

# Subject Index

## A

Alloys (See under type of alloy)  
 Aluminum  
   cavities near grain boundaries, 220, 233  
   cold working, 508  
   copper-aluminum alloys, 14  
   defects introduced by proton irradiation, 233, 478, 490, 508  
   grain size, 508  
   hardening, 490  
   helium transport to grain boundaries, 345  
   microstructural changes, 508  
 Amorphous transformation, 661  
 Analytical electron microscopy (See Electron microscopy)  
 Anisotropic diffusion, 70  
 Annealing mechanisms, 14, 847  
 Atomic spin orientation, 880  
 Austenitic steels (See Steels)

## B

Bias factors, 70, 414, 822  
 Binary alloys, 14, 38, 60, 700  
 Blistering, 866, 893  
 Bonds, intermolecular and intramolecular, 880  
 Brittle failure, 676  
 BUBBEX program, 437  
 Bubbles (See Vacancies and voids)  
 Bulk magnetization, 880

## C

Carbide evolution, 713  
 Cascade defects  
   collision cascades, 834, 847

  in copper, 48  
   in Cu-Au alloys, 38, 60  
   interstitial dislocation loops, 393  
 Cavities (See Vacancies and voids)  
 Cementite precipitation, 647  
 Channeling (See Vacancies and voids)  
 Charged-particle irradiation, 805  
   (See also under type of particle)  
 Chemical inhomogeneity, 822  
 Chemical-rate theory, 822  
 Chromium-manganese steel alloys, 195  
 Chromium-molybdenum steel alloys  
   carbide evolution in Fe-2.25Cr-Mo alloy, 713  
   ion damage in Fe-10Cr-6Mo-0.5Nb steel, 498  
 Chromium-nickel steel alloys (See Steels; Swelling)  
 Chromium-nickel-titanium steel alloys, 805  
 Chromium-steel alloys  
   dislocation evolution in Fe-10%Cr, 466  
   heavy-ion irradiation of HT-9 steel, 530  
   neutron irradiation of HT-9 steel, 545  
   nickel ion irradiation, 588  
 Cladding, 127, 146, 154, 676 (See also Metals; Steels)  
 Cold working, 114, 127, 154, 345, 508  
 Collision cascades (See Cascade defects)

## Composition

creep strength, influence on, 127  
 fluctuations and stability, 775, 788, 809

redistribution, 721, 748

solute segregation, influence on, 730

void swelling, influence on, 289, 315

Computer simulation, 834

Concentrated alloys, 809

Conversion electron Mössbauer spectroscopy, 743, 805, 880

Copper, 48

Copper-aluminum alloys, 14

Copper-gold alloys, 38, 60, 700

Creep, irradiation

anisotropic diffusion effects, 70  
 comparison of various sink strengths, 414

effects of stress on nickel alloys, 447

in ferritic alloys, 560

in Type 316 steel, 101, 127

in uranium, 432

Critical cavity size, 498

Critical-radius concept, 315

Cross-section technique, 748

Crowdions, 70

Crystal structure

**D**

D9 cladding, 146, 154

D66 alloy, 661

Damage (See Defects, radiation induced)

Decomposition, 743, 775, 788, 809

Defects, radiation induced (See also under type of defect)

in aluminum introduced by proton irradiation, 233, 478, 490, 508

bubbles (See Vacancies and voids)

cavities (See Vacancies and voids)

damage rate, 748

deformation, 805

growth, 70, 414

interstitial, 27, 393

nickel ion irradiation effects, 588

point, 14, 330, 822

production efficiency, 700

Deformation, plastic, 805

Denuded zones, 233, 345

Depleted zones, 90

Depth profile, 748, 857

Deuterium, 857

Diffusion

in aluminum, 220

anisotropic, 70

coefficients, 5

controlled growth, 432

in copper-15at.% aluminum, 14

in  $\text{Cu}_3\text{Au}$ , 38

in Fe-2.25Cr-Mo ferritic alloy, 713

in Fe-20Cr-20Ni, 5

helium transport to grain boundaries, 345

mechanisms, 14

in uranium, 432

Dimensional stability (See Swelling)

