Excellence-Spreading Activities in SARNET

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An important part of the European network project SARNET are the Excellence Spreading Activities. The principal objective of these activities is the dissemination of the knowledge and excellence already achieved, or being achieved in the research performed in the network. These activities also promote the management of knowledge in the area of severe accidents (SA) in LWRs.

The Excellence spreading activities currently pursued are:

- conduct courses on severe accident phenomenology and probabilistic safety analysis (PSA)
- publish course lecture notes
- prepare a text book on severe accident safety in LWRs
- conduct a mobility program for students and researchers for training, and for performing collaborative research.

The courses are designed to provide knowledge and insight to the students, researchers and the personnel in plants and safety organisations so that they understand how to analyse, prevent and manage severe accidents. The course attendees receive not only copies of the presentations but also lecture notes for use in their professional work. The text book will document the most pertinent and important knowledge-base on severe accidents, accumulated so far, in the form of a consistent and logical educational vehicle for students and researchers in this area. The mobility program financially supports the temporary (3to 6 months) movement of students and researchers from their native surroundings to laboratories and universities in other countries, in order to obtain training and to perform collaborative research.

In the 2005-2007 year of SARNET, two courses were conducted, a set of lecture notes were prepared and 19 students and researchers were delegated to other laboratories and universities. Most of the mobility actions involved persons moving from Eastern Europe to laboratories and universities in Western Europe. Another course is planned for presentation in early 2008.

A new initiative contemplated in the 4th year of SARNET is to disseminate the results achieved in the research conducted by the network in its first 3 years to the pertinent staff of the utility companies and the regulatory organisations. This will be accomplished through information letters/brochures.

A. Introduction

The Excellence-Sprerading Program in SARNET is now 3 years old. This program is funded at a relatively low level but it is a veritable pillar of the SARNET network of excellence, since its main objectives are (1) to preserve, nurture and disseminate knowledge that has been gained over the years in the light water reactor (LWR) severe accident phenomenology, methodology and practice, and (2) to educate and train young researchers and students so that there is a cadre of trained persons who can continue to maintain and improve the high standards of safety of nuclear power plants that have been achieved in the last 20 years of their operation throughout the World.

Consistent with the objectives outlined above, the excellence-spreading program is divided into three major activities, i.e. (a) the preservation and nurturing of knowledge through the development of a text book embodying what has been learnt so far about the LWR severe accidents (SA) since the TMI-2 accident, (b) the education of the young researchers and students through the conduct of annual courses, providing both the presentation material and the lecture notes in text format , and (c) the training of young researchers and students through actual hands-on research work in the various experimental and analysis development projects that are being conducted in the SARNET network. The last involves the mobility of researchers and students from their own institutions (research centers, universities) to those of the other partners for periods of a few weeks to several months. The young researchers and students go through a mentoring process during their delegation period and they acquire new knowledge from experts. Progress achieved in each of these activities will be described in some detail in the following paragraphs.

B. Development of the Text Book

The text book has been entitled “Light Water Reactor Severe Accident Safety”. The rationale for writing of a text book instead of a source book, was explained in the paper presented at the last ERMSAR meeting. A book outline was also presented in the same paper. The book follows the severe accident scenario. There is a long chapter on a historical review of LWR safety, which provides an overall perspective for the young researchers and students starting to learn the subject of reactor safety. The book length is expected to be 400 pages.

The first lecture course, which was organized in January 2006 was structured to follow the various phases in the progression of a severe accident scenario, e.g. the early in-vessel, the late in-vessel, the ex-vessel with bifurcation into the processes like steam explosion, direct containment heating and hydrogen combustion/detonation, which may cause early failure of the containment and the processes like melt/debris coolability and core-concrete interaction, which may cause late containment failure. Additional to the lectures on these topics were those on source term, probabilistic safety assessment, issue resolution and new designs. The lecturers were requested to write lecture notes on each of the topics, they individually lectured. The exercise of writing the lecture notes served as a practice run for the writing of the text book.

