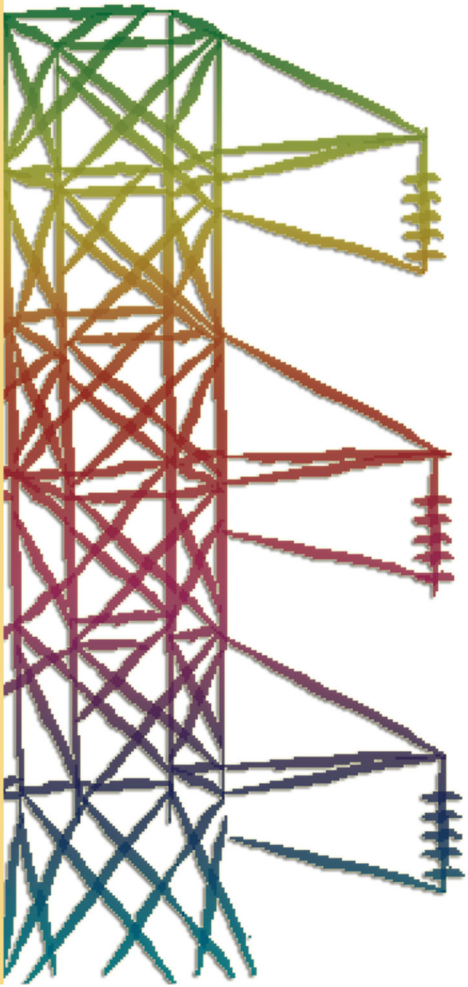
Ente per le Nuove tecnologie,
l'Energia e l'Ambiente

Ministero dello Sviluppo Economico

RICERCA SISTEMA ELETTRICO

# Linee guida per formazione ed educazione – Attività di formazione nell'ambito della valutazione e gestione della sicurezza di un deposito di rifiuti radioattivi. Analisi critica di esperienze internazionali

E. Zio, F. Cadini, D. Avram, J. De Sanctis



Report RSE/2009/126

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LINEE GUIDA PER FORMAZIONE ED EDUCAZIONE – ATTIVITÀ DI FORMAZIONE NELL'AMBITO DELLA VALUTAZIONE E GESTIONE DELLA SICUREZZA DI UN DEPOSITO DI RIFIUTI RADIOATTIVI. ANALISI CRITICA DI ESPERIENZE INTERNAZIONALI

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CIRTEN

CONSORZIO INTERUNIVERSITARIO

PER LA RICERCA TECNOLOGICA NUCLEARE

*POLITECNICO DI MILANO*

DIPARTIMENTO DI ENERGIA

# Linee Guida per Formazione ed Educazione

## *Attività di formazione nell'ambito della valutazione e gestione della sicurezza di un deposito di rifiuti radioattivi.*

## *Analisi critica di esperienze internazionali*

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**Lista acronimi**

| | |
|---|---|
| ANENT | Asian Network for Education in Nuclear Technology |
| CETRAD | Co-ordination Action on Education and Training in Radiation Protection and Radioactive Waste Management |
| CHERNE | Cooperation for Higher Education on Radiological and Nuclear Engineering |
| ECTS | European Credit Transfer System |
| ENEN | European Nuclear Education Network |
| ENETRAP | European Network on Education and Training in Radiological Protection |
| ERASMUS | European Community Action Scheme for the Mobility of University Students |
| EUNDETRAF | The European Nuclear Decommissioning Training Facility |
| EUTERP | European Training and Education in Radiation Protection Platform |
| ICARO | Intensive Course on Accelerators and Reactor Operation |
| ICT | Information and Communication Technologies |
| IP | Intensive Programmes |
| ITN | Instituto Tecnológico e Nuclear, Lissabona, Portugalo |
| NEA | Nuclear Energy Agency |
| NEPTUNO | Nuclear European Platform for Training and University Organizations |
| NWMO | Nuclear Waste Management Organization, Canada |
| OECD | Organization for Economic Co-operation and Development |
| SAFERELNET | Safety and reliability of industrial products, systems and structures |
| SPERANSA | Stimulation of Practical Expertise in Radiological and Nuclear Safety, Brussels Belgium |
| SCK•CEN | The Belgian Nuclear Research Centre |
| UPV | Universidad Politécnica de Valencia, Spagna |

## 1. Introduzione

### *1.1 Inquadramento del problema*

L'industria per la produzione dell'energia nucleare, di cui la gestione dei rifiuti radioattivi rappresenta uno degli aspetti più critici, ha grande bisogno di promuovere iniziative d'educazione e formazione. Infatti, in tutto il mondo cresce la preoccupazione sulla difficoltà di mantenere un numero adeguato di esperti per garantire il futuro uso sostenibile dell'energia nucleare. Anche se in alcuni Paesi si riscontra un aumento del numero di studenti iscritti ai corsi delle facoltà di ingegneria nucleare, in molti altri la formazione nucleare nelle università si è deteriorata a causa di decenni di stagnazione nel settore e di un'immagine impopolare dell'energia nucleare. Questo ha portato ad un numero insufficiente di studenti nei programmi di formazione nucleare offerti nel mondo, con conseguenti forti preoccupazioni per quello che riguarda la continuità delle conoscenze, esperienze e tecnologie nelle applicazioni nucleari.

In tempi recenti, i fondi dedicati alla ricerca e allo sviluppo di attività strategiche mirate alla preservazione a lungo termine delle conoscenze ed esperienze tecniche per l'energia nucleare, sono stati gradualmente ridotti in molti Stati. I finanziamenti governativi sono stati ridotti come conseguenza di una politica generale e motivata dal pubblico scetticismo sul futuro dell'energia nucleare come fonte di energia sostenibile e dalla convinzione di alcuni governi che l'industria nucleare, essendo ormai basata su una tecnologia matura, non dovesse essere più l'obiettivo primario di finanziamenti di ricerca e sviluppo. D'altra parte, gli investimenti industriali di costruttori ed operatori di centrali sono stati ridotti, ritenendo che tutta la ricerca e lo sviluppo necessari per la progettazione di una centrale nucleare fossero già stati fatti e per la mancanza di ordini di costruzione di nuove centrali che giustificassero attività di ricerca addizionali. Inoltre, gli effetti della deregolamentazione ed un mercato altamente competitivo hanno fatto spostare l'attenzione verso la ricerca di profitto a breve termine, che raramente si associa a tecnologie come quella nucleare dove la sicurezza è un aspetto critico.

Conseguentemente, anche l'insegnamento della tecnologia e sicurezza nucleare presso le università si è notevolmente ridotto ed il relativo ambito culturale e tecnico ha perso la sua attrattività nei confronti di nuovi ricercatori e professionisti, sollevando preoccupazioni sul problema della continuità e sviluppo di conoscenze e tecnologie nucleari.

Lo sviluppo di programmi di formazione nucleare a lungo termine e le relative risorse ed infrastrutture sono responsabilità dei governi, in condivisione ed accordo con le industrie interessate [1]. Un inadeguato mantenimento delle infrastrutture educative in tematiche nucleari inevitabilmente porta ad una continua diminuzione delle conoscenze tecniche e delle competenze necessarie per sostenere il funzionamento degli attuali impianti e per far fronte alle nuove sfide imposte da rinnovate richieste di energia nucleare. D’altra parte, la ricostruzione di un programma di formazione all’ingegneria nucleare a lungo termine, una volta perso, richiederebbe un investimento molto significativo di risorse. Dal punto di vista pratico, i tempi per lo sviluppo e l’organizzazione di opportunità educative potrebbero essere piuttosto lunghi, a causa dell’instaurarsi di un circolo vizioso nel quale le istituzioni potrebbero richiedere un ragionevole numero di potenziali studenti prima di investire risorse ma questi studenti potrebbero già guardare altrove in mancanza di un attrattivo programma e di mancanza di prospettive di carriera. Proprio in virtù di questo, agli inizi dell’era dello sviluppo della tecnologia nucleare fu deciso in primo luogo di investire in infrastrutture di educazione e formazione [1].

### *1.2 Obiettivi dello studio*

Attraverso una sintesi ed analisi critica delle pratiche di educazione e formazione alle tematiche nucleari, di sicurezza ed analisi di rischio già adottate in Italia ed in altri Paesi, il presente lavoro si propone di far emergere le esigenze, individuare le carenze e contribuire alla costituzione di una coscienza di sicurezza per la gestione partecipata dei rifiuti radioattivi in Italia.

In particolare, il rapporto illustra l'attività di studio delle esperienze sviluppate da Enti nazionali ed esteri, nell'ambito della formazione nucleare e, più in generale, dell'educazione in tematiche di sicurezza ed analisi di rischio con particolare riferimento agli aspetti legati allo smaltimento di rifiuti radioattivi.

Il lavoro è inserito in quanto previsto dal Piano Annuale delle attività oggetto dell'Accordo di Collaborazione fra ENEA e CIRTEN, nell'ambito dell'Accordo di Programma MSE-ENEA, tema di ricerca n. 5.2.5.8 "Nuovo nucleare da fissione"; linea progettuale LP4: Attività a supporto della individuazione e scelta di un sito e per la successiva realizzazione di un deposito di smaltimento dei rifiuti radioattivi di II Categoria e di un deposito di stoccaggio a medio-lungo termine dei rifiuti ad alta attività e lunga vita.

L'obiettivo dell'attività complessiva è quello di fornire una base per lo sviluppo di una strategia di ripresa e potenziamento dell'attività di formazione ed educazione alla sicurezza ed analisi di rischio con il coinvolgimento di tutti gli attori che svolgono un ruolo attivo nel problema della gestione dei rifiuti radioattivi. L'attività deve contribuire a ricreare, aggiornare e/o consolidare le competenze in Italia sulla materia in oggetto.

## 2. La necessità di formazione ed educazione alla sicurezza ed analisi di rischio nella gestione dei rifiuti radioattivi

Nella gestione dei rifiuti radioattivi, vi è una crescente esigenza di garantire l'adozione di efficaci soluzioni a lungo termine mediante processi decisionali che consentano di superare le continue situazioni di *empasse* causate dalle difficoltà di raggiungere accordi di compromesso ottimale tra le esigenze tecniche e quelle sociali [1]. In pratica, risulta sempre più difficile arrivare a soluzioni condivise anche se è ampiamente riconosciuta la necessità che il problema debba essere risolto.

