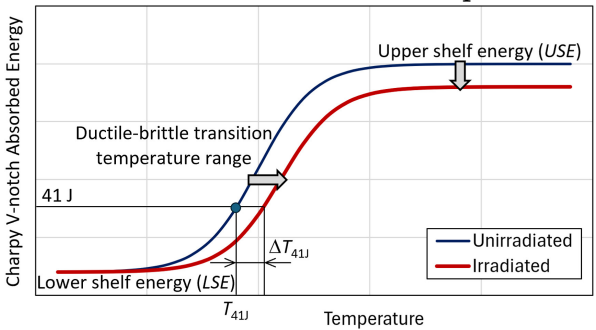
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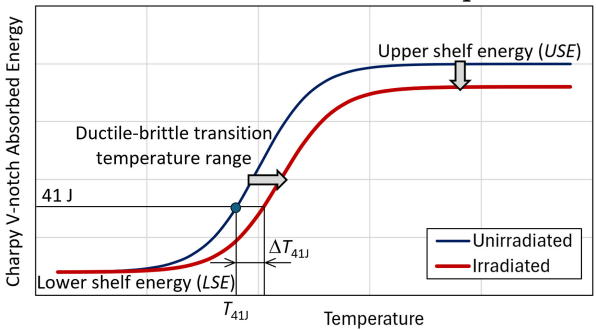
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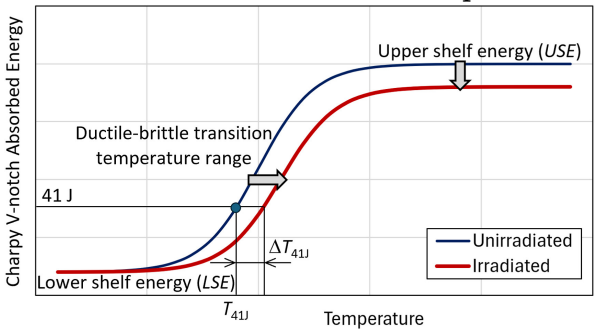
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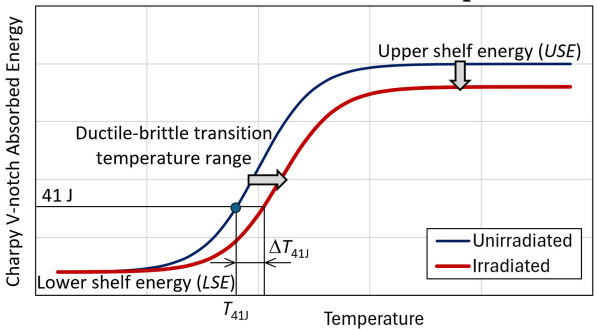
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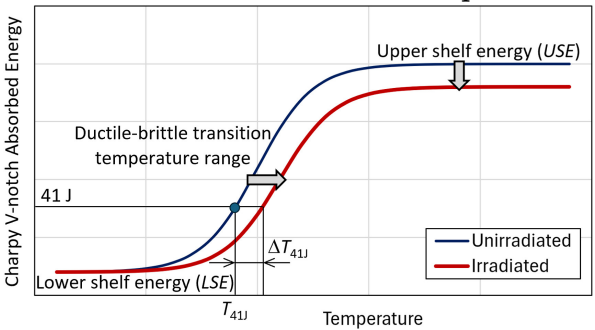
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Outline

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Why Nuclear Materials Matter

Nuclear Reactor Systems

Material Selection Criteria

Material Degradation & Failure

Summary & Preview

Unit 1 Summary – *Key Takeaways*

1. **Materials are central** to nuclear safety, economics, and plant lifetime
2. **Nuclear environment is unique:** simultaneous mechanical, thermal, chemical, and radiation loading
3. **Reactor types have different material needs:**
   - LWRs: Zr alloys, SS, low-alloy steels
   - Fast reactors: F-M steels, ODS alloys
   - Gen-IV: New materials required
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Key Terms Introduced – *Vocabulary for Nuclear Materials*

Reactor Types:

- PWR, BWR (LWRs)
- SFR (Sodium Fast Reactor)
- VHTR, GFR, LFR, MSR, SCWR
- Tokamak (fusion)

Materials:

- Zircaloy, M5, ZIRLO
- Austenitic/Ferritic steels
- Ni-based alloys (600, 690)
- UO_2, MOX, B_4C

Properties:

- Neutron absorption cross-section
- DBTT (ductile-brittle transition)
- Void swelling
- Creep, fatigue

Phenomena:

- Radiation damage, dpa
- SCC, IGSCC, IASCC
- Embrittlement
- Irradiation creep/growth

Course Preview – *Where We're Going*

Unit	Topic	Week
1	Introduction to Nuclear Systems	1
2	Crystallography Fundamentals	2
3	Radiation Damage Mechanisms	3–4
4	Defect Evolution & Transport	5–6
5	Structural & Cladding Materials	7–8
6	Nuclear Fuels	9–10
7	Corrosion in Nuclear Reactors	11–12

Next Week: Unit 2 **Crystallography & Materials Science Fundamentals**

- Crystal structures: BCC, FCC, HCP, Fluorite
- Crystal defects: vacancies, interstitials, dislocations
- Foundation for understanding radiation damage

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Reading Assignment – *Preparation for Next Week*

Required Reading

- Was, *Fundamentals of Radiation Materials Science*
  - Chapter 1: The Structure of Solids
- Murty & Charit, *An Introduction to Nuclear Materials*
  - Chapter 1: Overview of Nuclear Reactor Systems

Note

Optional Exploration

- NRC website: Reactor types and components
- IAEA PRIS: Operating reactor database
- GIF website: Gen-IV reactor descriptions

Discussion Questions – *Think About These...*

Questions for Reflection

1. Why can't we simply use stainless steel for *everything* in a reactor?
2. What makes the nuclear environment uniquely challenging compared to other high-temperature applications (e.g., gas turbines)?
3. How might climate change concerns affect the future of nuclear materials research?
4. If you were designing a Gen-IV reactor, what material properties would be your top priority?

Questions?

Thank You

Prof. Sharma

Department of Mechanical Engineering
School of Energy Resources
University of Wyoming

psharma3@uwyo.edu



Appendix A: Reactor Operating Parameters – *Reference Data*

Reactor	Coolant	T_{in} (°C)	T_{out} (°C)	P (MPa)	Neutrons
PWR	H_2O	290	325	15.5	Thermal
BWR	H_2O	275	290	7.0	Thermal
CANDU	D_2O	265	310	10	Thermal
SFR	Na	390	550	0.1	Fast
VHTR	He	490	950	7	Thermal
LFR	Pb	420	560	0.1	Fast
MSR	FLiBe	565	700	0.1	Thermal

Source: Compiled from various GIF and DOE sources

Appendix B: Thermal Neutron Cross-Sections – *Extended Reference Data*

Structural Materials:

Element	σ_a (barns)
Zr	0.18
Al	0.23
Mg	0.063
Fe	2.55
Cr	3.1
Ni	4.43
Mo	2.5
Ti	6.1

Control/Absorber Materials:

Element	σ_a (barns)
B-10	3840
Cd	2450
Hf	105
Ag	63
In	194
Gd	49000
Sm	5900
Eu	4600

Source: BNL National Nuclear Data Center

Appendix C: Common Nuclear Material Compositions – *Alloy Specifications*

Material	Nominal Composition (wt%)
Zircaloy-2	Zr-1.5Sn-0.12Fe-0.10Cr-0.05Ni
Zircaloy-4	Zr-1.5Sn-0.2Fe-0.1Cr
M5 (AREVA)	Zr-1.0Nb-0.13O
ZIRLO	Zr-1.0Nb-1.0Sn-0.1Fe
Type 304 SS	Fe-18Cr-8Ni-2Mn
Type 316 SS	Fe-16Cr-10Ni-2Mo-2Mn
Alloy 600	Ni-15Cr-8Fe
Alloy 690	Ni-30Cr-10Fe
A533B (RPV)	Fe-0.5Mo-0.5Ni-0.2C-0.5Mn

