Special Invited Talk

Radiation Shielding and its Interfaces : A Multidisciplinary Perspective

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Mr Chairman, Ladies and Gentlemen,

It is a great honour to be invited to give a speech in the closing session of this Conference.

It is a hard challenge to talk to you of « Radiation Shielding and its interfaces : a Multidisciplinary perspective ». However, not being myself a « true » shielding specialist, but having being involved in many of these « interfaces », I found the challenge a risky one, but also very interesting.

But, where to start ? Should I take a literary start and quote from the Master of Go of Kawabata Yasunari, when he writes at a climax of the game between the Master and his opponent Otaké, that « The Master shielded his « eyes » by playing White 122 in response to Black 121 » ... Was it the opening for a new perspective on « shielding » ? Unable to give an answer, I preferred instead to do a more modest historical homework and to go back to May 1983, at the closing session of the 6th ICRS, in Tokyo at that time.

And let me quote now from J. Butler closing address. He did emphasise that « During these years we have seen the remarkable development of shielding as a scientific discipline ... Shield designers are involved in a variety of multidisciplinary tasks concerned with the transport of activity in circuits and the atmosphere, optimisation studies ... prediction of fluence in pressure vessels ».

He went on by saying : « In the fields of medicine, manufacturing industry, and mineral exploitation ... the shielding practitioners are called in to design a whole range of diagnostic and process-control devices involving the use of accelerators or radioactive isotopes ».

That statement by J. Butler is even more applicable today. Shielding is a discipline which plays a crucial role at many cross-roads, some of them of an « historical » or « traditional » nature, some of them being of a rather new type.

Let me start with the field of accelerators and intense neutron sources. This is not, strictly speaking a « new » field, but its growing relevance has been underlined by the large number of papers at this conference and at the parallel series of the « SATIF » conferences.

Intense neutron source projects (SNS, ESS), based on spallation of high energy protons, are a challenging new field, and it is instructive to learn how much care and effort has been put in dealing with the shielding aspects at a successfully operating installation, like SINQ in the Paul Scherrer Institute in Switzerland (**Fig. 1**).

Shielding of heavy ion, proton or high energy electron accelerators is an area of extensive studies, both theoretical and experimental. Some of the present hypothesis on the beam characteristics, such as the beam losses related to halo phenomena, in the case of a high intensity proton beam, with $E_p \sim 0.5 \div 1$ GeV, and $i_p \sim 20 \div 40$ mA, lead to a relatively low

