Challenges and opportunities for enhancing the safety standards in nuclear industry.

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Nuclear Safety Standards
State of the Art of Nuclear Safety
Challenges
Opportunities
Conclusion

Based on French Academy report "Solidarité Japon", June 2011, Nuclear group,
www.academie-sciences.fr/activite/rapport/rads0611.htm

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Nuclear Safety Standards/State of the Art of Nuclear Safety

Nuclear Safety Standards (NSS) are standards (fundamental principles, requirements, guides) designed to ensure Nuclear Safety Objectives (NSO). NSS can be advisory or compulsory and are normally laid down by an "advisory" or a "regulatory" body. NSO are more expressed in general terms than in means or dispositions to be implemented.

Most of the IAEA NSS are not constraining on a juridical basis but they are considered as international references, as well are the ICRP recommendations for radioprotection leading to Basic Safety Standards (BSS).

The organisation of nuclear safety depends of the sovereignty of each country.

There is no international Nuclear Safety Authority.

WANO aims at increasing nuclear safety worldwide.

International OECD-NEA, IAEA, .. and transnational organisations (like ENSREG, WENRA, HERCA in Europe) try to harmonise regulations and practices.

ICRP: International Commission on Radiological Protection
OECD-NEA: Organisation for Economic Co-operation and Development-Nuclear Energy Agency
AEA: International Atomic Energy Agency
WANO: World Association of National Operators
ENSREG: European Nuclear Safety Regulator Group
WENRA: Western European Nuclear Regulators Association

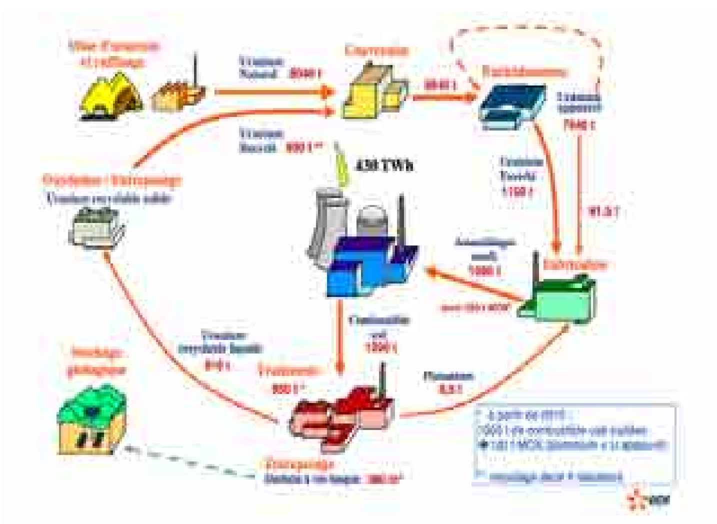
HERCA: Heads of the European Radiological protection Competent Authorities.

Nuclear safety includes three fields : the safety of installations, the radioprotection of everybody and the security of the public in the case of an accidents ranked 5 to 7 on the INES classification.

The basic strategy of nuclear safety is to prevent exposition to radiation, to prevent uncontrolled dispersion of radioactive substances and, if so (incident, accident), to take countermeasures and disposition to mitigate the effects.

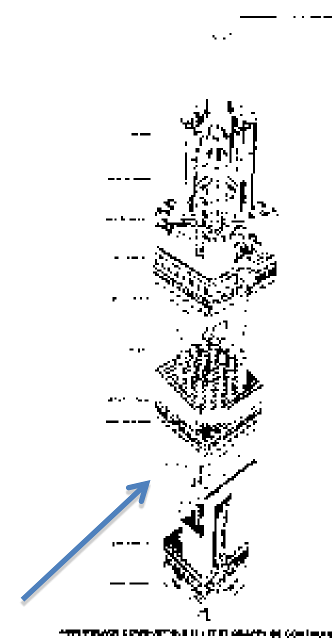
It apply to all of the installations of the « nuclear fuel cycle » from U mining to nuclear wastes management, considering all possible fatal natural and anthropic events and civilian and militaries industries