Dislocation

in aluminum, 220, 490

collapse of defect cascades, 48, 60

comparison of sink strengths, 414

evolution in austenitic steel, 371

evolution in Fe-10%Cr, 466

in fast-neutron-irradiated nickel and iron, 27

in Fe-Ni-C and Ni-C alloys, 647

in Fe-Ni-Cr alloys, 748, 758

helium transport, 345

in HVEM-irradiated stainless steel, 242

nucleation in uranium, 432

produced by high-energy cascades, 393

stress effects on nickel alloys, 447

Disordering, 38

Dual-beam irradiation, 268

## E

- Elastic interaction difference, 71
- Electrical resistivity, 38, 478
- Electron irradiation effects (See also Ion irradiation effects)
  - in chromium-manganese steel alloys, 268
  - in chromium-nickel steel alloys, 250, 268, 758
  - dislocation in stainless steel, 242, 371
  - in manganese-steel alloys, 743
- Electron microscopy
  - of collapse of defect cascades, 48, 60
  - of dislocation behavior in stainless steel, 242
  - of dislocation evolution in Fe-10%Cr, 466
  - of dislocation motion in aluminum, 490
  - of helium ion irradiated Monel-400, 893
  - of HT-9 ferritic steel, 530, 545
  - of microstructural changes in aluminum, 508
  - of Mo-Re alloys, 721
  - of nickel ion irradiation effects, 588, 647
  - of niobium alloys, 520
  - stability studies of defects in aluminum, 478
  - stress-effects studies on nickel alloys, 447
  - stress-effects studies on Type 316 steel, 101
  - void swelling, 250, 289
- Electronic band structure, 27
- Element composition (See Composition)
- Embrittlement, 617
- Energy density, 880, 893
- Enhanced vacancy accumulation, 220
- Exfoliation, 866, 893

Experimental Breeder Reactor, 146, 154, 161, 289

## F

- Fast reactors (See Reactors)
- Ferritic material, 466, 560, 588 (See also Steels)
- Ferromagnetic metals, 27
- Field ion microscopy, 90
- Fission gas, 432
- Flaking, 866
- Focussing, 220
- Frank loops (See Dislocation)
- Free energy, 661
- Fuel cladding tubes, 127

## G

- Gases (See also Helium effects)
  - bubble growth mechanisms in swelling, 432
  - hydrogen isotopes implanted into TiC, 857
- Gold (See Copper-gold alloys)
- Grain
  - boundaries, 220, 268, 345, 432, 617
  - size, 127
- Graphite precipitation, 647
- Growth, irradiation (See Swelling)

## H

- Hardening, 490
- Helium effects
  - in aluminum, 233, 478, 490
  - generation rate, 345
  - in HT-9 steel, 545
  - importance in void nucleation, 358
  - ion damage in Fe-10Cr-6Mo-0.5Nb steel, 498
  - ion implantation in metallic glasses, 866
  - ion irradiation of Cu-Au alloys, 700

Helium effects (*continued*)

- ion irradiation of Mo-Re alloys, 721
- ion irradiation of Monel-400, 893
- of nickel ion irradiation, 588
- preinjection in irradiated Fe-Cr-Ni alloys, 250, 758
- segregation in light-ion bombarded NiD8%Si, 617
- transport to grain boundaries, 345
- trapping in metals, 330
- void-precipitate association in austenitic steel, 161
- void radius, 315
- High-voltage electron microscopy (See Electron microscopy)
- Hydrogen isotope implantation in TiC, 857

**I**

- Inconel 600, 207
- Incubation, 345
- Interaction fields, 414
- Intermetallic phase, 545
- Intermolecular bonds, 880
- Interstitial considerations
  - comparison of sink strengths, 414
  - configurations, 27
  - dislocation loops produced by high-energy cascades, 393
  - loss, 220
- Intramolecular bonds, 880
- Invar, 775
- Inverse Kirkendall effect, 268, 775, 822
- Ion irradiation effects (See also electron irradiation effects; proton irradiation effects)
  - in Cu-Au alloys, 60, 700
  - in Fe-10%Cr alloy, 466
  - in Fe-2.25Cr-Mo alloy, 713
  - in Fe-10Cr-6Mo-0.5Nb alloy, 498
  - in Fe-Cr-Ni alloys, 127, 260, 289, 315, 758, 788
  - in Fe-Ni alloys, 788

- in Fe-Ni-C alloys, 647
- in ferritic steels, 498, 530, 588, 713
- hydrogen isotope implantation in TiC
- in metallic glasses, 866, 880
- in Mo-Re alloys, 721
- in Monel-400, 893
- in Ni-C alloys, 647
- in Ni-8%Si alloy, 617
- precipitate recoil, 834
- self, 5, 48
- in vanadium-base alloys, 730
- Iron, 27, 48, 834
- Iron-nickel-chromium alloys (See Steels; Swelling)