The lecture notes have been written, edited and compiled for distribution as a report, which is being published presently under the kind auspices of the CEA. A CD-rom is being distributed to the participants of this meeting. The lecture notes can not serve as a text book, since the latter has to be highly comprehensive and of the highest quality. Some topics were not covered in the lectures or the lecture notes. These additional topics include, e.g. (1) the structural aspects of containment failure, (2) the description of the models for the various severe accident processes that have been incorporated in the codes presently employed for severe accident safety analyses and risk assessment, i.e. ASTEC, MELCOR and MAAP, (3) severe accident progression for BWRs and CANDUs, detailing their differences from PWRs, (4) the mechanistic models and codes for the detailed description of some of the severe accident processes, and (5) the anticipated transients without scram (ATWS), etc.

All of the additional topics have also been assigned to various experts for writing of the text book. The names of the contributions for all the topics in the book were shown at the last ERMSAR meeting. There have been a few changes, but essentially the list of topics covered in the book and the contributors assigned remains to be the same.

The current status for the book is that writing is proceeding on the various topics of the book. It was deemed efficient to appoint leaders for each major section of the severe accident phenomenology, e.g. in-vessel accident progression/ex-vessel accident progression, etc.

The leaders are responsible for organising the writing of the various subchapters and for ensuring a high quality contribution for each subchapter in a reasonably correct English language.

The schedule calls for the final draft of the book to be completed by January 2008 after an extensive editing and peer review process. This draft will be sent to a publisher, who may send it for further review by independent reviewers. The goal is to have the published book available by September 2008, which is, perhaps, the date for the completion of SARNET-1 network.

We believe that the book on LWR Severe Accident Safety will be a premiere product of the SARNET network since the instructions to the authors of the various subchapters have stressed that it is imperative that the book should be of very high quality and that it is not a consensus statement but a critical evaluation. Thus, the authors(s) of each subchapter should be the one(s) who is (are)

- most knowledgeable of literature on the subject
- critical in evaluation and comprehensive in approach
- knowledgeable of how his (their) part fits in the total picture of severe accident (SA) safety
- not advertising the research work he (they) or his (their) institution performed.

More than two co-authors for each subchapter were not advised. The authors could receive input from other persons and in particular from the section leader. The objective is to involve the main experts and to proceed in an expeditious manner.

C. Development of the Courses

Two courses have been conducted so far. The first course was focussed on students and young researchers, while the second was primarily focussed on the engineers working in the nuclear power industry, technical service organisations (TSOs) and the regulatory bodies. It was clear, however, that in both of these courses there was some mixture of the background of the attendees.

The first course labelled as the SA Phenomenology Course was held from January 9 to 13 in Cadarache, France and was kindly organised by CEA with coordination services provided by Mr. Pascal Piluso. The course was also sponsored by the European Nuclear Education Network (ENEN). It must be stated at the outset that the course organization was superb.

The course program is shown in Table 1, showing the lecture titles and the names of the lecturers, who are all from the SARNET partner organizations. As mentioned earlier, following a lecture on a historical review of LWR safety, there were lectures on the various phases during the progression of a severe accident scenario. An afternoon of lectures was provided on Source

Term. Additional topics of interest for SA safety: PSA, risk assessment, environmental impact, issue resolution, and severe accident management (SAM) and mitigation were covered in reasonable detail. The severe accident mitigation designs of the Generation 3+ reactors, i.e. the in-vessel melt retention, as practised in the AP-1000 reactor and the ex-vessel retention of core melt as practised in the EPR resulting from a severe accident scenario, were described in 2 lectures. The ASTEC Code, which is another premiere product of the SARNET network was described very briefly. The course also included a tour of the severe accident experimental facilities, PHEBUS, VULCANO, MAESTRO and EPICUR, which exist on the Cadarache site.