INES: International Nuclear Events Scale

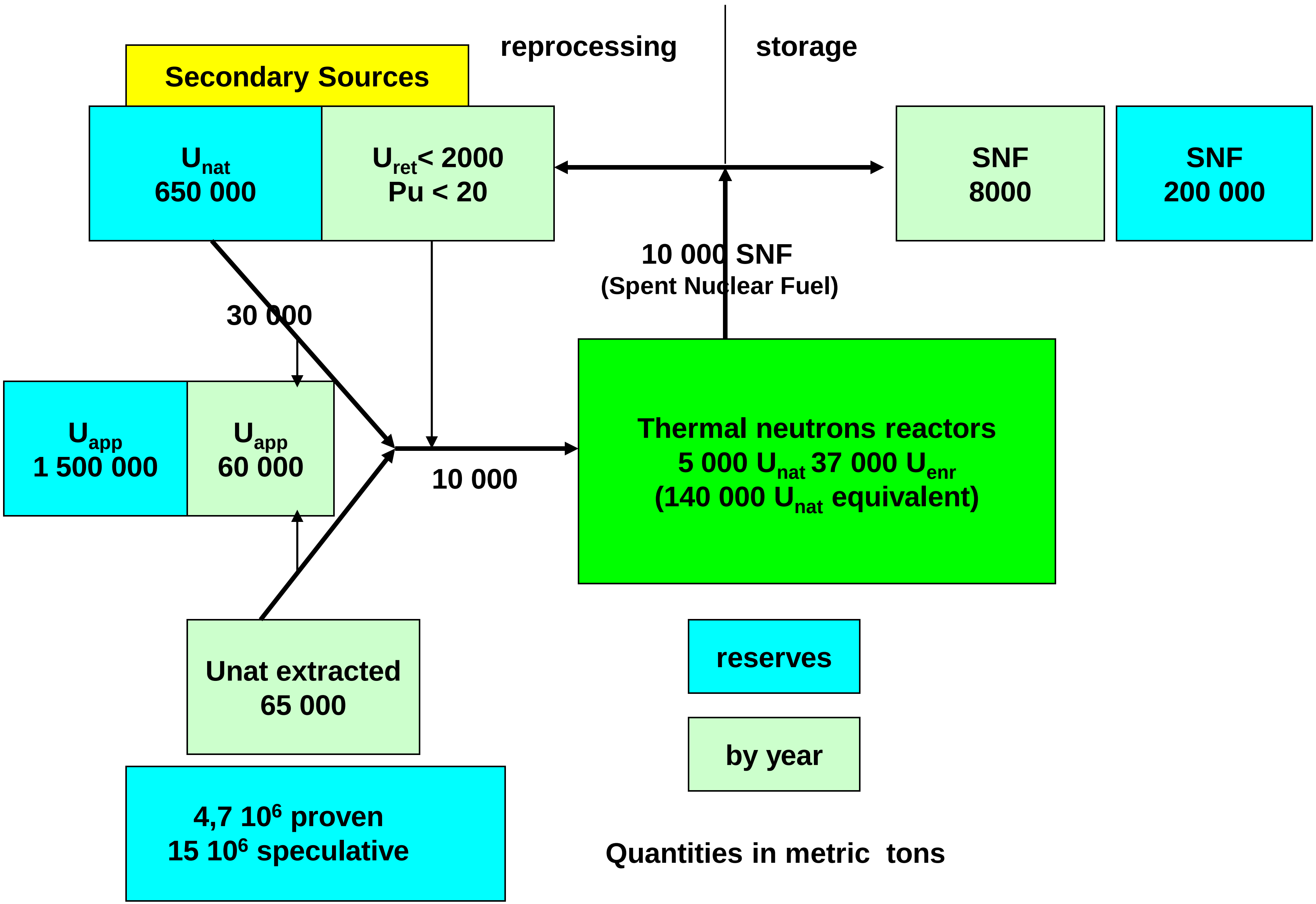


The radioactive matter, which presents the highest potential hazard, is the irradiated nuclear fuel. As its burn up (BU) increases it contains more and more FP, Pu, MA and its radioactivity increases from some kBq/cm^3 to some tens Ci/cm^3 (1Ci = 3,7 10^{10} Bq) as well as its thermal power : 0 to some 100 W/cm^3.