A causa di questa situazione, negli ultimi trenta anni si è assistito ad importanti cambiamenti nel modo di gestire le problematiche legate ai rifiuti radioattivi. In alcuni Paesi, soluzioni ingegneristiche sono state sviluppate, seppur lentamente, e sono in uso già da molti anni; in altri Paesi, a causa di problemi di carattere più politico che tecnico, le difficoltà nel portare avanti soluzioni sono risultate molto più pesanti. In ogni caso, ogni Paese sta progressivamente adottando controlli più rigorosi - una tendenza che è destinata a continuare nei prossimi decenni. La crescente consapevolezza ambientale ha portato a questo aumento di rigore ed all'aspettativa che gli addetti ai lavori prendano in esame le problematiche riguardanti la sicurezza della gestione di un impianto di smaltimento di rifiuti radioattivi con una maggiore consapevolezza tecnica e scientifica sui rischi associati.

Il cammino tecnico e decisionale che si sta percorrendo per giungere ad una soluzione efficace dei suddetti problemi richiede che la comunità scientifica ed ingegneristica mantenga le proprie competenze per sviluppare, migliorare ed ottimizzare le soluzioni di gestione dei rifiuti radioattivi e presentarle alla società in modo trasparente e comprensibile. Per molti Paesi è risultato assai difficile preservare le competenze tecniche e scientifiche in tale settore, a causa delle molte discontinuità nei programmi e del temporeggiamento decisionale da parte delle agenzie ed autorità governative coinvolte [1].

Ulteriori difficoltà nel mantenere le competenze necessarie, indipendentemente dalla soluzione tecnica scelta per la risoluzione del problema, derivano dal fatto che la gestione in sicurezza di un deposito di materiale radioattivo è un argomento multidisciplinare. Le ricerche e lo sviluppo delle soluzioni in questa direzione richiedono il coinvolgimento di esperti di diverse discipline, quali quelle dell'ingegneria strutturale, chimica e nucleare, della scienza della terra, della matematica, della fisica e delle scienze mediche. Altri aspetti importanti da prendere in considerazione sono quelli sociali, etici e politici che stanno alla base di un saldo processo decisionale a sostegno di realistici programmi di sviluppo [1][2][3].

Prendendo come esempio lo smaltimento geologico dei rifiuti ad alta radioattività, fino ad oggi notevoli risorse sono state investite per dimostrare la fattibilità tecnica della scelta del sito e costruzione del deposito. Nella maggior parte dei casi, tali depositi non saranno operativi prima della metà di questo secolo e la loro attività e chiusura definitiva potrà essere estesa sino al prossimo secolo. Tale scala temporale è senza precedenti nel mondo moderno, e ciò richiede dei solidi programmi di educazione e formazione strutturati in modo da garantire l'effettivo trasferimento di conoscenze e di esperienze acquisite sino ad oggi alle future generazioni che saranno i veri artefici delle decisioni chiave. Altrettanto importanti sono i concetti, i metodi e gli strumenti attualmente allo stato dell'arte, che devono essere continuamente aggiornati in risposta ai progressi nel campo della scienza e della tecnologia e alle nuove esigenze della società [1].

Data la vastità, difficoltà e criticabilità sociale del problema, potrebbe essere difficile per delle strutture nazionali indipendenti mantenere il trasferimento ed il potenziamento dell'ampia mole di conoscenze necessarie per la gestione dei rifiuti radioattivi. A causa di forti ritardi programmatici, alcuni Paesi hanno già sofferto di un impoverimento nell'ambito delle conoscenze e competenze tecniche. D'altro canto, oggi sembra plausibile pensare a salde collaborazioni internazionali strutturate, in cui le linee di sviluppo più attive e all'avanguardia potrebbero essere d'aiuto e punto di riferimento per quelle che soffrono di una battuta d'arresto. Per questo è necessaria una cooperazione internazionale, anche se in ultima analisi le esigenze di base per l'educazione e la formazione in questo settore devono emergere a livello nazionale [1].

Nelle università della maggior parte dei Paesi al mondo sono rimasti pochi programmi di studio atti a garantire un'alta formazione nell'ambito delle ricerca e sviluppo dell'energia nucleare. La capacità delle università di attrarre gli studenti più preparati e meritevoli a tali programmi, capaci di soddisfare le future esigenze di richiesta di personale e guidare la ricerca di punta nel settore, è già notevolmente compromessa. Un certo numero di preoccupazioni emergono evidenti [4]:

- La diminuzione del numero dei corsi riguardanti il nucleare e la loro diluizione;
- La diminuzione del numero di studenti interessati al nucleare;
- La mancanza di giovani ricercatori nelle università capaci di poter sostituire il personale docente in pensione;
- Il graduale invecchiamento delle strutture di ricerca, che vengono chiuse e non sostituite da nuove;
- La parte significativa del personale tecnico non laureato non entra nel settore dell'industria nucleare.

Attualmente nel settore industriale e presso gli istituti di ricerca vi è ancora un certo numero di persone qualificate e capaci di organizzare e strutturare corsi di formazione. Tuttavia, il calo atteso del numero di tali persone diventerà motivo di forte preoccupazione in un prossimo futuro.

Un aspetto da tenere in considerazione è che la percezione degli studenti è un importante fattore che contribuisce alla diminuzione delle iscrizioni nei corsi di studi delle università. Essa è influenzata dagli aspetti educativi, dal negativo comune sentire dell'opinione pubblica per ciò che riguarda il tema dell'energia nucleare, dal ridimensionamento graduale del settore, a riduzioni dei finanziamenti governativi per i programmi di sviluppo nucleari, anche se, per quest'ultimo aspetto, una certa pianificazione strategica sta emergendo. Le conseguenze di un basso numero di iscrizioni riguardano direttamente i tagli di bilancio e quindi la limitazione nell'attuazione di servizi e corsi di formazione per programmi nucleari. A meno che non venga subito fatto qualcosa per fermare questa spirale al ribasso del calo di interesse degli studenti e delle offerte accademiche, essa continuerà inesorabilmente [4].

Ulteriori approfondimenti delle preoccupazioni riguardanti lo sviluppo di una adeguata strategia di formazione ed educazione in ingegneria nucleare sono forniti in APPENDICE 1.

## 3. Strategia per formazione ed educazione alla sicurezza ed analisi di rischio

Specifici gruppi di lavoro sono stati costituiti in tutto il mondo per definire strategie di educazione e formazione per addetti ai lavori e pubblico su problematiche generali attinenti all'analisi dei rischi industriali, prevenzione dei rischi, attenuazione dei rischi, gestione dei rischi, nonché gli aspetti riguardanti la salute e la sicurezza sul lavoro.

In effetti, è opinione condivisa che l'educazione e la formazione giocheranno un ruolo molto importante nella [5]:

- Conoscenza e comprensione della sicurezza, mediante la costruzione di necessarie basi culturali per affrontare i problemi riguardo il controllo dei rischi;
- Creazione e rafforzamento delle competenze per individuare, valutare e gestire i rischi;
- Conservazione e rafforzamento delle competenze personali e professionali in questioni di sicurezza;
- Collaborazione per migliorare la sicurezza;
- Diffusione dei risultati della ricerca sulla sicurezza.

La strategia deve preoccuparsi di [5]:

- Come le persone possano apprendere in ambito accademico e industriale;
- Come l'apprendimento si possa tradurre in cultura;
- Come l'apprendimento si possa tradurre in prassi;
- Come la conoscenza possa essere conservata ed aggiornata (con e senza un uso continuo).

A tale proposito è necessario individuare le reali esigenze e le lacune in materia di sicurezza specificamente per quello che riguarda l'educazione e la formazione. In tal senso è necessario coinvolgere tutti i settori e le parti che potrebbero dare un contributo nell'ambito dello sviluppo della competenza e cultura in tema di sicurezza, trasversalmente tra i differenti settori industriali, organizzazioni pubbliche e governative, e raccoglierne i commenti e suggerimenti [5].

Come punto di partenza, andrebbe sviluppato uno scenario di attività d'educazione e formazione ed individuati gli strumenti per attuarlo (ad esempio, integrando ed estendendo ricerche effettuate in gruppi europei, come la rete tematica SAFERELNET [6]). Questo richiederà il confronto tra i differenti approcci di industrie e Paesi diversi. Un database on-line di materiali sulla formazione (ad esempio, opuscoli, lucidi, presentazioni di libri, seminari, conferenze, corsi e-learning, ecc.) potrebbe essere messo a disposizione su piattaforme nazionali di sostegno per la scelta del materiale di formazione più adatto alla diffusione transnazionale [5].

## 4. Strumenti per formazione ed educazione alla sicurezza ed analisi di rischio

Le attività di educazione e formazione sui temi della sicurezza ed analisi di rischio devono contribuire a costruire la cultura e le competenze necessarie per sviluppare e definire, a tutti i livelli delle attività industriali, le corrette azioni e misure atte a ridurre incidenti, infortuni, perdite, impatti nocivi sull'ambiente. Nel contesto del presente documento, gli strumenti per far ciò nell'ambito delle tematiche di sicurezza sono metodologie, strutture analitiche e modelli che riproducono la realtà e ne forniscono una migliore comprensione all'interno di specifiche attività formative ed educative. Essi consentono agli utenti di prevedere i potenziali scenari di incidente, stimarne le probabilità, analizzarne le conseguenze. I risultati, ottenuti dall'utilizzo competente di questi strumenti devono fornire le basi tecniche per prendere decisioni razionali [5].

Sembra opportuno specificare che, nell'ambito della formazione e dell'educazione, una *tecnica* è un metodo per attrarre, mantenere e stimolare l'attenzione degli utenti, concentrare le attività verso gli obiettivi prefissati, verificare i loro progressi. Le tecniche di formazione ed educazione sono sostanzialmente ereditate da altri settori, in particolare dalla psicologia, dalla pedagogia e dalla didattica; tuttavia, nell'ambito di interesse specifico devono essere analizzate e verificate dal punto di vista della loro idoneità ad aumentare la cultura della sicurezza industriale.

Tali tecniche devono essere la base per [5]:

- Programmi di progettazione industriale in sicurezza;
- Corsi di progettazione e di gestione della sicurezza, con interfacce di simulazione ed intelligenza artificiale:
    - Piattaforme aperte e sistemi modulari di educazione e formazione alla sicurezza ed analisi di rischio;
    - Banche dati condivise di materiale per la formazione e l'educazione in ambito di sicurezza industriale, punti di incontro per lo scambio di informazioni, corsi web-based, ecc;
- Valutazione dei risultati dei programmi e dei corsi per quanto riguarda il loro impatto sulla sicurezza industriale, ed eventuale *re-engineering*.