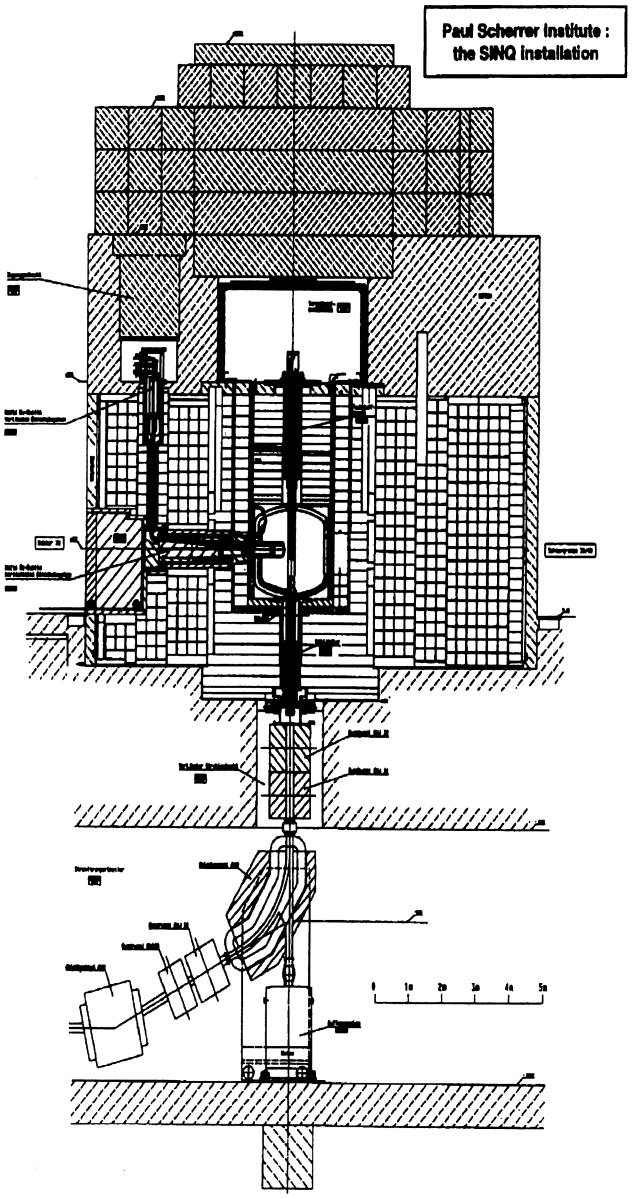

Figure 1

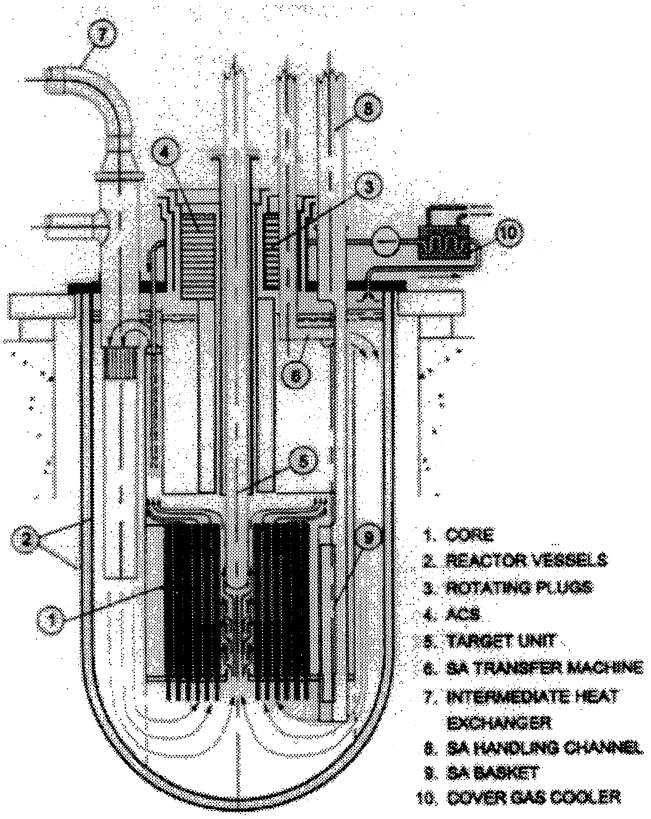

Fig. 2 Reactor System Assembly - Simplified Mechanical Scheme

loss rate of e.g. 1.2×10^8 protons/proton/metre. But this already requires a careful evaluation of biological shielding, of accelerator activation and heating, leading for example to maximum component lifetime considerations.

Little has been said at this Conference of the potential new field of Accelerator Driven Systems.

The coupling of the three major components of these systems, namely a proton accelerator, a spallation target and a subcritical reactor, as it is shown in most of the proposed designs, indicates potential severe problems, related to neutron streaming through the central cavity and high energy neutron attenuation through core and shielding structures (see **Fig. 2**). Without being a potential « show stopper », the shielding of ADS needs more attention, and probably sophisticated ad-hoc experiments to validate methods and data.

It has been remarkable during these days the interest shown for skyshine phenomena, with some delicate problems pointed out due to the evolution of doses at site boundaries, or the appropriate estimation of high energy secondary γ-sources, and it is evident the relevance of experiments such as those performed in Kazakhstan using two special purpose research reactors.

I turn now to the interface shielding/environment, in particular in the field of waste management.

Long term radiation effects within the engineered barrier system (EBS) of a HLW geological disposal are becoming a topic which needs detailed investigation. More studies of this type will certainly be performed in future, with the establishment of new underground laboratories, as it is the case in France now.

A specific field of interest is the impact of the so-called partitioning and transmutation (P/T) strategies on the fuel cycle installations, little discussed at this conference. These strategies are examined (in particular in Japon and Europe), to assess their potential in order to reduce the burden on the requirements for a deep geological storage.

Few studies have been devoted up to now to the relevant effect that have to be expected at the fabrication and at reprocessing of fuels and targets heavily loaded with Minor Actinides. The increase of doses and activities can become a significant liability for these strategies, and shielding specialists will have a relevant role in their assessment (see **Fig. 3**).