**K-L**

- Kirkendall effect, inverse, 268, 775, 822
- Laves phase, 661
- Liquid metal reactors, 146

**M**

- Magnetic isotropy, 27
- Magnetization, bulk, 880
- Manganese steel alloys, 195, 743
- Martensite, 530, 545
- Martensitic transformation, 758
- Mechanical properties, 508
- Metallic glasses, 866, 880
- Metals (See also Aluminum; Microstructure; Nickel; Steels)
  - annealing mechanisms, 14, 847
  - cold working, 114, 127, 154, 345, 508
  - composition, 127, 250, 289, 315
  - copper, 48
  - copper-aluminum alloys, 14
  - copper-gold alloys, 38, 60
  - creep (See Creep)
  - D66 alloy, 661
  - ferritic alloys, 530, 545, 560, 588, 595
  - fuel, 432

fuel cladding tubes, 127  
 gas-bubble growth mechanisms, 432  
 growth (See Swelling)  
 hardening, 490  
 helium trapping, influence of, 330  
 high-purity alloys, 250  
 Inconel 600, 207  
 iron, 27, 48  
 mechanical properties, 508  
 metallic glasses, 866, 880  
 molybdenum-rhenium alloys, 721  
 Monel-400, 893  
 niobium alloys, 520  
 nucleation, 647  
 PE 16, 345  
 precipitate dissolution, 508  
 softening, 508  
 3d-transition, 27  
 titanium carbide, 857  
 titanium-modified alloys, 146, 154  
 tungsten, 90  
 uranium, 432  
 vanadium-base alloys, 730  
 Zircalloys, 661, 676  
 Meteorites, 775  
 Microhardness, 520  
 Microscopy  
   electron (See Electron microscopy)  
   field ion, 90  
 Microstructure (See also Phase stability)  
   carbide evolution in irradiated FeD2.25Cr-Mo alloy, 713  
   dislocation evolution in irradiated Fe-10%Cr, 466  
   of Fe-Mn alloys under electron irradiation, 743  
   interstitial dislocation loops produced by high-energy cascades, 393  
   ion damage in Fe-10Cr-6Mo-0.5Nb steel, 498  
   ion-irradiated vanadium-base alloys, evolution in, 730

irradiated austenitic steel, evolution in, 371  
 of irradiated cast and aged duplex stainless steels, 595  
 of irradiated ferritic alloys, 530, 545, 560, 588  
 irradiated nonhomogeneous alloys, evolution in, 822  
 irradiated Type 316 steel, changes in, 114  
 of irradiated Zircalloys, 676  
 neutron-irradiated niobium alloys, changes in, 520  
 proton-irradiated aluminum alloys, changes in, 508  
 stress effects on irradiated nickel alloys, 447  
 void-precipitate association, 161  
 Molybdenum alloys, 721  
 Monel-400, 893  
 Mössbauer absorption, 880  
 Mössbauer spectroscopy, 743, 805, 880

## N

Nernsts theorem, 810  
 Neutron irradiation  
   of aluminum, 220, 233  
   of austenitic steel, 371, 661  
   of chromium-nickel steel, 260, 289, 315, 661, 775  
   of Cu<sub>3</sub>Au, 38  
   of Fe-Mn and Fe-Cr-Mn austenitic alloys, 195  
   of ferritic alloys, 560, 588  
   of iron and nickel, 27  
   of nickel-steel alloys, 775  
   of niobium alloys, 520  
   of tungsten, 90  
   of Type 316 steel, 114, 127, 154, 161, 207, 628  
   of Zircalloys, 661, 676  
 Nickel  
   defect cascade collapse, 48  
   defect structures in, 27

Nickel (*continued*)

- diffusion coefficients in Fe-20Cr-20Ni, 5
- dose and energy dependence of ion-irradiated Monel-400, 893
- graphite and cementite precipitation in Ni-C alloys, 647
- ion irradiation, 588, 713, 758, 788
- segregation in light-ion bombarded Ni-8%Si, 617
- steel alloys, 647, 775, 788
- stress effects on irradiation-induced microstructures of nickel alloys, 447
- swelling in alloys with varying percentages of nickel, 250, 289, 315
- swelling in Inconel 600, 207
- Nickel-chromium steel alloys (See Steels; Swelling)
- Nonequilibrium statistical theory, 393
- Nonhomogeneous alloys, 822
- Nucleation (metals), 647

**O**

- Ordering, 38, 743, 847
- Oxygen effects on void stabilization in stainless steel, 279

