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Materials subjected to fast neutron irradiation/Matériaux soumis à irradiation par neutrons rapides

Foreword

The science of nuclear materials is a subject that is difficult to teach. The difficulty stems from the diversity of the field, and the apparent lack of well defined and clearly visible principles that would determine the response of a material to irradiation. All the adverse factors needed to ensure the failure of an attempt by a scientist to rationalise, in quantitative terms, the observed changes in the properties of a material under neutron irradiation, are present. A material under irradiation is an open system, strongly interacting with its non-equilibrium radiation environment. The range of temperatures in which a material is expected to operate is broad, and generally the temperatures are high, making the proximity of phase transitions strongly felt, notably in terms of the effect of phase transitions on engineering properties. Safety issues make carrying out experimental work difficult and time consuming. The constraints on the accuracy of mathematical methods are so stringent that it is almost a matter of routine that an enthusiastic theorist becomes frustrated when trying to offer an explanation of some of even the most basic phenomena observed experimentally.

Furthermore, the materials on which nuclear or fusion technologies are founded are not simple. On more than one occasion our distinguished academic colleagues told us that the complexity of the properties of steels puts them beyond the reach of mathematical simulations, a point of view strongly backed by the long history of empirical development of the subject, which, in effect, is an example of a successful application of the "try and see" approach so typical of the field of nuclear materials. On the other hand, we argued that we knew of many areas of natural sciences that remained in a similar uncertain state, until the moment when a coherent effort backed by adequate available expertise revealed the underlying principles and revolutionised, and perhaps even trivialised, the pathway for subsequent development, opening new avenues for technological and industrial applications.

Our familiarity with the current state of the field of materials for fission and fusion applications suggests that it is going through a period of revolutionary renaissance at this very moment. The papers presented in this issue of the Comptes Rendus Physique are written by leading European experts in the experimental examination and mathematical modelling of materials subjected to fast neutron irradiation. They provide a comprehensive and up to date vision of the subject, showing that even the most difficult problems that have remained outstanding for decades can now be successfully addressed both in terms of the development of suitable experimental techniques for the examination of materials, and in terms of the formulation of well defined mathematical models.

The structure of this special issue follows the principle of going from general to particular, and from the past to the future. The reviews addressing the synergies between the nuclear fission and fusion fields, the fundamentals of radiation damage in materials, and the treatment of radiation effects in alloys, are followed by papers describing the most recent developments in mathematical modelling of materials. These include a comprehensive review of ab initio models of iron and iron-based systems, a critical assessment of the state of development of interatomic potentials for molecular dynamics simulations, a review of the strategy for linking experimental observations and kinetic Monte-Carlo and rate theory modelling, followed by a review of mathematical methods for the treatment of transport of defects and atomic species in alloys, and irradiation effects in non-metallic materials.

Examples illustrating applications of general methods to specific problems of stability of alloys under irradiation, helium and point defect accumulation and the effect of this on microstructure, mechanical properties and helium permeability of materials, thermal migration of radiation defects, the fundamentals of irradiation-induced hardening and applications of discrete dislocation dynamics to large-scale simulations illustrate the impressive scope of the

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application of the recently developed new mathematical algorithms to predictive modelling of processes occurring in materials under fast neutron irradiation.

The confidence in the quantitative theoretical predictions made using newly developed mathematical tools will also critically depend on the experimental validation of suitably chosen selected critical predictions. This special issue is crowned by three papers aiming at the future development of this subject. Here we have a comprehensive review of a new large-scale ion-beam irradiation facility that is presently being constructed at CEA Saclay and CNRS Orsay, an assessment of capabilities of high performance materials testing reactors including the Jules Horowitz Reactor that is presently being built at CEA Cadarache, and, finally, a review of the International Fusion Materials Irradiation Facility (IFMIF), a mandatory project that, in tandem with ITER (International Tokamak Experimental Reactor presently being constructed at Cadarache, France), will open the way to designing and operating a fusion power plant.

We hope that this comprehensive yet readily accessible set of original contributions and reviews, covering a broad range of issues presently dominating the development of nuclear fission and fusion materials science, will attract the attention of both established experts and students interested in this highly non-trivial and challenging subject.

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