The January 2006 course was a very successful undertaking with 77 fee paying attendees, 10 attendees with EU scholarships and 15 lecturers A photograph of the participants is shown in Figure 1. The attendees came from 27 different countries with 63% from the 15 original EU countries, 12% from the 10 new member countries of EU, 5% from the accession countries and 20% from the rest of the World. There were 5 researchers from China, 4 from Pakistan, some from Russia, USA, Canada and other countries. The lecturers were from organisations belonging to the SARNET consortium. The attendees had a mixed background with 37% having less than one year of experience in severe accidents. The attendees were requested to grade the lecture material and the lecturers. A very highly favourable overall average of 3.49/4 was obtained. All the lectures, except for those on Issue Resolution and on SAM and mitigation received high marks from the course attendees.

The second course was also given at Cadarche, France and it was kindly organised by IRSN with J.M. Mattei and T. Albiol serving as the course coordinators. As mentioned earlier, this course was focussed on persons working in the nuclear industry, nuclear TSOs and the nuclear regulatory organisations. The attendees came from 6 European countries and from Canada and South Africa . the Canadians sent seven persons. The course was held from March 12th to 16th 2007. The distribution of the participants was as follows: 9 from nuclear utilities and vendors, 9 from safety authorities, 15 from TSOs and 5 from a research organisation (AECL in Canada). Most of the lecturers were from IRSN, the origins of the others were: 1 from SKI in Sweden, 6 from CEA and EDF in France, 2 from GRS and FZK in Germany, one from VTT in Finland and one from CIEMAT in Spain. Thus, there was a fairly good representation of European countries, both among the participants and the lecturers.

The course lecture program is shown in Table 2. it has been put in the same format as that for the first course to afford a comparison of the two courses. Abstracts were provided by most of the lecturers to the participants before the start of the course.

A significant change from the program of the first course is to include presentations on the Boling Water Reactor (BWR). The BWR core configuration is different from a PWR and the SA scenarios are also quite different. Lecturers from SKI Sweden and from GRS, Germany described the BWR system and showed how the severe accident proceeds in a BWR. The accident management actions practiced for the BWRs in Sweden were explained, e.g. the filling up of the dry-well in the BWR, as practiced in Sweden, makes the ex-vessel scenario very different from that of a PWR. The lecturers explained these differences. There was also a lecture on the available instrumentation systems in the various plants and a lecture was provided on the data and methodology uncertainties and their effect on the estimated consequences of severe accidents as calculated by the codes ASTEC, MELCOR and MAAP.

The second course was also very successful with 38 paying participants. The fee charged for the second course to an attendee was 2000 € from a non-SARNET organisation and 1000 €

from a SARNET organization. These fees were substantially higher than those charged for the first course. They are still less than the going rate for most of the educational courses scheduled every year by several organisations, e.g. CEA, ETH in Switzerland and others.

A third course is currently in the planning stage for holding it in the February-March 2008 time frame. This course is planned as a joint endeavour between the SARNET network and the OECD/NEA. The tentative title of the course is “Severe Accident Analysis, Applications and Management Guidelines”. This course will be focussed not only on the young researchers and students, but also on the persons working on severe accident in the nuclear industry, nuclear TSOs and the nuclear regulatory organisations. The philosophy and rationale of the course is explained in the following paragraphs.

The course objective is to teach the students and the young nuclear safety engineers, how to determine the consequences of severe accident scenarios for PWR and BWR plants through analysis with the codes developed for this purpose, i.e. ASTEC, MELCOR, and MAAP.
The consequence determination will be upto the point of source term, i.e. the magnitude and character [physical (liquid, aerosol), chemical (speciation)] of the fission products that (a) could leak from the containment and (b) could be released to the environment in the form of a large release in the event of a containment failure. The challenges to early failure of containment, i.e. DCH, Hydrogen, steam explosion, to late failure of containment, i.e. containment pressurization, basemat failure and to containment bypass, e.g. S.G. tube rupture will be identified. Most of these are not treated well by the codes.

The consequence determination is part of the PSA-2 effort in which the probabilities of various events (e.g. station black-out, loss of flow, complete loss of ECCS, etc.) are determined. These actually define the probability of a certain SA scenario. To determine the risk, the consequences have to be determined, and that is the main focus of this course.