Maggiori dettagli sull'utilizzo di strumenti di formazione ed educazione in ambito di sicurezza industriale sono riportati in APPENDICE 2.

Oltre ai classici e moderni metodi di analisi di sicurezza ed analisi del rischio [7][8][9][10][11][12][13], che devono essere armonizzati tra i diversi settori industriali e le diverse nazioni, l'educazione e la formazione per la sicurezza industriale può beneficiare di due principali aree di sviluppo tecnologico negli strumenti di lavoro: software per la simulazione e metodi d'intelligenza artificiale. Questi metodi di simulazione e computazione numerica offrono la possibilità di migliorare notevolmente il processo di apprendimento, di renderlo più accessibile ed efficace.

I software di simulazione ed i metodi d'intelligenza artificiale possono essere sviluppati ad hoc per scopi educativi o essere adattati da altre applicazioni, (ETPIS, "Piattaforma Tecnologica Europea sulla Sicurezza Industriale" [14]). In tutti i casi, le interfacce utente devono essere progettate sempre in conformità alle specifiche del progetto dell'attività di educazione e formazione [5].

Le applicazioni di simulazione numerica stanno acquisendo un ruolo principale nella formazione e nell'educazione alla sicurezza. Il loro sviluppo ed utilizzo mirano ad integrare la cultura della sicurezza con la competenza sulla valutazione e gestione del rischio per una risposta ottimale in situazioni di emergenza. Attraverso l'utilizzo di questi strumenti, lo studente è in grado di capire da un' "esperienza virtuale" le conseguenze delle azioni errate e di comportamenti non sicuri, nonchè l'importanza di avere acquisito una buona pratica. In generale, la simulazione di scenari di incidente può servire come utile strumento per promuovere e migliorare la prassi di gestione della sicurezza nei diversi settori industriali [5].

Alcuni concetti riguardanti gli strumenti di simulazione per l'educazione e la formazione sulla sicurezza sono discussi con dettagli aggiuntivi, in APPENDICE 2.

Altre applicazioni in materia di sicurezza possono beneficiare dell'uso di metodi basati sull'utilizzo dell'intelligenza artificiale. Questi possono essere metodi di supporto alle scelte decisionali, strumenti di orientamento per gli utenti per selezionare l'opzione migliore, o strumenti di diagnostica che aiutano a individuare le possibili cause di un comportamento anomalo del sistema in situazioni altamente incerte [5].

## 5. Progetti ed attività esistenti per la formazione ed educazione alla sicurezza ed analisi di rischio

In generale, la formazione è un’attività valorizzata da quasi tutte le aziende. La formazione è spesso considerata essenziale per le attività delle aziende e, in molti casi, è tutelata da un apparato giuridico. Le aziende offrono programmi di formazione in diverse aree tematiche sia per favorire un'ampia base di conoscenze e sia per formare competenze specifiche nelle attività dell’azienda. La formazione è ideata sia per i nuovi laureati e sia per il personale esperto, con l'obiettivo di aumentare le competenze nelle specifiche funzioni all'interno dell'azienda. L’ “house training” è destinata principalmente ai lavoratori dipendenti ed è pagata dall’azienda. Nel caso di partecipazione di allievi esterni all’azienda, si prevede un pagamento per seguire tali programmi di formazione. A causa delle piccole dimensioni di alcune aziende, o del ristretto numero dei gruppi di partecipanti, alcune aziende hanno difficoltà ad organizzare i corsi di formazione. In questi casi, i corsi di formazione vengono mutuati da altre organizzazioni, aziende, consulenti esterni, istituzioni universitarie oppure vengono istituiti corsi di formazione inter-organizzati tra le aziende [4].

Nello specifico degli aspetti di formazione in materia di sicurezza ed analisi di rischio, la rete tematica SAFERELNET ha fornito una base contenutistica per attività formative, mirata a costruire competenze per soluzioni efficaci in sistemi, impianti e strutture di varie industrie. Al suo interno, sono stati strutturati e sperimentati corsi sulle metodologie qualitative e quantitative per la valutazione dei rischi e della sicurezza, sull’analisi di sistema, sull’analisi d'affidabilità ed altro ancora. L'enfasi principale ha riguardato l'uso di metodi per la progettazione di prodotti, costruzione d’impianti, di sistemi industriali e di strutture ottimali da un punto di vista economico e di sicurezza.

SAFERELNET ha organizzato diversi questionari sulla formazione in materia di sicurezza e di analisi del rischio per l'industria e le università; alcuni esempi sono riportati in APPENDICE 3.

In Italia esistono corsi universitari sull’analisi del rischio e sulla sicurezza. In merito a quest’ultima tipologia di iniziative di formazione, al Politecnico di Milano presso il Dipartimento di Energia ad esempio, sono organizzati ogni anno due corsi di formazione permanente sulla sicurezza, *Tecniche innovative per la valutazione dell’affidabilità e disponibilità di impianti industriali* e *Sicurezza industriale: tecniche di valutazione del rischio.*

A livello mondiale, un altro esempio degno di nota è l’IAEA Network of Centers of Excellence (COE) in Training and Demonstrations of Waste Disposal Technologies [18]. Per ulteriori dettagli si rimanda all’ APPENDICE 3.

Nel campo specifico delle tecnologie nucleari, i temi della formazione necessariamente ricoprono aree multidisciplinari, con conoscenze teoriche e competenze pratiche. Corsi teorici possono riguardare argomenti come la fisica dei reattori, la termo-idraulica, la radiochimica, la radioprotezione e la fisica medica; procedure di funzionamento di impianto, analisi di sicurezza, strumentazioni meccaniche ed elettriche, strumentazione e controllo, regolamenti e norme, codici di simulazione. Corsi di abilità pratica possono riguardare "operator hands-on training by simulators", esercitazioni pratiche di procedure in sala di controllo, esperienze di laboratorio di misure nucleari, radioprotezione, prove non distruttive, saldature e manutenzione.

Per quanto riguarda lo specifico settore nucleare, come detto in precedenza, le esigenze di formazione sono generalmente in aumento. Con il consolidamento del settore nucleare nei Paesi membri dell'OECD/NEA, un decremento nella formazione potrebbe essere anticipato. In realtà è vero il contrario; l'aumento dei requisiti normativi e la necessità di forza lavoro competente ha portato ad un aumento del bisogno di formazione. Solo il Belgio, l'Ungheria, la Turchia, e la Spagna hanno mostrato una diminuzione del numero di allievi tra il 1990 e il 1998. Allo stesso modo, la quantità di tempo dedicato alla formazione è aumentata nel corso di tale periodo per tutti i Paesi, tranne la Francia, l'Ungheria e la Turchia [4].

Ulteriori dettagli sui programmi formativi in ambito di sicurezza, analisi di rischio e tecnologie nucleari sono riportati in APPENDICE 3.

## 6. Corsi universitari sulle tematiche nucleari

Per quanto riguarda l'educazione universitaria sui temi dell'energia nucleare, il calo di iscrizioni verificatosi su un lungo periodo di tempo ha spinto le università a ridurre il numero di corsi offerti a causa della sempre minore domanda degli studenti. Alcune istituzioni hanno cercato di aumentare l'attrazione dei loro corsi ampliando i contenuti o cambiando il loro nome. La maggior parte delle università ha cercato di "commercializzare" i propri corsi di nucleare attraverso un'ampia gamma di attività, e con il finanziamento di borse di studio. Iniziative, tuttavia, rimaste isolate. I vantaggi si potrebbero moltiplicare se le università ed altre organizzazioni condividessero gli sforzi verso tale direzione. In altre situazioni, tali corsi si sono fusi con quelli di chimica, meccanica, energetica o ambientale.

La collaborazione può aiutare le università e gli istituti di ricerca a fornire alta qualità nell'istruzione, attraendo l'interesse per l'industria nucleare, fornendo opportunità uniche per gli studenti e, quindi, promuovendo l'innovazione ed i momenti creativi. I governi dovrebbero fornire un sostegno attraverso lo sviluppo di reti tra università, industria ed istituti di ricerca, fornendo [4]:

- Un quadro istituzionale di studi per gli studenti in programmi comuni tra università, industria ed istituti di ricerca;
- Grandi impianti sperimentali, come i reattori di ricerca, che le università e gli istituti di ricerca possano condividere per la ricerca o l'educazione, così come gli impianti di ricerca per il combustibile nucleare e di stoccaggio per il combustibile esaurito;
- Adeguati investimenti da parte dell'industria per la ricerca universitaria e lo sviluppo dei progetti.

Presso l'Università degli Studi di Bologna, in collaborazione con l'Enea, è stato istituito un master di secondo livello denominato: *Progettazione e Gestione di Sistemi Nucleari Avanzati*.. Alcune esperienze in questo senso sono in corso a livello europeo, quali ad esempio, la rete CHERNE (http://www.upv.es/cherne/), il progetto ENEN (http://www.enen-assoc.org/) ed il corso dell'Unione Europea ICARO (http://www.fjfi.cvut.cz/kdaiz/speranza/index.html). Per maggiori dettagli su questi progetti, si rimanda all'APPENDICE 3

## 7. Conclusioni

L’educazione e la formazione nucleare non sono ancora ad un punto di crisi, ma sono certamente in condizioni di stress in molti dei Paesi membri del OECD/NEA. I bisogni dell’industria nucleare nel campo delle risorse umane e della ricerca sono diminuiti in quanto, raggiunta la maturità, essa cerca principalmente di essere più competitiva nel settore energetico liberalizzato.

Come conseguenza delle attuali strategie economiche, l'industria nucleare sta attraversando un periodo di consolidamento. Le università hanno subito il calo delle esigenze del settore, riducendo il loro impegno di ricerca ed insegnamento. Ciò ha portato ad una preoccupante erosione della base di conoscenze, come chiaramente indicato nella presente relazione. Tuttavia, vi è la responsabilità di garantire che, perlomeno, ci siano le risorse e le competenze adeguate per affrontare i problemi legati alle attuali attività nucleari – relativamente agli esistenti impianti e strutture operative – ed alle questioni di smantellamento delle centrali dismesse.

Vi è anche l’obbligo nei confronti della prossima generazione di mantenere e far progredire le conoscenze nucleari in modo che il ruolo dell’energia nucleare possa essere adeguatamente valutato, e future scelte possano essere considerate con cognizione di causa- anche da quei Paesi che attualmente hanno una moratoria nucleare. I governi devono intensificare e rispondere a queste responsabilità ed a questi obblighi.