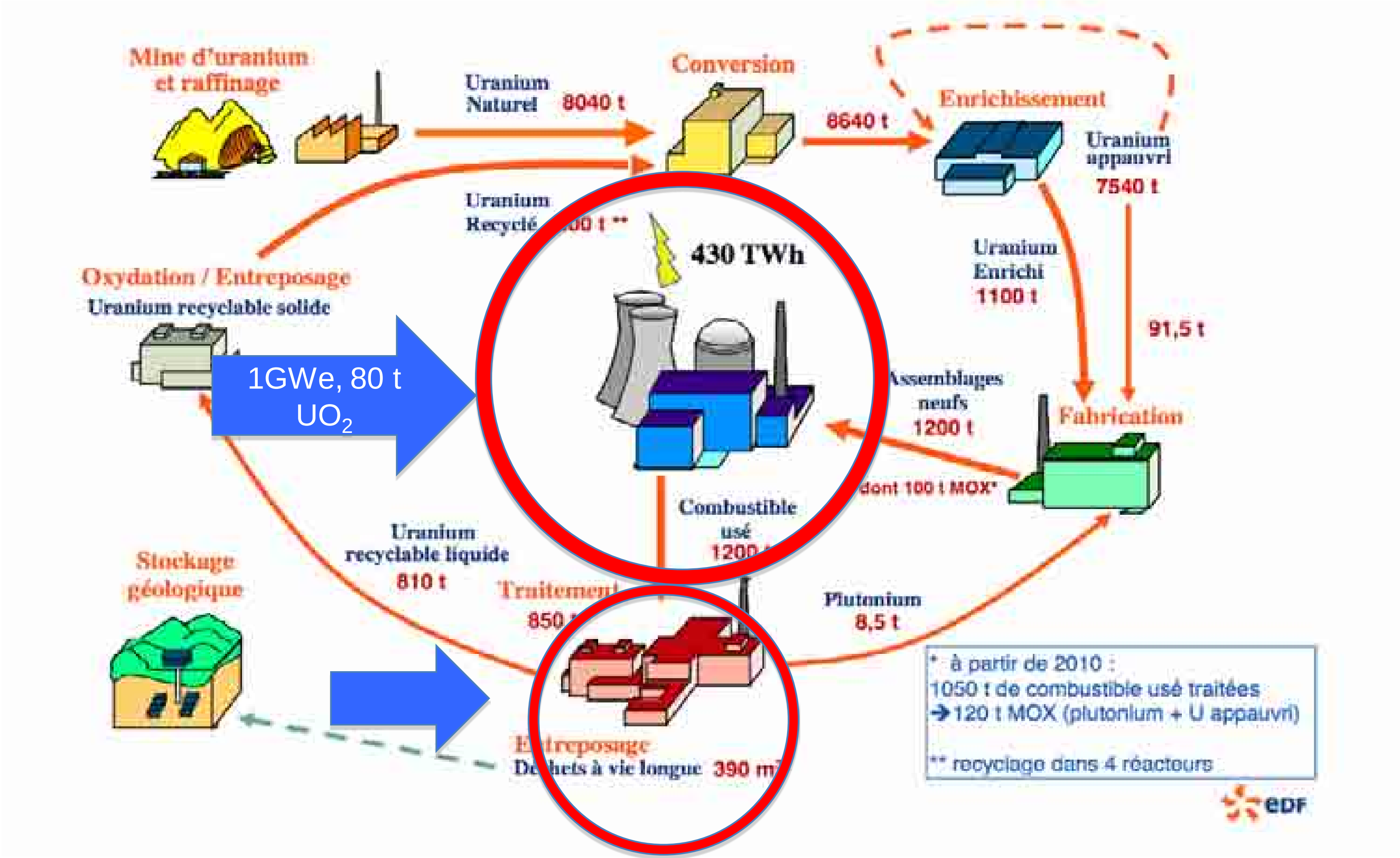
500 kg of UO_2



Worldwide circulation and storage of radioactive matter



Nuclear reactors and reprocessing spent fuel facilities are mainly of concern in Nuclear Safety. The most dreaded event is the nuclear core melting with formation of corium.



NSS in nuclear industry are well established (IAEA, WANO, ICRP, AEN, national and shared multinational national regulations, …) according to lessons which has been learn from the operated 14 000 reactors equivalent years over the world, incidents and major accidents (TMI, Chernobyl) included, as well as those of the associated nuclear cycle facilities.

So NSS include, in principle, the state of the art with respect to nuclear safety.

Safety of most of the Generation II reactors has been improved with regard of TMI-1979 feedback, but only Generation III reactors comply, in addition of the enhancement of the « classical safety » (it is to say to to provide water and electricity), with the containment of corium and large plane crash, two major improvements which would restrain the displacement of living people and the restrictions on goods marketing

Improvement of nuclear safety is the recurrent and the main concern of : operators who are, in any case, responsible of the nuclear safety of their installations, the safety Authorities which are in charge of controls and the other Authorities which are in charge of public security (both appointed by the states).

After the Fukushima severe accident (7 on INES) many countries ask to upgrade NSS