In the field of « source inventory », the paper presented by Swiss specialists, underlines the strong correlation between topography and meteorology and their impact on modelling of accidental atmospheric releases. Also these type of studies could become more popular in future.

In fact, shielding studies will become probably a significant part of the sustainability assessment of the nuclear option.

In the area of pressure vessel fluence and doses evaluation,

As an example, in the case of a heterogeneous recycling of MA (Am + Cm) targets, the impact on the fabrication and reprocessing are significant :

Impact on fabrication and reprocessing of (Am+Cm) targets, expressed as multiplying factor with respect to the fabrication and reprocessing of a standard, high burn-up, fast reactor fuel (EFR-type)

	Fabrication of a (Am+Cm) target	**Reprocessing of targets irradiated up to 90 % fission rate**
Specific power	× 32	× 32
γ dose	× 2500	÷ 3.5
Neutron source	× 840	× 10 ÷ 20

Fig. 3 Consequences on the fuel cycle of partitioning/transmutaion

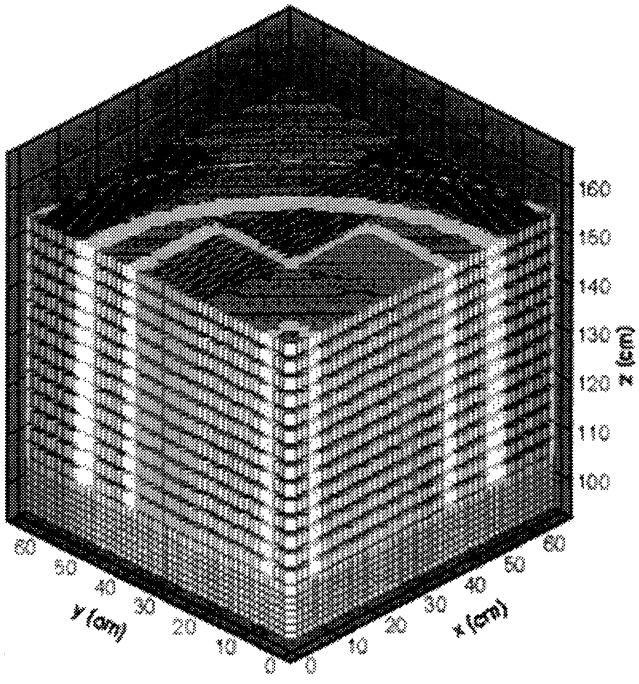

Fig. 4 Mesh distribution for the VENUS-3 model

the interaction of shielding analysis, plant designers and material scientists, is a well established reality. Work performed both on the analytical and experimental side, using existing power reactors, have been reported by Russian, Korean and French specialists, underlining the degree of maturity of the experimental and analytical tools, in order to provide relevant information, to be used in plant lifetime extension assessments.

The best example of the relevance of the international collaboration in this field, is the series of experimental benchmarks and analysis organised by the Nuclear Energy Agency on the VENUS experiments performed in Belgium. The predictive power of the current data and calculation tools has progressed in a spectacular manner, as it was demonstrated at this Conference (**Fig. 4**).

Closely linked, but not limited to the pressure vessel radiation fluence evaluation, is the problem of the radiation induced material damages, which has been a constant worry for shielding designers. A new area of research in this field, is represented by the damage induced by protons and high energy (E > 20 MeV) neutrons in the structures of intense neutron sources and accelerator driven systems.

This brings me to the classical interface with nuclear physics, and in particular with nuclear data. I will quote only three examples to underline the extent of interface research in this field. First, there is the extension of evaluated nuclear data libraries from 20 MeV to approximately 200 MeV, which allow to better predict high energy neutron transport problems, which can, once more, be representative of problems related to the design of intense neutron sources or ADS (see **Fig. 5**). Second, there is the continuous requirement of variance-covariance data, to be associated to the powerful sensitivity analysis tools, that have been developed within both Monte Carlo and deterministic transport codes. This need was already expressed e.g. in the previously mentioned closing speech at Tokyo 1983 by J. Butler. The fact that this need is still far from being fulfilled, is an indication of the alarming reduction of international efforts in the nuclear data field. Recent signs of some revival (e.g. the proposal of a new installation, called neutron TOF, at CERN-Geneva for high resolution cross-section measurements) are extremely welcome in this respect.