Un’educazione nucleare sufficientemente solida e flessibile è fondamentale per mantenere il settore e sostenerlo nel suo processo d’evoluzione. Da questo punto di vista, gli istituti di ricerca e l'OECD/NEA condividono i vantaggi e le responsabilità nel sostenere in maniera vigorosa il mantenimento e lo sviluppo dei programmi di formazione nucleare. Tali programmi devono essere strutturati in maniera tale da fornire i mezzi e contribuire a coordinare le attività, negli interessi degli studenti, al fine di fornire le competenze necessarie ai futuri esperti della comunità universitaria ed industriale in tema di energia nucleare.

I governi hanno responsabilità importanti nella preservazione dei programmi nucleari nelle università che devono essere in grado di attrarre studenti di prima qualità. Le strutture disponibili per l’educazione nucleare risentono di un processo di invecchiamento ed il numero di studenti è in declino; queste situazioni si aggravano a vicenda. Per spezzare la spirale al ribasso, i governi dovrebbero finanziare l'ammodernamento supportando la ricerca sospesa e lo sviluppo del nucleare su una base competitiva e fornire borse di studio per i migliori e più brillanti laureati e studenti universitari.

**Guidelines for training and education (ENGLISH VERSION)**

## 1. Introduction

### *1.1 Problem statement*

The nuclear energy industry, of which radioactive waste management is one of the most critical facets, is in great need of education and training. Indeed, there has been growing concern worldwide that it might be difficult to maintain the necessary number of experts to assure the sustainable utilization of nuclear power into the future. In spite of the fact that some countries are experiencing an increase in the number of students enrolling in nuclear engineering, nuclear education at universities has been historically deteriorating in many countries, due to decades of stagnation of the industry and an unpopular image of nuclear energy itself. As a result, an insufficient number of students have entered the nuclear educational programmes offered around the world, raising strong concerns about the continuity of knowledge, experience and technology in nuclear energy applications.

On the other hand, establishing the adequate long-term educational programme and providing the resources and infrastructures for its support are generally seen as primary responsibilities of the government, in partnership with the interested industry [1].

Failing to maintain the infrastructure of nuclear education, inevitably leads to a continued decrease in the technical knowledge and expertise needed to support the operation of the current nuclear systems and to respond to the new challenges posed by the revived demands for nuclear energy. Even more, re-building a long-term programme of nuclear engineering, once lost, would require a significant investment of resources, in the order of what was invested to establish the infrastructure in the first place, at the beginning of the rise of nuclear energy technology [1]. On the other hand, the lead time for developing replacement educational opportunities can be quite long, as most institutions require reasonable prospects for the number of potential students before investing resources, and these potential students may look elsewhere in lack of an attractive research programme and expanding career fields.

In recent years, funding dedicated to long-term strategic activities of nuclear energy research and development, corporate knowledge preservation and technical expertise maintaining has been reduced in many countries. Industry funding by the plant designers and operators has been reduced in view of the belief that all research and development needs for the initial design of plants have been satisfied and the lack of commitments to build new plants does not justify new activities. Furthermore, the effects of deregulation and the highly competitive market place have shifted the attention to short term profitability research, which is rarely the case for safety-critical technologies such as the nuclear one.

On the other side, government funding has also been reduced as a result of the general political and public skepticism in the future of nuclear power as a sustainable source of energy and the belief by some governments that the nuclear industry, as a mature technology, is not the primary target for research and development funding in the future. As a fallback, teaching in nuclear technology and nuclear safety at universities has diminished considerably and, consequently, lost its attractiveness for new researchers and professionals, which raises concerns about the continuity of knowledge in nuclear technology even in universities.

## 1.2 *Objectives of the study*

Through a synthesis and a critical analysis of risk education and training in various Countries, the present work aims at contributing to the formation of a safety conscience for the participatory management of radioactive wastes in Italy.

In particular, the report illustrates studies and experiences by national and international Organizations, in the field of risk education and training methodologies within the practice of surface disposal of radioactive wastes.

The work is framed within the Annual Plan of activities of the Collaboration Agreement between ENEA and CIRTEN, in the area of the MSE-ENEA Program Agreement, research theme no. 5.2.5.8 “New Nuclear from Fission: Activity in support to the characterization and selection of a site and the successive realization of a disposal deposit for radioactive wastes of Category II and of a medium-long term storage deposit for long-lived and high-radioactivity wastes.

The overall objective of the research activity is that of providing the basis for the development of a participatory strategy of communication and information, with the involvement of all stakeholders which have a role (active or passive) in the issues of radioactive waste management. The activity must contribute to recreate, update and/or consolidate the competences in Italy on the subject.

## 2. The need for training and education on safety and risk analysis for radioactive waste management

There is a growing need for improved long-term solutions for the management of radioactive wastes. The last thirty years have seen significant changes in the way that these hazardous materials are handled. Every country is moving towards progressively more rigorous controls - a trend that is likely to continue and develop in the next decades. Growing environmental awareness has led to this increased stringency, while making people more personally aware of the potential hazards of these wastes, and concerned with respect to the safety of the dedicated waste management facilities. As a result, it is becoming more difficult to implement agreed solutions: although it is widely acknowledged that something needs to be done, there is often a paralysis in the decision-making phase, owing to the difficulties of achieving technical consensus and social endorsement of any specific proposal [1].

Careful engineered solutions for radioactive wastes are being put into operation slowly in some countries (and, indeed, have been used for many years in a few), others are having real problems in moving forward, mostly due to public and political opposition rather than technical difficulties.

In the midst of this, it is of utmost importance that the scientific and engineering communities maintain their expertise to develop, improve and optimize radioactive waste management solutions and present them to society in transparent and understandable ways. Because of the frequent discontinuities in the programmes due to seemingly unavoidable temporizing by the decision makers and agencies concerned, maintaining the need and expertise has been difficult in many countries [1].

Additional difficulties in maintaining the required competence come from the fact that regardless of the option finally chosen, safe and secure long-term management of radioactive wastes is a multidisciplinary activity. Researching and developing solutions require the involvement of teams of experts in a diversity of disciplines, structural, nuclear and chemical engineering, geosciences, mathematics, physics and health sciences being central. There is also an important requirement for non-technical, social, ethical and political competence to solidly underpin the decision-making of realistic practical programmes. Project development and implementation teams must be able to communicate easily with the full spectrum of stakeholders, decision makers, the media and local communities [1][2][3].

Taking geological disposal as example, considerable resources have been invested to demonstrate the technical feasibility of site selection and construction of radioactive waste repositories to date. In most cases, such repositories will not be operational before the middle of this century and their operations and final closure may stretch into the next century. Such a time perspective is unprecedented in the modern world and requires robust training and education programmes, structured to guarantee the effective transfer of the vast inventories of knowledge and experience accumulated by today's planners to their successors, who will make the key decisions. Equally important, the concepts, methods and tools that are currently state-of-the-art must be continuously updated in response to advances in science and technology and to requirements of the society [1].

Given the breadth of scope of the problem, and its societal criticality, it may be difficult for independent national structures to maintain, transfer and enhance the broad-based knowledge required in the management of the radioactive waste issues. Owing to programme delays, some countries have already seen a decline in once comprehensive technical capabilities. On the other hand, it seems more robust to think of structured international cooperations, in which programmes that are more active can help those that might be suffering temporary set-backs. This is a sensible plea for international cooperation, although it stands that the basic needs for education and training in this area arise at the national level [1].

In most countries there are now few remaining comprehensive, high-quality nuclear technology programmes at universities. The ability of universities to attract top-quality students to those programmes, meet future staffing requirements of the nuclear industry, and conduct leading-edge research in nuclear topics is becoming seriously compromised. A number of concerns exist [4]:

- The decreasing number of nuclear programmes and their dilution.
- The decreasing number of students taking nuclear subjects.
- The lack of young faculty members to replace ageing and retiring faculty members.
- Ageing research facilities, which are being closed and not replaced.
- The significant fraction of nuclear graduates not entering the nuclear industry.

There currently appears to be enough trainers and quality staff in industry and at research institutes. However, the provision of suitable trainers in the near future is becoming a concern because of the university situation.

Student perception, an important factor contributing to low enrolment, is affected by the educational circumstances, negative public perception, the downsizing of the industry, and reductions in government-funded nuclear programmes, where little strategic planning is occurring. Low enrollment directly affects budgets, and budgetary cuts then limit the facilities available for nuclear programmes. Unless something is done to arrest it, this downward spiral of declining student interest and academic opportunities will continue [4].

More information on concerns regarding the development of a good practice of training and education are provided in APPENDICE 1.

## 3. Strategy for training and education on safety and risk analysis

Many specific focus groups have been formed worldwide, whose activities of education and training regard both workers and public on all issues, principles and methods relevant to industrial risk analysis, risk prevention, risk mitigation, risk management as well as on occupational health and safety.

Education and training is believed to play a major role in [5]:

- Knowing and understanding safety, by building the cultural basis necessary for dealing with risks
- Creating and enhancing skills for identifying, assessing and managing risks
- Maintaining and enhancing personal and professional competencies in safety issues
- Collaborating to improve safety
- Disseminating safety research results.

On the other hand, the strategy for innovative research actions will continue to cover [5]:

- How people learn in the academic and industrial environment
- How learning is translated into culture
- How learning is translated into action
- How Knowledge is updated and maintained (with and without continuous use).

In this respect, identifying the actual needs and gaps in safety research specifically for education and training, requires that prospective activities be initiated by approaching all safety players across the different industrial sectors, government and public organizations, to collect their feedbacks [5].

At the start, the scenario of the existing educational and training activities and tools should be created (e.g., integrating and extending the research done in European groups such as the SAFERELNET thematic network, [6]). This can be an important starting point for comparing the approaches in different kinds of industries and different countries. As a result, an online database on training materials (e.g., brochures, transparencies, presentations, books, seminars, conferences, e-learning courses, etc.) could be made available to support national platforms in choosing the training material most apt for national dissemination [5].

## 4. Tools for training and education on safety and risk analysis

The usage of tools in safety education and training aims at building the culture and expertise necessary to develop and devise, at all levels of industrial activities, the proper actions and measures for reducing accidents, injuries, losses, and claims. In the context of this document, *tools* are methodologies, analytical frameworks and models that reproduce reality and assist in its understanding. They allow users to predict potential accident scenarios, estimate their probabilities and analyze their consequences; their results, findings and insights are utilized as guide for making decisions [5].