Challenges

Designs of installations and the dispositions taken to prevent or/and to mitigate accidents result from a deterministic or/and a probabilistic « Safety Case Analysis » (SCA) which leads to an evaluation of the risks and consequently to the parries to be implemented.

SCA help also to the planning and the coordination of all means to manage the emergency and post accidental periods and to take care of the exposed to radiation and/or stressed people.

SCA dealing with reactors need to understand deeply the physical and chemical phenomenons which occur during an accident and how they can go on, the characteristics of the dispersed radioactive matter as well as the characteristics of the contaminated areas and, the radioactive hazard versus effective dose.

Considerable researches have been already conducted (national, international network Sarnet , …).

Nuclear safety is not only the respect of basic safety functions, rules and regulations but it must lie on a scientific evaluation.

Any improvement in the basic knowledge of the behaviour of nuclear fuel far from nominal conditions can help to improve NSS. Any improvement in accident management goes in the same way.

Main processes in the case of a loose of cooling

3000 ° Cfuel

Zr

2000 ° C

1000 ° C

300 ° C

2300-2500
$Zr_{liq} + UO_2 + \dots = corium$
Corium is leached
(UO_{2+x}/H_2O)

FP , An release

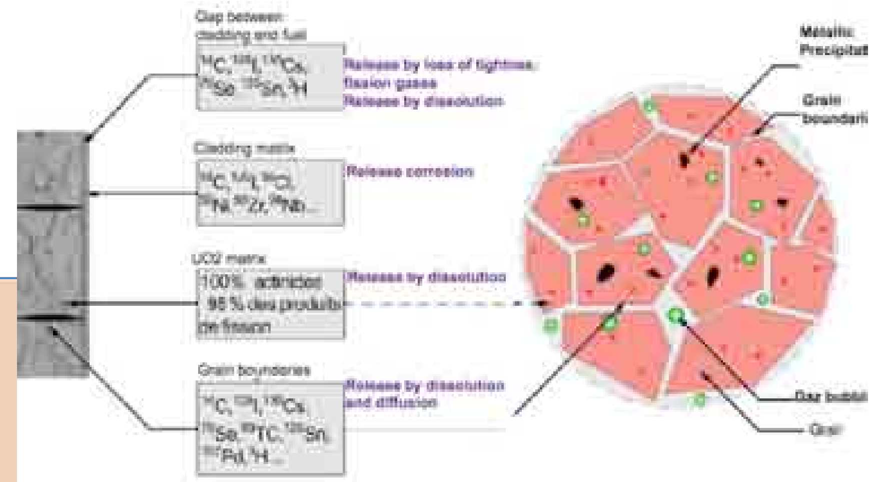
1850
Zr melts

Around 1000
Cladding changes (α to β, ΔV>0) and explodes
Fuel is leached (UO_2/H_2O)