The third example is the experimental work still being

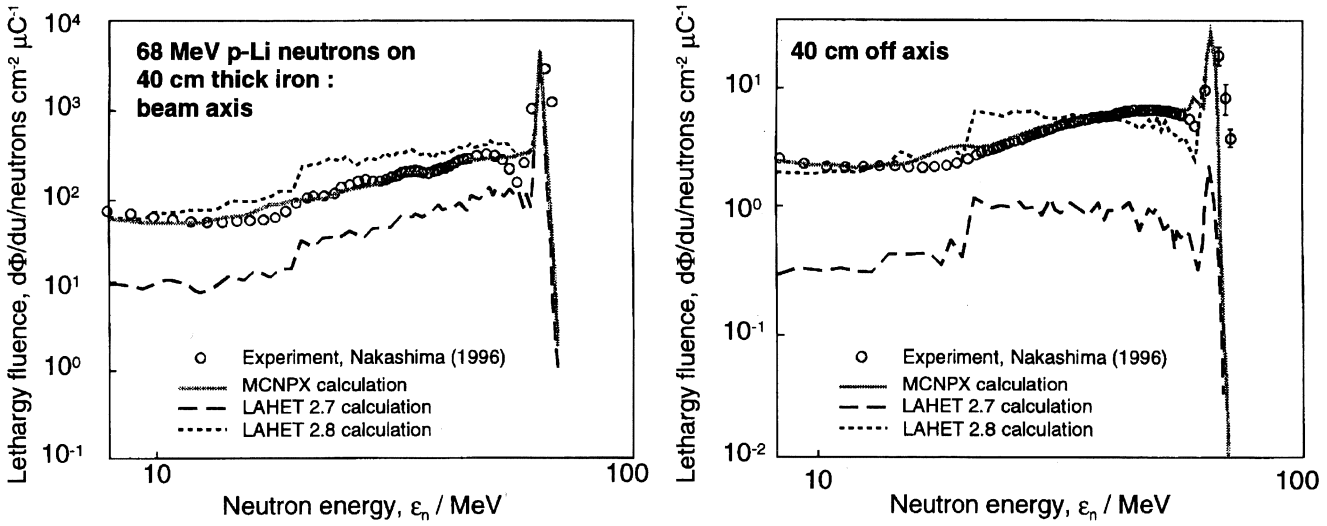

Fig. 5 Comparison of MCNPX calculations of neutron transmission through 40 cm of iron with measurements of Nakashima et al. The neutron source was generated via the 68-MeV ^{7}Li(p,n) reaction. Results are shown for neutron transmission on axis, and 40 cm off axis. Calculations from two versions of the LAHET-MCNP code system are also shown.
From M. B. Chadwick et al., Nucl. Sci. Eng. 131, 293 (1999)