**P**

- Peak-damage region, 748
- Peak zone, 220
- Phase stability
  - compositional fluctuations of alloys, 809
  - in Fe-Cr-Ni alloys, 758
  - in Fe-Mn and Fe-Cr-Mn alloys, 195
  - in Fe-Ni-C and Ni-C alloys, 647
  - in Type 316 steel, 114
  - void-precipitate association, 161
- Phase transformations, 676, 805 (See also Microstructure)
- Phenomenological rate equations, 817

- Phosphide, 114
- Phosphorus, 289
- Point defects (See also Defects, radiation induced)
  - annealing mechanisms of, 14
  - fluxes, 822
  - helium trapping, influence on metals, 330
  - in nonhomogeneous alloys, 822
  - properties of, 14
  - void swelling in Fe-Cr-Ni alloys, 250

## Precipitates and precipitation

- dissolution, 508
- evolution, 628
- extraction, 588
- in Fe-Cr-Ni alloys, 758
- graphite and cementite, 647
- in HT-9 ferritic steel, 530, 545
- in Mo-Re alloys, 721
- near a collision cascade, 847
- in neutron-irradiated Zircalloys, 676
- recoil resolution, 834
- in vanadium-base alloys, 730
- void-precipitate association in Type 316 steel, 161
- Preferential recovery, 847
- Proton irradiation effects (See also Ion irradiation effects)
  - in aluminum, 233, 345, 478, 490, 508
  - compositional redistribution in Fe-Ni-Cr alloys, 748
  - phase transformations in chromium-nickel-titanium steel alloys, 805
  - stress effects on irradiated nickel alloys, 447
  - in tungsten, 90

**R**

- Radiation-induced segregation (See Segregation and compositional redistribution)
- Rate theory, 330, 371

Reaction kinetics, 70  
Reactors  
    Experimental Breeder Reactor, 146, 154, 161, 289, 545, 628  
    fast, 114, 127  
    Fast Flux Test Facility, 146, 154, 195, 207, 545  
    HFIR, 161  
    liquid metal, 146  
    reflector assemblies, 207  
    WWR-K, 847  
Recoil mechanisms, 5, 220, 834  
Reduced activation, 195, 268  
Reflector assemblies, 207  
Refractory metals, 520  
Relative susceptibility, 880  
Resistivity, electrical, 38, 478  
Rhenium alloys, 721  
Rutherford backscattering spectroscopy, 700, 721

## S

Scanning electron microscope, 893  
Secondary ion mass spectrometry (SIMS) measurements, 7  
Segregation and compositional redistribution  
    in Cu-Au alloys, 700  
    in Fe-Cr-Mn alloys, 268  
    in Fe-Cr-Ni alloys, 252, 264, 268  
    in Mo-Re alloys, 721  
    in Ni-8%Si, 617  
    in Type 316 steel, 161  
    in vanadium-based alloys, 730  
Self-interstitial atoms, 70  
Self-ion irradiation, 5, 48  
Separation of alloy components, 847  
Silicon, 5, 289, 617  
Simulation, 748  
Sink strength, 345, 414  
Small-angle neutron scattering, 595  
Softening, 508  
Solute segregation (See Segregation and compositional redistribution)  
Spallation neutrons, 90

Spectroscopy, Mössbauer, 743, 805, 880  
Spinodal decomposition, 775, 788, 809  
Stability  
    of composition, 809  
    of radiation defects in aluminum, 478  
Stabilization, 279  
Steels (See also Metals; Microstructure; Swelling)  
    austenitic (See also herein under alloy composition)  
        amorphous transformation of laves phase, 661  
        compositional redistribution under proton irradiation, 748  
        microstructural evolution under radiation, 371  
        relative importance of helium and vacancy accumulation in void nucleation, 358  
    chromium-manganese steel alloys, 195  
    chromium-molybdenum steel alloys, 498, 713  
    chromium-nickel steel alloys  
        amorphous transformation of laves phase, 661  
        compositional redistribution under proton irradiation, 748  
        diffusion coefficients of nickel and silicon in Fe-20Cr-20Ni, 5  
        element composition influence on void swelling, 250, 289, 315  
        microstructure change in cast and aged steels, 595  
        phase stability, 758  
        point defect dynamics, 822  
        spinodal-like decomposition, 775, 788  
    Type 316 steel  
        D9 cladding, 146, 154  
        helium transport to grain boundaries, 345