FP (I,Cs) release

800 to 1200
Zr is oxidised
$Zr + H_2O_{liq, vap} = ZrO_2 + H_2$

H_2 release

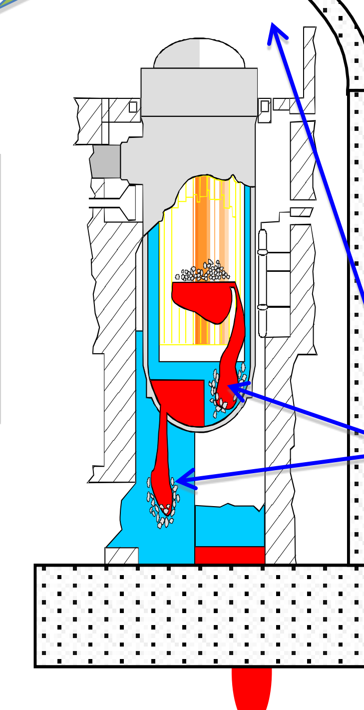


Core vessel and primary coolant system

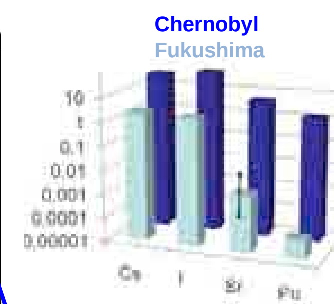
Radiolysis H_2 and oxydants products release