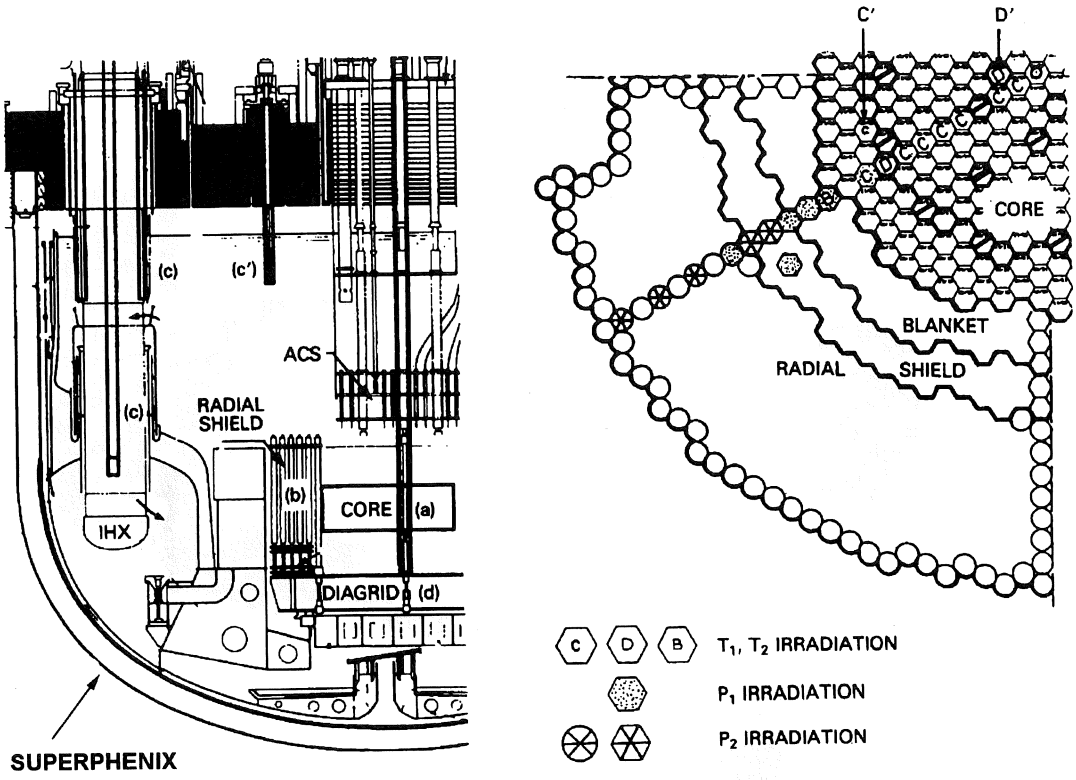

Fig. 6 In-vessel measurement points and loading of experimental subassemblies for foil irradiation at star-up

performed in order to improve fission yield data, to make more complete and reliable data libraries, which should help the work of shielding specialists in the assessment of neutron sources, including the case of high burn-up fuels or even in the frame of the assessment of potential future cycles, like the Thorium cycle.

Of course, the most well known interface is the one with applied mathematics. In this area it has been traditional to watch for progress both in the field of Monte Carlo and in the field of deterministic methods. This conference has been no exception. Monte Carlo methods are widely used, but still improved, in terms of acceleration/biasing techniques. Examples are the powerful importance - based method to reduce variance in MC BEND (and the more extensive use of adjoint Monte Carlo), and also the « non-analog » simulations introduced in the TRIPOLI code.

A very significant initiative to promote Monte Carlo methods has been reported, namely the « Research Committee on Particle Simulation with the MC method », established in 1999 by the Atomic Energy Society of Japan, which is hardly surprising in view of the extent and of the quality of the activities performed in this field in Japan.

Three-dimensional deterministic methods (including finite elements) are today well established and they are competing very well, their use and reliability having been much improved in recent years.

Since the solution of tough streaming problems is still the measure of the power of a shielding calculation tool, the results of the recent benchmark organised by the NEA, the so-called Kobayashi benchmark, are of high relevance in order to provide confidence in the capabilities of 3-D deterministic methods and offer some hints for a better use of advanced computing systems.

Personally, I found also fascinating the revival of the « old » build-up factors methods, where we used to concentrate all our art and understanding of the physics processes during particle transport in complexe media. Maybe it's time to re-edit the old good Rockwell book, with some outstanding updated appendix !

I kept my final remarks to deal with experiments and experimental techniques. At this conference several relevant experiments have been reported. I will mention here only three categories. First, there was a strong effort to present a consistent picture of the experiments performed at zero-power at start up of the MONJU reactor. These experiments, together with those performed at SUPERPHENIX (see **Fig. 6**), represent an invaluable database for liquid metal cooled fast reactors, which should be carefully preserved and possibly documented in a common manner. Whatever will be the future for Fast Reactors and whatever will be the result of the present investigations of alternative coolants (lead alloys, gas), the MONJU and SUPERPHENIX data, will stay essential to optimise and assess future shielding concepts.

Second, I will quote the analytical experiments performed at the TIARA facility in this country, which provide basic information in the field of high energy neutron transport. We should put our imagination at work, in order to extend these experiments to higher neutron energies and to develop powerful and accurate detectors.