Another focus of the course is severe accident management (SAM) and development of SAM guidelines (SAMG) that a utility company may follow and which are endorsed by the regulatory organisations in order to: a) prevent a severe accident from occurring, and b) mitigate its consequences if it ever occurs. In the context of (b), it should be stated that a SA has to be stabilized and terminated to assure the public that the consequences do not continue ad-infinitum. In this context there should be a possibility of evacuation, but for a short time.

The preventive measures for SAM are basically designed for those consequences of SA, which can lead to a large FP release, i.e. primarily due to the early failure of the containment. Thus, the following SAM measures are in the guidelines:

- ingniters for control of hydrogen in the US ice condenser and BWR MARK-3 plants
- passive catalytic recombiners for control of hydrogen in all European plants
- depressurization in all PWRs through PORVs to prevent a high pressure accident with its higher probability of the occurence of DCH.
- to avoid adding water to the cavities under the vessel for all German and French PWRs.

There are contrary opinions in some other countries about some of the above measures.

The SAMGs for mitigation of SA consequences in the event of a late failure of containment include those that stabilize and terminate the accident. Most important is to achieve coolability by adding water, which is not assured for current LWRs. In this context a reactor design may have to:

- spread the melt and cool as in EPR.
- achieve in-vessel retention as in AP-1000.
- provide a core-catcher as in the VVER-1000.

The current perspective of the SAM measures is to almost eliminate the risk of a severe accident and to not disrupt the life of the population near or far from a nuclear plant in which a SA has occurred. The projected regulations are tough and that is the reason for the large emphasis on the SAM measures.

D. The Mobility Program

As mentioned earlier, the objective of the mobility program is to train students and young researchers through actual hands-on research experience in the various experimental and analysis development activities that are being pursued by various partners in the SARNET network. It is also a ‘European Integration’ activity in severe accident education and research since the students and researchers trained under this program become the future links for collaboration between and among the different universities and research laboratories.

The program consists of (1) student summer internships and (2) research delegation at the laboratory of a SARNET partner. The financial grant provided by the SARNET network for the students is 1000€/month for upto 3 months and for a researcher 1500€/month for upto 6 months. Larger length delegations can also be funded if the delegation is for an extended research project. The researchers have to belong to the organisations in the SARNET network, however, the students can belong to any university in the country that is part of the SARNET network.

A procedure of application and approval has been established. The research to be conducted should be within the framework of the research that is being conducted in the SARNET network. The student training and studies should also be in the general framework of the work that is being performed by the partners in the SARNET network. The host organisation in collaboration with the delegating organisation agree on the work scope for the research or studies a delegate will pursue and the time period for the delegation. The SARNET topical coordinator has to agree that the workscope is of interest to SARNET. The application with the support documents is submitted to the coordinator for Excellence Spreading. After approval and transmittal to the SARNET coordinator, the mobility action can be started. The funding is provided to delegation organisation in case of a researcher delegation and to the host organisation in case of a student delegation.

The mobility program in the third year of SARNET had a better response than in the earlier years. There were a total of 12 mobility actions this year. This may be due to the urgings of the Excellence Spreading coordinator to obtain offers on the research and study topics and asking partners to find and encourage young persons to apply. It is clear however, that there is not a large pool of students and young researchers in our field and we can not hope to have a very large number of mobility actions. The mobility actions that took place in the year 2006-2007 are shown in the Table 3. This year a larger fraction of delegates are female engineers not only from the Eastern European and candidate countries going to Western European institutions but also from Spain. This is a good mark for SARNET. The early delegations were for quite short terms but the more recent ones are for terms of 6 to 8 months.

E. Dissemination of SARNET Research Results

SARNET network, being 3 years old has started to produce significant results, which should be disseminated to organisations, who would have an interest in these results. Such perspective organisations are the nuclear industry, the nuclear technical support organisations, the nuclear regulatory organisations and IAEA. An initiative contemplated in the fourth year of SARNET is to disseminate the results achieved in the research conducted by the network in its first three years to the pertinent staff of the above-mentioned organisations. This would be in the form of information letters/brochures, selected from the information posted on ACT and the SARNET website. We believe that this will provide greater visibility to the SARNET network.