Possible release of Radionuclides

Possible release of Radionuclides

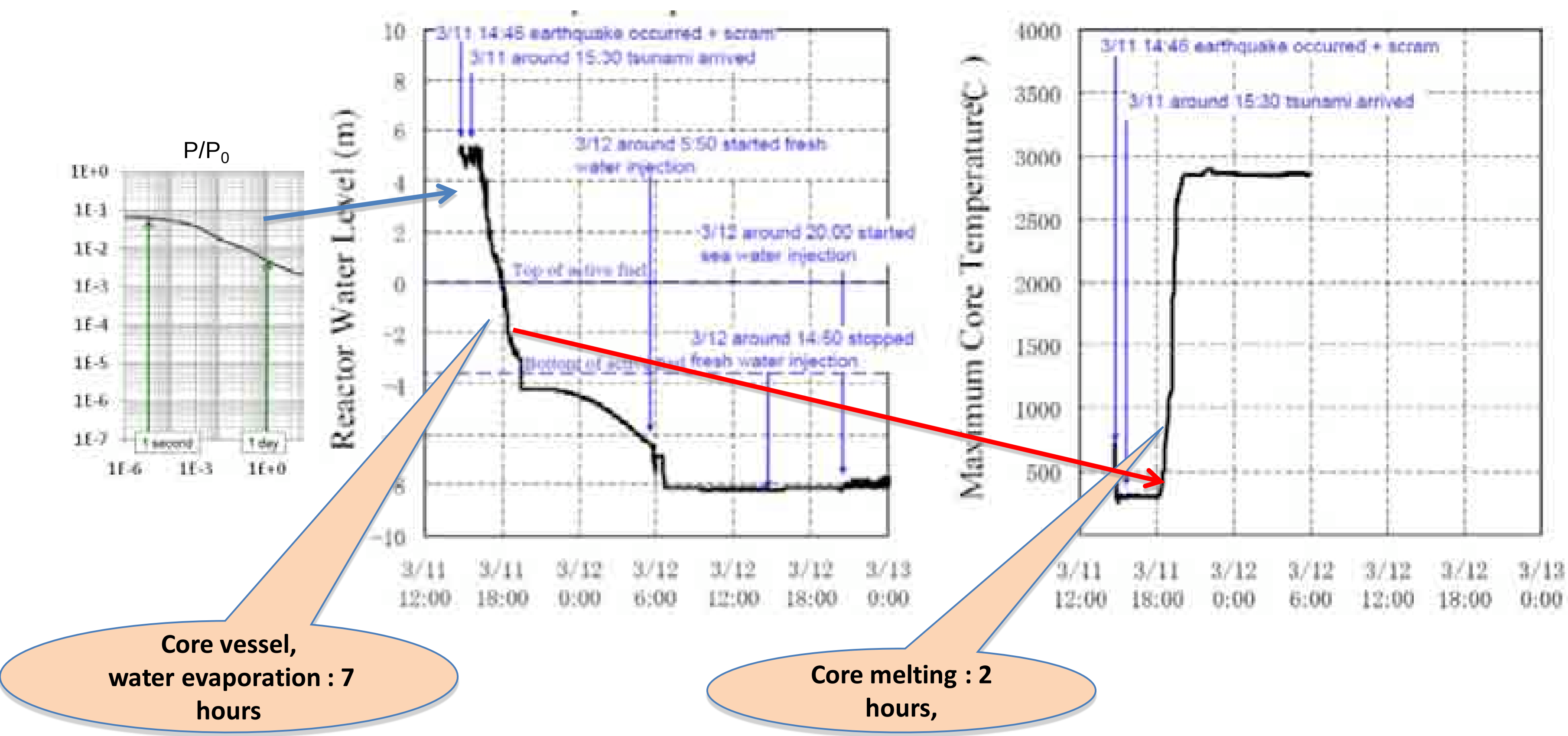


Possible explosions
$H_2 + O_2$ or
ΔP of H_2O_{vap}



The Fukushima accident has confirmed what was known about the behaviour of non-cooled nuclear fuel and has given the kinetics of the irreversible processes that can occur

Analyse of Tepco from 15 Mai 2011



Each accident boosts the research in the field of safety because it brings to light new scientific and societal phenomenons

Fukushima accident has shown in addition (1):

That independent events with very low probability can occur quasi simultaneously. The challenge is to re-examine the "SCA methodology" to take into account these events as potentials initiators of a serious accident.

The difficulties to cool the nuclear fuel (nuclear core and pools). The challenges are to assure additional indoor and outdoor water reserves (improvement of defence in deep), to limit the quantities of fuel sub-assemblies in reactors pools, and to consider a containment system for potential radioactive emission from these facilities.

That radwaste production, including contaminated water, can be important and if so a major societal problem . The challenge is to manage quickly these wastes avoiding dissemination of radioactivity and to decontaminate water for recycling.

The difficulties to control chemical hazards (explosions of H_2 or H_2O vapour). The challenge is to install large capacities for management of H_2 (passive recombination) and to control the cooling of corium.

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Fukushima accident has shown in addition (2):

That the emission of radioactive substances to local environment can last a long time, without the dilution that occurs in the case of long distance transportation. The challenge is to model the local/short distance transport/deposition of radionuclides.

The necessity to decontaminate large areas allowing a quick come back of population. The challenge is to find methods without dispersion of radioactivity in another places.

Fukushima accident has shown new phenomenons :

Hot fuel/water reaction

Corium/water reaction

Radiolysis of H_2O at very high temperature

Fukushima accident has led to some questions:

Question on the validity of the probability of severe nuclear accident : core melting (without or with dispersion of radioactivity) is above the probabilities estimations (10^{-4} by reactor and by year)

Questions on the safety of nuclear energy

Question about transparency and credibility of information.