Besides the classical and modern methods of safety and risk analysis [7][8][9][10][11][12][13], which need to be harmonized across the different industrial sectors and nations, the education and training for industrial safety can greatly benefit from two main areas of technological development of tools: simulator software (SW) and artificial intelligence. Their hybrids offer the possibility of dramatically enhancing the learning process, and making it friendlier, more effective and persistent.

Simulator software and artificial intelligence tools can be developed ad-hoc for educational purposes or be adapted from other applications, both existing or proposed by other focus groups within the European Technology Platform on Industrial Safety (ETPIS, [14]). In all cases, suitable user interfaces must be designed in accordance to the specifications of the planned education and training activity [5].

Applications of numerical simulators are gaining a principal role in training and education. Their development and use aim at integrating the culture of safety with the competence of risk assessment and management, for optimal operator behavioral response in emergency situations. Using these tools, the student is able to understand by "virtual experience" the consequences of erroneous actions and unsafe behaviors as well as the relevance of good practices, among other things. Similarly, accident simulation can serve as a tool for promoting improved practices in the different industrial sectors by training [5]. A number of simulation concepts for safety education and training are discussed with additional details, which can be found in APPENDICE 2.

Other safety-related applications can involve the usage of artificial intelligence-based systems. These can be either decision support systems, tools guiding users to select the best option, or diagnostic tools, which help detecting possible causes of anomalous system behavior in highly uncertain situations [5].

In the context of training and education, a *technique* is a method for attracting, maintaining and stimulating the attention of users to focus their activity according to predefined objectives, verifying their progress and assessing new activities. Techniques for training and education are expected to be essentially inherited from other areas, especially psychology, didactic and pedagogy.  However, the relevant educational and training techniques should always be analyzed and validated from the point of view of their suitability to increase the industrial safety culture .

Such techniques can be useful for [5]:

- Programme design;
- Course contents design and management including simulation and artificial intelligence interfaces:
  - Open platforms and modular system for education and training;
  - Creating shared databases of materials for training and education in industrial environment, meeting points to share information, web-based courses, etc.;
- Evaluation of performance of programmes and courses with respect to their impact in industrial safety and possible re-engineering.

More details of tolls use for training and education are given in APPENDICE 2.

## 5. Existing projects and activities on training and education in safety and risk analysis

Companies offer training programmes in a number of subject areas, to support both broad-based knowledge and specific skills development. Training is designed for both new graduates and experienced staff, with the aim of increasing the competence of the trainees in their specific function within the organization. In-house training is intended mainly for employees and is paid for by the company. When external applicants attend, they must pay for the training. Because of the small size of some organizations, or the small size of groups for specific training, some organizations find it difficult to organize in-house training courses. In those cases, training is either bought from other organizations, companies, consultants and university institutions or inter-organizational training units are set up [4].

The value of training is highly regarded by almost all organizations. Training is often considered to be essential to the organization’s mission and in many cases is reinforced by an operative legal framework.

For example, the Thematic Network SAFERELNET is concerned with providing safe and cost effective solutions to industrial products, systems, facilities and structures across different industries, throughout organized courses on risk assessment methodology, safety assessment, system analysis (fault tree, event tree analysis, reliability block analysis), qualitative risk analysis, system reliability and more. The main emphasis is on the use of reliability-based methods for the optimal design of products, production facilities, industrial systems and structures from the point of view of balancing the economic aspects associated with providing predefined safety levels, with the associated costs of maintenance and availability.

SAFERELNET has organized several questionnaires on safety and risk analysis training, for industry and university members, which are reported in APPENDICE 3.

There are also in Italy many university courses on risk and safety analysis. At Politecnico di Milano, within the Energy Department are organized every year two permanent training courses on safety, *Tecniche innovative per la valutazione dell’affidabilità e disponibilità di impianti industriali* and *Sicurezza industriale: tecniche di valutazione del rischio*.

At a worldwide level, it is worth noticing the IAEA Network of Centers of Excellence (COE) in Training and Demonstrations of Waste Disposal Technologies [18]. Further details are reported in APPENDICE 3.

In the nuclear technology field, the subjects of training cover broad areas in both theoretical knowledge and practical skills. Theoretical courses may cover subjects such as reactor physics, thermal-hydraulics, radiochemistry, radiation protection and health physics, operation procedures, accident and safety analysis, mechanical and electrical equipment, instrumentation and control, regulations, simulation codes and safeguards. Courses in practical skills may include: operator hands-on training by simulators, practical drills in control room procedures, laboratory exercises of non-destructive testing, welding, and maintenance.

In-house nuclear technology training is generally increasing, with a wide range of courses being offered. With the nuclear industry consolidating in OECD/NEA member countries, a decrease in training might be anticipated. In reality the opposite is true; increasing regulatory requirements and the need for more flexible workforces have led to increasing training requirements. Only Belgium, Hungary, Turkey, and Spain have shown a decrease in the number of trainees between 1990 and 1998. Likewise, the amount of time devoted to training has increased over this period for all countries except France, Hungary, and Turkey [4].

More details are presented in APPENDICE 3.

## 6. University courses on nuclear topics

With respect to nuclear education, a declining enrollment has been experienced for a long time, pushing universities to reducing the number of offered courses to match student numbers. Some institutions have sought to widen the appeal of their courses by broadening content or changing the name. Others have merged nuclear programmes with mechanical, energy, or environmental programmes. In addition, most universities are trying to market their nuclear courses through a wide range of activities, from open days to scholarships. Initiatives, however, have been taken largely in isolation. Benefits would multiply if universities and other organizations shared techniques and efforts.

Furthermore, collaboration can help universities and research institutes to provide high quality education, attract positive attention to the nuclear industry, provide unique opportunities for students and, hence, foster innovation and create momentum. Governments should provide support by developing educational networks between universities, industry and research institutes by providing [4]:

- An institutional framework for students to study in joint programmes among universities, industry and research institutes.
- Large experimental facilities such as research reactors that universities and institutes share for research or education as well as nuclear fuel and storage facilities for spent fuel.
- Matching investments from industry for university research and development projects.

The University of Bologna offers, in collaboration with ENEA, the master study course *Design and Management of Advanced Nuclear Systems.* Other experiences in this sense are underway at the European level, e.g. the CHERNE network (http://www.upv.es/cherne/), the ENEN project (http://www.enen-assoc.org/) and the ICARO course (http://www.fjfi.cvut.cz/kdaiz/speranza/index.html). For further details on these initiatives, see APPENDICE 3

## 7. Conclusions

Nuclear education and training are not yet at a crisis point, but they are certainly under stress in many of the OECD/NEA Member countries, the notable exceptions being France and Japan. The needs of the industry, in both recruitment and research, have declined as it has reached maturity and seeks to be more competitive in a deregulated energy sector. However, a sufficiently robust and flexible nuclear education is crucial to support the industry as it evolves. Research institutes and the OECD/NEA also share the benefits and responsibilities of maintaining vigorous education programmes. They can provide creative means and help to co-ordinate activities in order to interest candidates in becoming the future experts of the university and industrial community. In addition, governments have important responsibilities for keeping nuclear programmes in universities healthy and capable of attracting top-quality students.

As a consequence of current economic strategies, the nuclear industry is going through a period of consolidation. Universities have reacted to the decreasing requirements of the industry by reducing their commitment to research and teaching in nuclear areas. This has led to a worrying erosion of the knowledge base that is clearly identified in this report. Yet, there is a responsibility to ensure that, at the very least, resources and expertise are adequate to address properly the nuclear activities that are necessary today – operating plants and facilities and addressing decommissioning issues. There is also an obligation to the next generation to maintain and advance nuclear expertise so that the role of nuclear power can be adequately assessed, and future options can be informatively considered – even by countries that currently have a nuclear moratorium. Governments need to step up and meet these responsibilities and obligations.

The facilities available for nuclear education are ageing and the number of students is declining; these situations aggravate each other. To break the downward spiral, governments should fund modernization by supporting outstanding nuclear research and development on a competitive basis and provide scholarships for the best and brightest graduate and undergraduate students.

## APPENDICE 1

A broad and deeply rooted nuclear education competence is essential to master properly the wide area of science and technologies extensively used in the nuclear domain. The universities and advanced technical schools are the only institutions capable of providing this education. In-house training, as a complementary form of education, is important for the proper and wise operation of nuclear facilities. This type of education is mostly, although not exclusively, provided by industry [4].

Failure to take appropriate steps now will seriously jeopardise the provision of adequate expertise tomorrow. One must act now on the following recommendation (Table 1).

**Table 1: Recommendation for adequate expertise**

| **Strategic role of governments** |
|---|
| • Engage in strategic energy planning, including consideration of education, manpower and infrastructure.<br>• Contribute to, if not take responsibility for, integrated planning to ensure that human resources are available to meet necessary obligations and address outstanding issues.<br>• Support, on a competitive basis, young students and provide adequate resources for vibrant nuclear research and development programmes including modernisation of facilities.<br>• Provide support by developing "educational networks or bridges" between universities, industry and research institutes. |
| **The challenges of revitalising nuclear education by university** |
| • Provide basic and attractive educational programmes.<br>• Interact early and often with potential students, both male and female, and provide adequate information. |
| **Vigorous research and maintaining high-quality training** |
| • Provide rigorous training programs to meet specific needs.<br>• Develop exciting research projects to meet industry's needs and attract quality students and employees (research institutes). |
| **Benefits of collaboration and sharing best practices** |
| • Industry, research institutes and universities need to work together to co-ordinate efforts better to encourage the younger generation.<br>• Develop and promote a programme of collaboration in nuclear education and training, and provide a mechanism for sharing best practices in promoting nuclear courses between Member countries. |

*Concern 1: The decreasing number and the dilution of nuclear programmes*

The number of universities that offer nuclear programmes, i.e. curricula that consist of a set of courses on nuclear subjects, is declining. Faced with declining enrolment, some universities have combined forces and reduced the number of courses to match the number of students. For example, in Belgium, six university nuclear programmes have been coalesced into two. As universities try to appeal to a wider audience by offering nuclear programmes as options in more mainstream science programmes, nuclear programmes are being reduced to the level of individual courses with a broadened, and hence diluted, content.

Some departments have sought to widen the appeal of their courses either by broadening the content or by changing the name. However, while advanced energy systems or nuclear and radiological engineering may be more successful in attracting students, they are much less specific, in both name and content to, for example, nuclear engineering. In some universities, nuclear programmes have been merged with mechanical, other energy-related, or environmental programmes. While this approach keeps nuclear education alive in the short term, there is the danger that the nuclear content will diminish with time and may eventually disappear altogether.