F. Conclusions

The Excellence-spreading Program of the SARNET network has set itself the goals of preserving and disseminating the knowledge about severe accidents and to educate and train young researchers and students. The knowledge-preservation through the writing of a text book is of special importance since it will be a legacy, which can be updated periodically. It will serve as a vehicle for the education of students and as a reference text for the researchers, who will be increasingly attracted to the nuclear energy field in Europe. It is becoming increasingly clear to this author that nuclear energy will have a resurgence in an increasingly near future.

Figure 1

Severe Accident Phenomenology Course; Jan 9-13, 2006, Cadarache **Table 1**

Monday, Jan 9	**Tuesday, Jan 10**	**Wednesday, Jan 11**	**Thursday, Jan 12**	**Friday, Jan 13**
9:00-10:00 **Registration – Coffee** 10:00 –10h20 **Opening** *J.C. Bouchter (CEA)* *JC Micaelli (IRSN)* 10:20 –12h20 **Introduction** • SARNET • ASTEC • Defence in depth • WASH-1400 study • TMI-2 • Chernobyl • Classification of accidents *B.R. Sehgal (KTH)*	9:00-11:00 **Late In Vessel** • Focusing effect • External cooling • Gap cooling • Vessel failure *C. Mueller (GRS)* 11:20-12:20 **Early containment failure DCH** *Leo Meyer (FZK)* 11:00-11:20 **Coffee Break**	9:00- 12:20 **Ex Vessel** • Spreading • MCCI and basemat behaviour • Ex vessel FP and gas release • Coolability *C. Journeau (CEA)* *H. Alsmeyer (FZK)* 11:00-11:20 **Coffee Break**	9:00- 12:20 **Safety assessment** • PSA Level 1,2: Principles and overview of pratices • Risk informed Analysis • Issue Resolution • Environmental impact and human health risk *B.R. Sehgal (KTH)* *Ming ANG (NNC).* *I.Ivanov (TUS)* 11:00-11:20 **Coffee Break**	8:30-10:00 **SAM and mitigation** • Procedures, guides, emergency planning • Passive and active systems • Existing plants, New designs • Generations II, III, *T. Daguse (EDF)* 10:30-12:00 **In Vessel Retention** VVER-440, AP-1000 Passive plants *B.R. Sehgal (KTH)* 10:15-10:30 **Coffee Break**
12:20-14:00 **Lunch**	12:20-14:00 **Lunch**	12:20-14:00 **Lunch**	12:20-14:00 **Lunch**	12:00-13:30 **Lunch**
14:00 – 17:30 **In Vessel** • Fuel degradation and reflooding • H2 production • FP release from core • In vessel progression • Reactors/scenarios *F Fichot (IRSN)* *K. Trambauer (GRS)* 15:30-16:00 **Break**	14:20-15:40 **Hydrogen** • H_2 risk • H_2 distribution in the containment • H_2 mitigation *W. Breitung (FZK)* 16:10-17:40 **Steam explosion** *D. Magallon (JRC)* 15:40-16:10 **Break**	14:00-17:30 **Source Term** • Transport in primary system/ containment, containment bypass • Chemistry effects (Iodine, Ru) • FP mitigation (sump, spray, filters) *B. Clement (IRSN)* *C. Housiadas (DEM)* 15:40-16:10 **Break**	14:00-17:30 **Visits** • MAESTRO,EPICUR (IRSN) • PLINIUS platform (CEA) • PHEBUS facility (to be confirmed) *P. Piluso (CEA)*	13 :30-15 :00 **Ex Vessel Retention** EPR, VVER-1000 *C. Journeau (CEA)* 15 :00-15 :40 **ASTEC-DEMO** *J.P. van Dorsselaere (IRSN)* 15:40-16:15 **Feedback-Conclusion** 15:00-15:40 **Break**