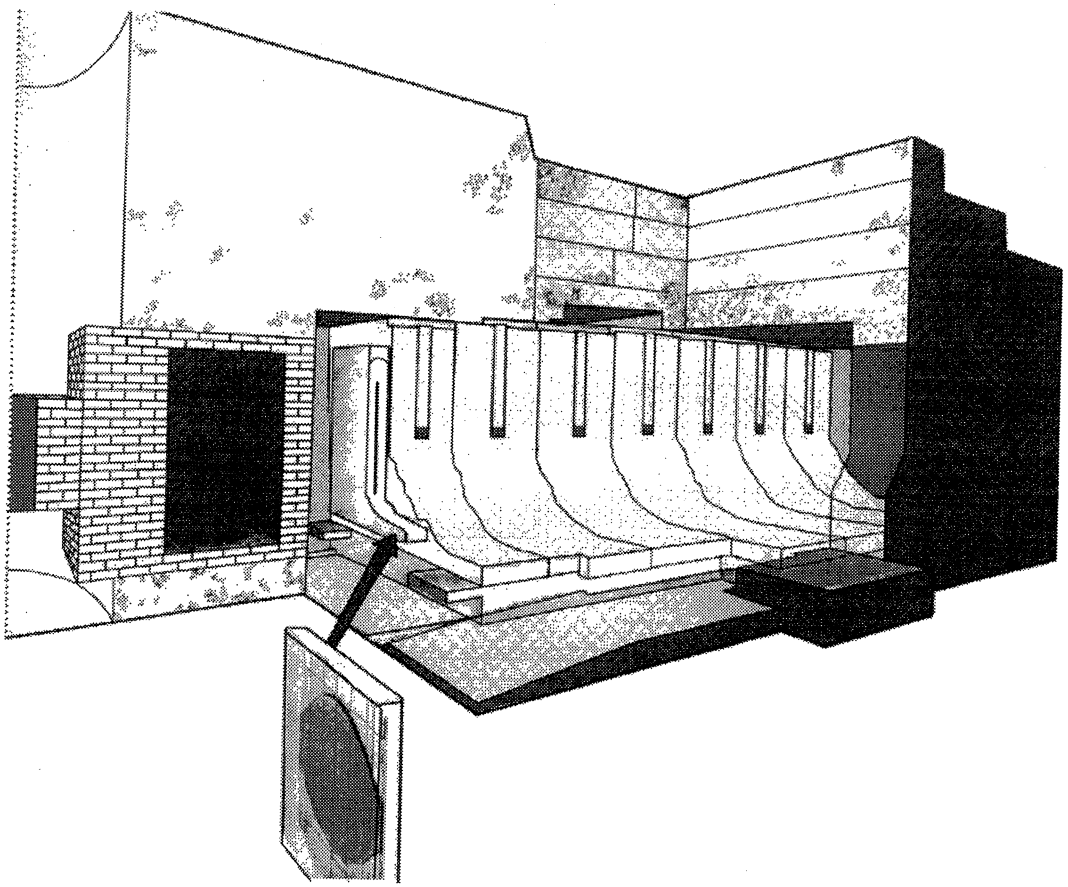

Fig. 7 3D view of the EURACOS2 sodium experiment as stored in SINBAD

Finally, it is clear that streaming experiments, such as those performed in support of fusion machine design, still provide much needed data in order to validate methods. The use of sophisticated instrumentation will help in that task.

It is of course difficult to tackle the problem of the possible need for future experiments. In other areas (like criticality - safety) the need for future experiments is discussed in the frame of international cooperations (once more under the sponsorship of OECD-NEA), in order to optimise resources and to provide better arguments in order to establish cost/benefit assessments.

An international initiative in this field could be valuable and could be a matter for discussion in the frame, e.g. of the Nuclear Science Committee of NEA.

This committee has been active in providing the frame to build-up an integral experiment data base (SINBAD) described at this Conference (see **Fig. 7**), which provides a unique tool in order to preserve valuable knowledge in an effective way. To set up a data base has been a big step forward in the right direction, in particular if it deals with « experimental » data. However, there are still efforts to be devoted both to keep it as a « living » initiative, and to enlarge it to other valuable experiments, which could be lost with declining resources of individual laboratories.

These databases can be used also to preserve knowledge related to experimental techniques and their accuracy.

The bottom line is that, in view of its multidisciplinarity and wide range of challenges, shielding as a scientific discipline needs and benefits from an international environment. The best example is this very Conference and its outstanding program, put together by our hosts, to whom we are grateful to have provided to us such an exciting and enjoyable week.

Now, should I dare to go back to the future ? Can we spell out certainties, should we dare to make projections ?

Instead, I think that is better for me to stop here and quote once more from my literary souvenirs. It was Kenko Yoshida, who wrote early in his « Essays on Idleness » (Tsurezuregusa) : « The most precious thing in life is its uncertainty » !