- Type 316 steel, helium transport to grain boundaries (*continued*)
  - microstructural change, 114
  - modified for fuel cladding tubes, 127, 146, 154
  - oxygen effects on void stabilization, 279
  - precipitate evolution, 628
  - relative importance of helium and vacancy accumulation in void nucleation, 358
  - swelling, 101, 114, 127, 146, 154, 207, 358
  - titanium modified, 146, 154
  - void-precipitate association, 161
- chromium-nickel-titanium steel alloys, 805
- chromium-steel alloys, 466, 530, 545, 588
- D66 alloy, 661
- diffusion coefficients of nickel and silicon, 5
- dislocation during swelling of HVEM-irradiated stainless steel, 242
- duplex stainless steels, 595
- element composition
  - creep strength, influence on, 127
  - oscillations, 775, 788
  - void swelling, influence on, 289, 315
- ferritic (See also herein under alloy composition)
  - carbide evolution in Fe-2.25Cr-Mo alloy, 713
- fine-scale microstructure in cast and aged duplex stainless steels, 595
- heavy-ion irradiation of HT-9 steel, 530
- ion damage in Fe-10Cr-6Mo-0.5Nb steel, 498
- neutron irradiation of HT-9 steel, 545
- ferromagnetic, 27
- helium trapping, influence of, 330
- manganese steel alloys, 195, 743
- martensite, 530, 545
- martensitic transformation, 758
- nickel-chromium steel alloys (See chromium-nickel steel alloys)
- nickel-steel alloys, 647, 775, 788
- noncubic, 70
- oxygen effects on void stabilization in stainless steel, 279
- Type 304 steel, 242
- void-precipitate association, 161
- Stereomicroscopy, 676
- Stress effects, 70, 101, 447
- Surface damage, 866, 880, 893
- Swelling
  - in aluminum, 220
  - anisotropic diffusion, caused by, 70
  - in austenitic steel, 371
  - charged particle induced, 127
  - in chromium-manganese steel, 195, 268
  - in chromium-nickel steel, 250, 268, 289, 315, 775, 788
  - comparison of various sink strengths, 414
  - compositional dependence, 127, 146, 154, 289, 315
  - compressive stress effects on, 101
  - dislocation in HVEM-irradiated stainless steel, 242
  - in Fe-10Cr-6Mo-0.5Nb ferritic steel, 498
  - of ferritic alloys, 560, 588
  - gas-bubble growth mechanisms in metal fuel, 432
  - helium preinjection, influence of, 255
  - in Inconel 600, 207
  - interstitial dislocation loops produced by high-energy cascades, 393
  - in manganese steel, 195
  - neutron induced, 114, 127, 146, 154



nickel concentration, influence of, 255  
 in nickel-steel alloys, 775, 788  
 oxygen effects on void stabilization in stainless steel, 279  
 precipitate recoil, 834  
 relative importance of helium and vacancy accumulation, 358  
 temperature dependence, 255  
 tensile stress effects on, 101  
 transient period in Type 304 steel, 242  
 in Type 316 steel, 101, 114, 127, 146, 154, 207, 358  
 in vanadium-base alloys, 730  
 void-precipitate association, 161

## T

Theoretical models of microstructural evolution in austenitic steel, 371  
 3d-transition metals, 27  
 Titanium carbide, 857  
 Titanium-modified Type 316 steel, 146, 154  
 Transmission electron microscopy (See Electron microscopy)  
 Transmutation atoms, 478, 490  
 Transport efficiency, 5  
 Tungsten, 90

## U

Uranium alloys, 432

## V

Vacancies and voids (See also Dislocation)

in aluminum near grain boundaries, 220, 233  
 cavity evolution in austenitic steel, 371  
 in chromium-manganese steel alloys, 268  
 in chromium-nickel steel alloys, 268  
 concentration, 90  
 critical cavity size, 498  
 density, 242  
 element composition influence on void swelling, 289, 315  
 enhanced vacancy accumulation, 220  
 in Fe-Ni alloys, 775, 788  
 in Fe-Ni-C and Ni-C alloys, 647  
 in Fe-Ni-Cr alloys, 748, 758, 775, 788  
 gas-bubble growth mechanisms, 432  
 growth modeling, 250  
 helium trapping, 330, 345, 358, 478, 490, 866  
 in HT-9 ferritic steel, 530, 545  
 migration enthalpy, 5  
 in niobium alloys, 520  
 nucleation, 242, 345, 358  
 oxygen effects on void stabilization in stainless steel, 279  
 properties, 14  
 sink strengths, comparison of, 414  
 stability, 279  
 swelling (See Swelling)  
 void-precipitate association, 161  
 Vanadium-base alloys, 730

## W-Z

WWR-K reactor, 847  
 Zircalloys, 661, 676