Severe Accident Phenomenology Course; March 12-16, 2007, Cadarache Table 2

Monday, March 12	Tuesday, March 13	Wednesday, March 14	Thursday, March 15	Friday, March 16
9.30-10.15 **Opening** *T. Albiol (IRSN)* *J.M Mattei (IRSN)* 10.15-10.45 • **Core melt progression** *G. Cenerino* 10.45-11.00 Coffee Break 11.00-13.00 • **Sequences with potential early release** *F. Goux*	9.00-9.30 • **General PWR Design** *A.D. Chamberdel* 9.30-1030 • **Plant Design and Severe Accident Progression** *A.D. Chamberdel* *G. Nahas* 10.30-10.45 Coffee Break 10.45-11.45 • **Procedures, Recovery and PSA-2 for PWR** *A.D. Chamberdel*	9.00-9.30 • **General BWR Design** *L. Agrenius* 9.30-1030 • **Plant Design and severe Accident Progression** *L. Agrenius* 10.30-10.45 Coffee Break 10.45-11.45 • **Procedures, Recovery and PSA-2 for BWR** *L. Agrenius* *H. Loffler*	9.00-11.00 • **Vessel failure** • **Debris coolability for PWR** *C. Journeau* 11.00-11.15 Coffee Break 11.15-12.15 • **Ex-vessel progression for BWR** *L. Agrenius*	9.00-10.00 • **Containment behaviour** *W. Plumecocq* 10.00-11.00 Coffee Break 11.15-13.15 • **Fission product transport in containment** *L. Herranz* *A. Auvinen* *B. Clement*
13.00-14.30 Lunch	13.00-14.30 Lunch	13.00-14.30 Lunch	12.15-13.45 Lunch	13.15-14.45 Lunch
14.30-16.00 • **Progression of a severe accident** *C. Seropian* 16.00-16.15 Coffee Break 16.15-17.45 • **Models** *JP Van Dorsselaere*	14.30-17.30 • **Visit of Phebus and International Source Term Program facilities**	14.30-18.30 • **Severe Accident Phenomenology** • **Core degradation** • **H_2 generation** • **DCH** • **Induced primary breaks** *J.M. Seiler* *F.Fichot* *L.Meyer* *G. Cenerino*	13.45-14.45 • **Konvoi PWR and BWR** *H. Loffler* 14.45-15.45 • **Basemat penetration** *M. Cranga* 16.00-17-00 • **Steam explosion** *D. Magallon* 17.00-18.00 • **H_2 Mitigation** *J.C. Sabroux*	14.45-15.45 • **Uncertainties and conclusions** *B. Clement* 15.45-16.00 Coffee Break 16.00-17.00 • **Participants' advice and wishes** *P. Richard*

MOBILITIES IN 2006-2007

Table 3

Name	Type	Research Area	Organisation	Host organisation	Duration months
Stanislava Stubnova	R	ASTEC	UJD Slovakia	IRSN	3
Boryana Atanasova	R	ASTEC	INRNE, Bulgaria	IRSN	3
Antoneta Stefanova	R	CORIUM	INRNE, Bulgaria	FZK Quench Facility	2
Nora Ver	R	CORIUM	KFKI, Hungary	FZK, Quench Facility	3
Polina Tusheva	Ph.D.	ASTEC	TUS, Bulgaria	GRS	2
Andrea Bachrata	M.S.	CORIUM	CTU Czech Republic	KTH	2
Katarina Meciarova	M.S.	ST	Comenius. U. Slovakia	IRSN	1
Dimiter Popov	Ph.D.	CORIUM	TUS and Kozloduoy NPP, Bulgaria	KTH	3
Matteo Bucci	Ph.D.	Containment (hydrogen)	Univ. of Pisa, Italy	Saclay, CEA	8
Carlos Montenegro-Palermos	Ph.D.	ASTEC	UPM, Spain	IRSN	6
Cristina Ibanez-Lllano	Ph.D.	PSA-2	CSN. Spain	CEA	6
Berno Simon	M.Sc.	CORIUM	TU, Aaachen, Germany	KTH	4