Appendix: Glossary of Acronyms – *Part 1: Reactor Systems & Components*

AGR	Advanced Gas-cooled Reactor	**LMFBR**	Liquid Metal Fast Breeder Reactor
ATF	Accident Tolerant Fuel	**LWR**	Light Water Reactor
BWR	Boiling Water Reactor	**MSR**	Molten Salt Reactor
CANDU	CANada Deuterium Uranium	**PWR**	Pressurized Water Reactor
CRDM	Control Rod Drive Mechanism	**RPV**	Reactor Pressure Vessel
GFR	Gas-cooled Fast Reactor	**SCWR**	Supercritical Water Reactor
HLW	High-Level Waste	**SFR**	Sodium-cooled Fast Reactor
HTGR	High-Temperature Gas Reactor	**SG**	Steam Generator
HWR	Heavy Water Reactor	**SMR**	Small Modular Reactor
LFR	Lead-cooled Fast Reactor	**VHTR**	Very High Temperature Reactor

Appendix: Glossary of Acronyms – *Part 2: Degradation Mechanisms*

DBTT	Ductile-to-Brittle Transition Temp.	**IGSCC**	Intergranular SCC
DHC	Delayed Hydride Cracking	**LOCA**	Loss of Coolant Accident
dpa	Displacements Per Atom	**NRT**	Norgett-Robinson-Torrens (model)
ECP	Electrochemical Corrosion Potential	**PCI**	Pellet-Cladding Interaction
FAC	Flow-Accelerated Corrosion	**PKA**	Primary Knock-on Atom
FGR	Fission Gas Release	**PWSCC**	Primary Water SCC
HBS	High Burnup Structure	**RIA**	Reactivity Initiated Accident
HWC	Hydrogen Water Chemistry	**RIS**	Radiation-Induced Segregation
IASCC	Irradiation-Assisted SCC	**SCC**	Stress Corrosion Cracking
IGA	Intergranular Attack	**TGSCC**	Transgranular SCC

Appendix: Glossary of Acronyms – *Part 3: Materials & Testing*

CVN	Charpy V-Notch (test)
FCC	Face-Centered Cubic
BCC	Body-Centered Cubic
HCP	Hexagonal Close-Packed
HAZ	Heat-Affected Zone
MA	Mill Annealed
MOX	Mixed Oxide (fuel)
NMCA	Noble Metal Chemical Addition
ODS	Oxide Dispersion Strengthened
RT_{NDT}	Reference Temperature (NDT)
SS	Stainless Steel
TD	Theoretical Density
TEM	Transmission Electron Microscopy
TRISO	TRi-structural ISOtropic (fuel)
TT	Thermally Treated
USE	Upper Shelf Energy
XRD	X-Ray Diffraction

Note

Note This glossary covers acronyms used throughout ME 5203. Additional terms will be defined as they are introduced in each unit.

Appendix: Key Symbols & Units – *Quick Reference*

Radiation Units:

ϕ	Neutron flux (n/cm^2·s)
Φ	Neutron fluence (n/cm^2)
σ	Cross-section (barn = 10^{-24} cm^2)
dpa	Displacements per atom
E_d	Displacement threshold energy (eV)
T	Recoil energy (eV)

Mechanical Properties:

σ_y	Yield strength (MPa)
σ_u	Ultimate strength (MPa)
K_{IC}	Fracture toughness (MPa$\sqrt{\text{m}}$)
ΔDBTT	DBTT shift (°C)

Thermal/Corrosion:

k	Thermal conductivity (W/m·K)
E_{corr}	Corrosion potential (V vs. SHE)
i_{corr}	Corrosion current density (A/cm^2)
ppb	Parts per billion
ppm	Parts per million

Fuel Parameters:

GWd/t	Gigawatt-days per tonne
MWd/kg	Megawatt-days per kg
FIMA	Fissions per Initial Metal Atom
%TD	Percent theoretical density