Question about authority's decisions to manage accident

Instant release, instant leaching of volatil FP (I, Cs,..) in % of fuel inventory

Hot UO_2 + H_2O Aq, vap → Few to few tens %

Zr $_{melt}$ + UO_2 + M(Fe sub-assemblies) + MX (control roads) + .. = Corium → Few %

Cor stoichiometry depends on redox, T, damage, BU, ..

Hot UO_{2+x} + H_2O Aq, vap →

Release
Few % (up to 2,5)

Leaching
Few tens % (up to 35)

TMI, x = 0,14, Phébus PF x = 0,23 to 0,42,
U^{4+} U^{6+} Zr, Fe, Cr, ε Nd, Pu, Ce.
For x = 0,25 oxide is U_4O_9 (3 UO_2, UO_3).

Inventory, t = 0

UOX, 3,5 % en ^{235}U, 35 GWdt^{-1}

^{131}I, 8 d , 8,25 g/t, 4 10^{16} Bq/t

^{134}Cs, 2 y, 0,649 g/t, 2 10^{15} Bq/t
^{137}Cs, 30 y, 1280 g/t, 4,2$10^{15}$ Bq/t

Opportunities

Fukushima does not ask to call into question NSS but it calls first to apply NSS with an increased rigor and then to improve" some standards".

Fukushima gives the opportunities to :

Increase the pool of national/international independent experts

Connect the national safety organisations to enhance and share expertise (2010 IAEA proposition)

Increase the credibility of SCA and make it comprehensible and known to the public

Check the capacity of reactors to resist to non-considered events at the conception

Give high priority and supports to basic, applied and technological researches in nuclear safety, merging both operators, specific safety organisations and academic research organisations.

Researches

Boost the research on the occurrence probability of natural and anthropic events

Boost basic and applied research on radiology : 1) radiobiological effects of low doses (re-foundation of the LNT, Linear Non Threshold relationship), 2) effects of chronic low doses (insufficient knowledge), 3) dose limits for intervention and/or evacuation (harmonization of practises) and iodine distribution

Boost the research to manage accident remediation : 1) rapid and complete characterisation of the contamination of soils (species and radiation measurement), 2) rapid and complete characterisation of contamination of living materials (dose evaluation for people) 3) large reduction of the contamination of soils (protocols and measurements must be defined on a common basis), 4) behaviour of I and Cs in recycled materials, 5) set up of a crisis epidemiology (sort out and follow up of exposed people).

Boost the research for current reactors particularly considering potential « extended lives » : 1) ageing of components (nuclear vessel, cables systems), 2) prevention of chemical hazards, 3) viability of systems, 4) human and organisational factors,