During the period of the survey, some new courses have been started. France started 6 programmes, Japan started 3 programmes, and Mexico started new Master and Doctoral programmes. Some of the new courses are directly related to nuclear power and deal with fuel cycle and waste management. Others are more biased towards engineering and deal with reliability, safety systems, and thermal hydraulics; and some lie outside nuclear power but have a nuclear content, for example, radiation science and nuclear medicine.

*Concern 2: The lack of young faculty members to replace ageing and retiring faculty members*

The number of full-time faculty members in nuclear fields has decreased in the United Kingdom and the United States but has increased in France and Japan. In other countries, the numbers have remained fairly constant over the period in question. The numbers of part-time faculty members in the field are generally rising, especially in countries where the number of full-time faculty members is falling.

The generally observed average age of faculty members is construed as a risk to sustaining high-quality expertise. The age distribution of faculty members peaks at 41-50 and 51-60 in most countries (Table 2). The average age of faculty members is almost 50 years. Most universities have a retirement age around 65.

The main concern is that there are few young faculty members coming through. This is particularly worrying in countries where the age peak is 51-60, and it is a serious concern where the age peak is 41-50. When faculty in these age brackets and above have retired, there will be a significant drop in the number of faculty members. The inevitable outcome will be a reduction in the number and choice of courses, which in turn, will dramatically affect the quantity and quality of graduates. From these graduates will come the next generation of faculty members, and unless something is done to arrest it, the downward spiral will continue.

**Table 2: Age distribution and average age of faculty members in 1998 [4]**

| **Country** | **Age distribution (% of total)** | | | | | | **Average age** |
|---|---|---|---|---|---|---|---|
| | **21 – 30** | **31 – 40** | **41 – 50** | **51 – 60** | **61 – 70** | **71 +** | |
| Belgium | 6 | 1 | 31 | 47 | 14 | 0 | 52 |
| Canada | 13 | 19 | 31 | 34 | 3 | 0 | 45 |
| Finland | 13 | 25 | 25 | 25 | 13 | 0 | 46 |
| France | 49 | 33 | 5 | 8 | 5 | 0 | 34 |
| Hungary | 7 | 16 | 33 | 30 | 14 | 0 | 48 |
| Italy | 0 | 10 | 31 | 29 | 28 | 2 | 54 |
| Japan | 3 | 18 | 23 | 43 | 13 | 0 | 50 |
| Korea | 0 | 5 | 57 | 36 | 2 | 0 | 49 |
| Mexico | 0 | 20 | 52 | 18 | 9 | 0 | 47 |
| Netherlands | 0 | 60 | 0 | 40 | 0 | 0 | 44 |
| Spain | 4 | 32 | 46 | 4 | 14 | 0 | 45 |
| Sweden | 19 | 19 | 22 | 15 | 22 | 4 | 47 |
| Switzerland | 0 | 0 | 27 | 73 | 0 | 0 | 53 |
| Turkey | 15 | 37 | 30 | 15 | 3 | 0 | 41 |
| UK | 9 | 21 | 24 | 34 | 9 | 2 | 47 |
| US | 1 | 15 | 35 | 35 | 13 | 1 | 50 |
| **TOTAL** | **7** | **18** | **29** | **33** | **13** | **1** | **48** |

*Concern 3: Ageing research facilities, which are being closed and not replaced*

Most of the universities are equipped with experimental facilities capable of supporting a diverse curriculum. Many universities not equipped with experimental facilities on their campus have access to such facilities at nearby large research laboratories.

Most university equipment and facilities are over 25 years old. Many research reactors and hot cells have been decommissioned, and no replacements are planned. However, although three radiochemistry laboratories were closed, four new ones were opened, and laboratories for radiation measurement are regularly modernised.

Generally, there is a decline in facilities, which will increasingly affect the capability of universities to do leading-edge research for industry. Because the industry is currently concentrating on operating existing plants more efficiently, it could be argued that this is not important at present. However, such a decline erodes future capability and deters both students and faculty members from working in the nuclear area.

*Concern 4: The significant fraction of nuclear graduates not entering the nuclear industry. The current supply of entry-level workers in nuclear areas may not meet demand in some countries*

By and large, at both the undergraduate and Masters levels, only 20% to 40% of students choose to continue to study; at the Doctoral level, between 30% to 70% of graduates, depending on the country, choose a career at an academic institution or nuclear research institute. It is also evident that a significant fraction (20-40%) of graduates in nuclear fields at all levels do not enter the nuclear industry. Some countries are already reporting that the number of students choosing a nuclear orientation is too low to respond to industry needs. It appears that this mismatch may grow.

*Concern 5: Repercussions of the deteriorating university situation on inhouse training*

Generally, in terms of facilities and trainers, the needs of the industry are being met. As the industry evolves, it would be expected that in-house training competence evolves so that demand is always satisfied. However, it must not be forgotten that, with early retirement schemes operating in many organisations, a considerable number of those trainers are likely to retire over the next few years. While young trainers are coming through, the numbers are not as large as those that will be leaving. Given the deteriorating university situation, the provision of suitable trainers in the near future is a matter of concern.

Certainly, with the decline in university facilities and faculties, there will be little opportunity to outsource training there. Also, because the situation regarding nuclear education is roughly the same from one country to another, there can be no guarantee that what is no longer available at home can be obtained abroad. There is already evidence that companies, if not actively collaborating, are at least making available places in courses to other organisations, and it may be expected that this trend will continue.

*Concern 7: The lack of communication and co-ordination*

To attract candidates to university programmes, collaboration with other, often foreign, universities was considered to be highly beneficial. However, several universities deplored the lack of communication and co-ordination among universities within their own country. This deficiency has led to a lack of coherence and completeness of programmes – for example, some topics are not covered or, conversely, lecture content overlaps between programmes.

Collaboration between industry and academia varies widely. Where collaboration exists and runs effectively, it is highly valuable, particularly when a university is involved in nuclear professional activities with industry. Collaborations keep the academic subjects relevant to the actual problems encountered in industry – a key element for attracting students to the field.

Traditionally, a main area of collaboration has been between the research or development branch of industry and a university. This aspect of collaboration is not as great now as it was in the past. Government participation in collaborative programmes has generally declined. It most often appears limited to the financial support to large-scale expensive facilities such as university research reactors and a few research programmes.

By and large, the collaborations among industry, research centres, and governments frequently rely more upon personal initiatives than upon an institutional policy. However, institutions that do have active collaborative programmes tend to find their situations more satisfactory, particularly in the area of recruitment.

### Efforts to encourage the younger generation

A wide range of initiatives to encourage the younger generation to enroll in nuclear subjects have had great success and are shown in Table 3. However, these are often made by individuals rather than by organisations; there are few coherent national initiatives.

**Table 3: Examples of best practice [4]**

| |
|---|
| • **Create a pre-interest in the nuclear domain.**<br>Include steps such as advertisements aimed at undergraduate candidates, high school “open days” at campuses or research facilities; regular reactor visits and campus tours for students; newsletters, posters, and web pages; summer programmes; preparation of a resource manual on nuclear energy for teachers; sponsorship of an advanced laboratory for high school students; recruiting trips and nuclear introduction courses for freshmen; and conferences given by industry and research institutes. |

| |
|---|
| • **Add content to courses and activities in general engineering studies.**<br>Increase emphasis on nuclear in physics and applied physics courses; organise seminars on nuclear in parallel or in liaison with the existing curriculum using speakers external to the university; set up informational meetings on the nuclear sector, existing graduate programmes, research and thesis topics; discuss employment potential and professional activities; and call attention to the environmental benefits of nuclear (energy from fission, fusion, and renewables in comparison to fossil resources). |
| • **Change programme content in nuclear science and technology education.**<br>Include advanced courses (such as reliability and risk assessment); broaden the programme to include topics such as nuclear medicine and plasma physics; assure that the education covers the full scope of nuclear activities (fuel cycle, waste conditioning, materials behaviour); provide early real contact with hardware, experimental facilities, and industry problems; and provide interesting internships in industry and research centres. |
| • **Increase pre-professional contacts.**<br>Encourage the participation of students in activities of the local nuclear society and its “young generation” network. |
| • **Provide scholarships, fellowships, and traineeships.**<br>In addition to promoting several support activities (mostly technical), industry participates financially by providing scholarships and, in several instances, has initiated new educational and training schemes. The size of the awards varies widely from one country to another. Academic societies, national research institutes, and governments also provide financial help. The number of these grants has remained relatively stable. |
| • **Strengthen nuclear educational networks.**<br>Establish and promote national and international collaborations in educational and/or training programmes, e.g. summer school, specialists’ courses. |
| • **Provide industry employees’ activities that are professionally more interesting and challenging and that pay more than those in the non-nuclear sectors.**<br>It is an exception, rather than the usual case, that a higher salary is used as a means to attract younger graduates. |
| • **Provide early opportunities for students and prospective students to “touch hardware”, interact with faculty and researchers, and participate in research projects.** |
| • **Provide opportunities for high school and early undergraduates to work with faculty and other senior individuals in research situations.**<br>Use the Web and other information techniques to proactively develop more personal communication with prospective students. |

**The important role of governments in nuclear education**

Governments are responsible for doing what is clearly in their countries’ national interest, especially in areas where necessary actions will not be taken without government. They have an important multifaceted role in dealing with nuclear issues: managing the existing nuclear enterprise, insuring that the country’s energy needs will be met without significant environment impact, influencing international actions on nuclear matters that affect safety and security, and enhancing technology competitiveness [4].

- *Role 1: Managing the existing nuclear enterprise*: Whether one supports, opposes, or is neutral about nuclear energy, it is evident that there are important current and long-term future nuclear issues that require significant expertise. This is largely independent of the future of nuclear electric power. These issues include: continued safe and economic operation of existing nuclear power and research facilities, some of which will significantly extend their planned lifetimes; decommissioning and environmental cleanup; waste management; maintaining the safety of nuclear deterrent forces in the absence of nuclear testing; and advancing health physics. These needs call for a guaranteed supply of not only new students, but also high-quality students and vigorous research.
- *Role 2: Preserving medium and long-term options*: While few new nuclear power plants are currently on order, governments must consider and protect their countries' medium and long-term energy options. Expertise must be retained so that future generations can consider the role of nuclear power as part of a balanced energy mix that will reduce CO2 levels, preserve fossil fuel resources, contribute towards sustainable development, and respond to geopolitical and other surprises that are sure to occur.
- *Role 3: Sustaining international influence*: The safe operation of nuclear installations is of paramount importance, and countries will only seek advice and be influenced by those who are at the cutting edge of nuclear technology. When the developing world moves to further exploit nuclear technology, the OECD/NEA Member countries, among the developed nations, must have the access and the necessary influence to assure that it is done in the appropriate manner with regard to such issues as safety, environment, waste management, and non-proliferation.
- *Role 4: Pushing the frontiers in the new technologies*: Investment in nuclear research and development has created new technologies and brings benefits to a wide area, as nuclear technology has widespread multidisciplinary character and requires the enhancement of many cutting-edge technologies with varied non-nuclear applications. Government should consider nuclear research and development as a part of their technology policy to enhance technology competitiveness.