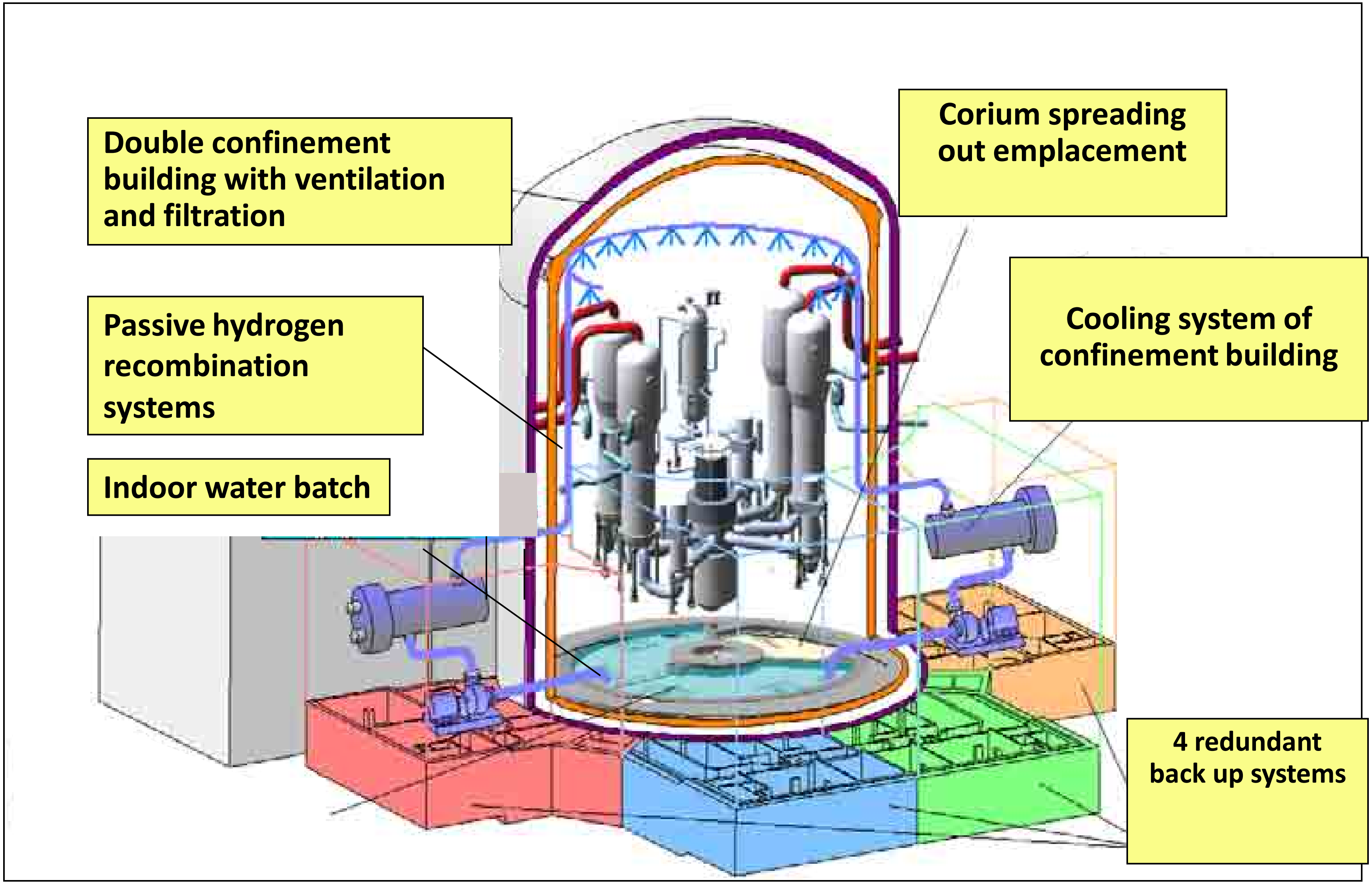
Boost basic and technological research on severe accidents

Basic research : 1) fuel behaviour at high temperature and corium formation 2) physicochemical properties of PF and TU (volatilisation, lixiviation from fuel - UO_2- and corium - UO_{2+x}), 3) transport of radionuclides (vessel core reactor, primary loop, containment building, environment) 3) model the dispersion of radionuclides in near and far field according to weather forecast

Technological research : 1) loose of cooling and insertion of reactivity (cladding oxidation and hydruration, sub-assemblies behaviour) 2) behaviour of corium against steel, water and concrete (inside and outside the vessel core reactor)

Boost innovative researches : new materials, new cladding, new fuels, wireless transmission of measurements, removed control of reactor operations, …sarcophage safety, …

Typical Generation III reactor



Conclusion

International community must call to :

Increase the role of IAEA

Enhance co-operations : crossed glances on nuclear safety enhance detection of failures

Apply common Nuclear Safety Standards and Basic Safety Standards (and enhance them), be careful to NSS or BSS based on consensus

Base « Safety Case Analysis » on a scientific approach in addition to the respect of regulations

Give heavy supports to boost the research in Nuclear Safety

LES RECHERCHES ACTUELLES SUR LES ACCIDENTS DE PERTE DE REFROIDISSEMENT