## APPENDICE 2

### Tools for training and education

- *Direct numerical simulation*: the simulator gives numerical results with graphical support. It requires an important capacity of abstraction and good skills in using a computer. However, it can be used -for instance- to learn about the extent of the consequences of accidents in chemical environments, release/spread of smoke/gas, fires, explosions, electrical risks, etc. and to acquire skills in designing or operating processes, devices or machines in a safer way.
- *Screen simulation*: this kind of simulator is usually used in computer games, such as racing or flight simulators. An imaginary reality is created in the computer screen. It requires few or none special hardware. Despite such simulator could create some confusion if they were identified as game, they are very flexible and can be used for different purposes in education and training.
- *Full extend simulation*: training is carried out in a copy of the controls of a real system. The unique difference is that behind the control there is no a real facility, device or machine but a simulator. Users identify the situation as “real with no risk” generating a high performing learning process. It is being used in training of operators of critical systems, such as aircraft or nuclear power plants. High cost of the associated hardware limits the application of full extends simulators for very critical operations.
- *Virtual reality*: the control of a real system or the whole real system is created by the simulator and communicated to humans using special interfaces. Virtual reality could contribute to reduce costs of e.g. full extend simulation or used to analyse manual operations of assembly maintenance, etc.

**APPENDICE 3**

**SAFERELNET questionnaires [6]:**

**Industry members**

- Indicate industry sector and number of employees in your company.

- Does the company have any procedures for "on-the-job-training" in relation to risk and reliability ? *(If so, indicate the main items which are included as part of the training activity. Further indicate type of course material, i.e. whether it is in the form of manuals, lecture notes, books, and whether computer exercises are applied)*

- Is there any systematic "within-company" training in relation to risk and reliability ? *(If so, indicate the main items which are included as part of the training activity. Further indicate type of course material, i.e. whether it is in the form of manuals, lecture notes, books, and whether computer exercises are applied)*

- Specify "Continuing Education"-courses offered by universities within your industry sector if such exist. *(If so, indicate the main items which are included as part of each course. Further indicate type of course material, i.e. whether it is in the form of manuals, lecture notes, books, and whether computer exercises are applied)*

- Does there exist any other external (i.e. outside the company but within the industry sector) training activities in relation to risk and reliability? *(If so, indicate the main items which typically are included as part of the training activity. Further indicate type of course material, i.e. whether it is in the form of manuals, lecture notes, books, and whether computer exercises are applied)*

- Has your company performed any training of employees from other companies or of university students ? *(If so, indicate the main items which typically are included as part of the training activity. Further indicate type of course material, i.e. whether it is in the form of manuals, lecture notes, books, and whether computer exercises are applied)*

- Does your company have a specific policy with respect to giving the employees opportunities to achieve a Doctoral degree at specific universities ?

- Does there exist any text books/handbooks/manuals or other documents which are employed as basic references and/or for self-study purposes within your company ? (If so, please provide a list of such documents)

- Are there any specific computer programs which are applied by your company in relation to risk and reliability assessment ?
  *(Please also list names of such programs if relevant) If so, is there any systematic training of employees in relation to application of these programs.*

**University members**

- Please indicate the number of employees plus doctoral students within your division. Indicate the same numbers for the corresponding faculty

- Please list courses related to risk and reliability within your own division and the corresponding faculty. For each course, give a list of the main items that are included. Further indicate type of course material, i.e. whether it is in the form of manuals, lecture notes, books, and whether computer exercises are applied.

- Please list courses related to risk and reliability within other faculties at your university. For each course, provide a list similar to that above. Further indicate type of course material, i.e. whether it is in the form of manuals, lecture notes, books, and whether computer exercises are applied.

- Are the courses related to risk and reliability at your university typical in comparison with those given by other universities in your country ? If not, please provide further information on relevant differences.

- Does your division and/or faculty have a systematic policy in relation to recruiting employees from certain sectors of the industry for Doctoral degree studies ?

- Has your university performed any training of employees from companies within relevant industry sectors ?
  *(If so, indicate the main items which typically are included as part of the training activity, further indicate whether training was performed at the university or outside the campus, further indicate number of participants)*

- Are there any specific computer programs which are applied at your university in relation to risk and reliability assessment ?
  *(Please also list names of such programs if relevant. Please also indicate in which courses the different programs are being applied, and to which extent they are being applied in relation to the excercises)*

***ICARO course***

*Summary*

Nuclear techniques are essential in energy production, industry, research, and medicine. The statement of the European Commission of sustainable development clearly shows the importance to preserve and enhance competence in the field of nuclear technology.

The main objective of this practical course is to give students the opportunity to practically study the application of nuclear techniques in the environment of an actual working situation, with an access to large equipments (reactor and accelerator) which are not available in most of the partner institutions.

The target group are engineering students at the Masters level. Students at PhD level may be admitted.

The main activities are practical exercises using the facilities of the research centre ITN Lisboa with introductory lectures and round table discussions. Moreover, the participants will learn to include safety aspects and quality culture of applying ionizing radiation in their future work, and will incorporate a consciousness on radiation hygiene.

The practical exercises will be organized in international subgroups, allowing the participants to communicate and interact with students of different countries and cultural background.

*Main objectives:*

- To improve the quality and to increase the volume of student and teaching staff mobility throughout Europe, so as to contribute to the achievement by 2012 of at least 3 million individual participants in student mobility under the Erasmus programme and its predecessor programmes.
- To improve the quality and to increase the volume of multilateral cooperation between higher education institutions in Europe.
- To increase the degree of transparency and compatibility between higher education and advanced vocational education qualifications gained in Europe.
- To improve the quality and to increase the volume of cooperation between higher education institutions and enterprises.
- To facilitate the development of innovative practices in education and training at tertiary level, and their transfer, including from one participating country to others.

- To support the development of innovative Information and Communication technologies (ICT) - based content, services, pedagogies and practice for lifelong learning.

*Priorities:*

- To Focus on subject areas which do not readily lend themselves to extended periods of study abroad for their students.
- To Are a part of integrated programmes of study leading to recognized double or joint degrees.
- To Present a strong multidisciplinary approach.
- To Respond to demonstrated needs and challenges at European level (including the needs of enterprises) and contribute to the dissemination of knowledge in rapidly evolving and new areas.
- To Use ICT tools and services to support the preparation and follow-up of the Intensive Programme (IP), thereby contributing to the creation of a sustainable learning community in the subject area concerned.

*Objectives*

The experience of previous workshops has shown that they play a trigger role in increasing student and teacher exchanges between the partners. The contacts established and their preparation have led to new bilateral Erasmus agreements. The personal relations between the professors allow to better specify the contents of the student exchanges, improving the correspondence between the Erasmus student expectations and what the target university may offer him.

The present IP project is a part of a wider cooperation between the partners within the informal network CHERNE (Cooperation in Higher Education for Radiological and Nuclear Engineering), the aim of which being to develop a true multilateral collaboration in this field, using the Erasmus actions (staff and student mobility, intensive programmes), but also organizing other common activities with their own resources or with private sponsorship.

Some of these other activities imply cooperation with enterprises. The present project rather contributes to develop the teaching cooperation with a research centre. To some extent, research centers are also enterprises as they develop more and more activities of a commercial character.

Another aspect that is developed in the network is the organization of internship periods in a company of a foreign country, thanks to the help of the network's partner in this country. This exchange formula should play an increasing role, as the job market for engineers in the nuclear field is now very clearly a European open market, not a national one.

*Priorities*

Despite of this European character of the job market, the higher education is still organized at a national, sometimes regional level. With the decreasing interest for the nuclear field during many years, the offer of formation was decreased, and each university active in the nuclear field can only offer a limited part of the full choice of specialized matters. Establishing the cooperation at European level is thus a necessity to maintain the possibility for the students to acquire the specialized knowledge of their choice. The present IP will contribute to this goal.

This IP will gather the students in a relatively short time of two weeks to introduce them practically into subject areas which mostly can only be studied theoretically in their home institution. Multidisciplinary aspects are present in the IP through the round tables on sustainability and ethics.

Two of the partners (the coordinator and UPV - Universidad Politécnica de Valencia) have established a cooperation that leads to double degree. The present IP will be included in this cooperation. It should also contribute to answer to the main challenge of the nuclear industry: to maintain, develop and disseminate the knowledge in nuclear engineering and to enhance the level of expertise needed for the safety of existing facilities as well as for the expected new developments. The IP will also include student's talks and a round table devoted to the contribution of new nuclear techniques (generation IV) to the sustainable development: this is in agreement with the needs and challenges of the European Union, as stated by the Lisbon Strategy, i.e. the preservation of the energy supply by keeping all the energy options open and the retention and enhancement of the technological and scientific skills in the nuclear field.

*Project background and aims*

Education in the field of nuclear science and engineering has declined dramatically during the past two decades. This decline involved the number of students and in consequence the number of teaching staff and the infrastructure in educational institutions. This situation can be observed in practically all countries of the EU and there are national and international efforts to preserve the competence in nuclear technologies. In view of the small number of students presently being interested in this area it is obvious that cooperation between different institutions is mandatory. Many of the surviving institutions do have only very limited resources to train the students in the laboratory. On the other hand it is clear that the safe use of radioactive sources and installations producing ionizing radiation requires, besides the strong theoretical background, a practical experience which cannot be obtained from literature. The high costs of replacing equipment in nuclear technology make it extremely difficult to maintain up to date laboratories in educational institutions. Moreover the opportunities to get access to large scale facilities like reactors and accelerators for educational purposes are very limited. To promote the awareness of the potential working areas it is thus highly desirable that large scale facilities actively participate in the educational process. An additional challenge in education is the ongoing globalization in all professional areas. This challenge also requires cooperation on an international scale. Finally, education in nuclear science and engineering provide a contribution to the worldwide efforts in tackling the fundamental issues of climate changes and energy supply.

In view of this background, the first objective of the course is to build larger groups of students to gain access to large nuclear facilities and to share the existing facilities of the participating educational institutions for practical training. The students of nuclear engineering and related areas will acquire experience in the working environment of large scale nuclear facilities. In this regard, the course will be organized in Portugal, at the Technological and Nuclear Institute (ITN) of Lisboa. ITN is a State Laboratory under the Ministry of Science, Technology and Further Education, endowed with scientific, administrative and financial autonomy. ITN has as attributions to perform and promote scientific research and technological development, in particular in the field of nuclear sciences and technologies, radiological protection and safety, as well as, in that domain, to undertake graduated and post-graduated education activities and the permanent knowledge update of technicians, and also to promote the public knowledge of science in its areas of specialization. ITN operates unique infrastructures that it makes available to the community, namely the Portuguese Research Reactor, the Van de Graaff accelerator, the ion implanter, the helium liquefier, the laboratories for dating, isotopes, radiation metrology, and others. Given these peculiar features and the available facilities, the choice of ITN as the local organizer will allow optimally achieving the important objectives not only of offering good practical formation but also of giving insights into actual research facilities.

A second objective is to develop expertise and skills in nuclear/radiological applications by these practical exercises: the students will be confronted in practice to the special radiation safety aspects in the applications of ionizing radiation. This IP brings the participating students out of their usual educational environment and routine, and let them experience the real life world of professional experts in their professional environment.

A third objective is to develop the cooperation between European partners. The possibility to form international teams in the IP helps to develop channels for exchanging experiences and information about new developments in nuclear technology and the organization of nuclear safety in the different countries. It is hoped that these exchanges will result in permanent links, including research, and will contribute to enhance competence in nuclear technologies in Europe.

A last objective is to develop communication and interaction between the different national groups. To enhance contacts, all exercises will be organized for small subgroups that will be as internationally mixed as possible.

This IP offers the participating institutions and their students the opportunity to engage themselves in the field of climate changes and sustainable energy supply with round tables discussions prepared by the students.

All the participating educational institutions strongly support collaboration on the European level and increasing students mobility. Hence the International Policy Statements of the participating institutions show great overlap in their contents.

The main objective has always been to guarantee and to increase the opportunities for our students on the labor markets , locally and abroad.

The participation in an IP will not only enhance the technological knowledge of the students, but also improve their social skills, their cultural knowledge and their languages. Especially this IP 'ICARO' will contribute to the realization of the European Policy Statement of the participating institutions. This IP contributes to the creation of a common European Educational Area as the participating institutions exchange their respective ideas and implementations of the Bologna process and try to harmonize their standards according to these policies.

The matters instructed in the course are considered as a practical part of the syllabus organized in each of the participating institutions. To an extent that varies from one partner to the other, this practical part could not be organized or only partially organized in each institution separately, because of the absence of access to similar facilities, or the difficulty to organize practical courses on such facilities. Clearly, the European cooperation is here essential to open the access to large equipments.

Innovative aspects are the interdisciplinary approach (economical, ethical and safety aspects included) to the various applications and discussions on the future and sustainability aspects of these techniques, in particular through round tables discussions including economical, ethical and safety aspects.

The main characteristic of the project from the pedagogical point of view is the approach of a highly specialized and difficult field - nuclear technology - by practical work, and the confrontation/discussion in practice with colleague-students from different background and different countries.

The program consists of lectures to introduce to, repeat and reconnect the relevant topics. Practical lab exercises with data analysis create practical competences in applying these techniques. In addition, students reflect the course topics by preparing presentations on some experiments in international groups. A consequent systematic approach to radiation safety will create an awareness and responsibility towards this issue. Economical sustainability and ethical papers will be prepared by the national groups before the course and presented and discussed during round table conferences during the course.

Since the practical exercises will also be guided by highly specialized scientists, the students will get insight in the complexity of research work in nuclear areas.

The beneficiaries are students in nuclear and radiological engineering or closely related fields of the master level. PhD students may also be admitted. They will be selected according to their willingness to participate, to their academic results, and to their knowledge of the teaching language (English), with a special attention on gender issues, and to promote the participation of disabled students and of members of cultural minorities. Instructors are specialists from the partner institutions and from ITN. The students are assisted by the accompanying professors. This offers the unique possibility to ensure an optimal knowledge transfer between the specialist and the students, since barriers like language, pedagogical deficiencies of the specialists can be bridged.

This program provides a type of highly specialized skills which is in use in many different fields of industries, research, and authorities. It is a very good example for higher advanced stages of the European Qualification Framework where interdisciplinary experience coupled with personal responsibilities and decision-making under consideration of the socio-economic field (including the radiation safety aspects) are described. We attempt to provide these competences on a European level reflecting the international dimension of the disciplines involved.

**CHERNE network**

The CHERNE initiative is a proposal to develop a non-formal wide-scope open network to enhance cooperation, competence as well as equipment sharing between its partners. It should not be seen as a competition to the existing networks and welcomes any activity that would be organized in collaboration with them. But it has its own organizational philosophy and wants to keep its specificity.

CHERNE is an open, non-profit and non formal association, constituted as a network of Institutions of Higher Education, including Research Institutions closely linked to higher education, active in the radiological and/or nuclear field, which agree with the basic rules of the network, as expressed by the present declaration.

*Activities*

- Cooperation between the institutions should enhance the mutual support by learning from each other, by exchanging experiences, and by regular mutual reflections on what we can do to counteract the 'less interest among students' and the 'less interest among the academic and political authorities' and also on what we can learn from more successful or from less successful partners.
- The scope of CHERNE is not limited and any activity related to higher education in radiological and/or nuclear engineering can be proposed.
- The list of the CHERNE activities, including the secretariat, the workshop, as well as the list of their organizers, is established annually at the end of the general assembly, for the past year and for the forthcoming year.
- Most of CHERNE activities will be organized for students.
- CHERNE activities are offered in priority to students of full members, and their organization should involve at least one European academic member.
- Development of local activities made available to other students of the network should be kept as interesting.
- Without excluding the organization of workshops devoted to teaching tools or methodology, or to common research subjects, we refer hereafter to «CHERNE activities» that should directly benefit to students of the partner's universities, mainly at the Master level. If the activity is open to other participants, this should not limit the access of the students.
- The language used in CHERNE activities is English. The partner(s) organizing the activity will communicate all documents well in advance to the other partners, in order to allow them to produce translations for their students when necessary.

- The CHERNE activities will be organized at no cost, or a very low fee, for the students coming from other partner universities/institutions. The organizing partner will find and propose cheap accommodation for the students coming from abroad.
- When possible, the organization of CHERNE activities will be included in ERASMUS exchanges. Therefore, the partners are encouraged to sign bilateral ERASMUS agreements. When possible, an activity might be organized as ERASMUS intensive programme. The recognition of ECTS credits should be organized in the framework of these bilateral agreements.
- CHERNE partners will be attentive to the necessity to include practical training in their activities for the students, including when possible an access to big facilities.
- A CHERNE activity should include at least a one-week/2 ECTS module.
- Teaching modules are clearly seen as a possible kind of activity, but other types of cooperation may be also developed such as material for modules conveniently adapted in each university, e-learning, etc.
- Whereas experimental activities will usually imply the travel of students to the facilities, for theoretical/computational modules the professor might rather go to the students.

**ENEN project**

The ENEN Association has developed into one of the cornerstones of the European Higher Education Area in the nuclear field and acquired considerable visibility in academic and industrial circles.

Resources within the ENEN Association are coordinated with other education and training organizations and End User networks to ensure that there is no future shortage of skills to continue the safe and efficient operation of Europe’s nuclear industry and the next generation of nuclear power plants, to maintain and develop the wealth of non-power nuclear applications in our modern societies, to protect and monitor people and their environment with respect to radiation and radioactive contamination, to take care of decommissioning and dismantling obsolete nuclear installations, and eventually to ensure the safe disposal of radioactive waste in underground storage facilities and selected geological formations.

In this way, the ENEN-II project will provide means to strengthen European co-operation, for mitigating prospective risks of scarceness of both researchers and skilled academic teachers in the fields of radiation protection, analytical radiochemistry, radioecology and geological disposal of radioactive waste. It will harmonize the education programme to the current and future needs of the End Users and create attractive courses, which arouse students to choose and pursue studies in those fields. To some extent, the academic programmes set up within the project could also be used as pedagogic materials for professional training activities.

Beyond the educational and training objectives, the ENEN-II project will federate European academic efforts for improving and developing multidisciplinary research. The development of new academic research programmes generally implies a heavy investment in both human resources and equipment. Organizing a constructive dialogue between End Users, teachers and researchers, pooling resources, structures and facilities, and facilitating access and mobility will help to accelerate the emergence of new research programmes. In this way, ENEN-II contributes to the construction of the European Research Area [15].

*Project objectives and state of the art*

Nuclear energy, and without any doubt also non-energy applications of nuclear technologies, still play an important role in satisfying the present society needs and are expected to continue this role in the future, independently of the current social perceptions and political decisions. Existing plants will operate for several decades from now; reprocessing will continue; decommissioning of plants will last until the second half of the century; and waste management will be around at least until towards the end of the century. All of these facilities need to be managed safely, demanding high quality, technically competent personnel with nuclear specific skills to staff also the Licensees organizations, the Support companies and the Regulatory bodies. In addition, radiation protection specialists will be required. Under pressure by the commitments of the Kyoto protocol, confronting tangible effects of global warming and facing the disappointing contribution of renewable energy sources with respect to the expectations to fulfill current energy requirements, a slow but unmistakable change in policies is observed in favour of the reactivation of nuclear programmes. Major countries have decided to construct new large nuclear power plants after an extensive evaluation of viable alternatives and in full consensus with the public opinion. Clearly an apparent scarcity of professionals in the nuclear fields would hypothecate such decision [15].

Still some adverse effects of the deregulation of the markets are affecting society: the pressure to reduce costs and the lack of a centralized long term planning. It still means that educational and training structures for a few students or trainees in nuclear disciplines are not maintained; although pre-retirements in the industry will be curbed, retirement and replacement rates will remain an issue as well as the change of the required professional profiles by the industry. Lack of long term planning, predictable regulations and political opportunism will continue to paralyze or postpone decisions with respect to nuclear issues and result in fragmented “last minute”, local initiatives to palliate problems “as they arise”, that makes any particular solution inefficient and, in some cases, only partially effective. The problem has been identified worldwide and several references can be found in the USA where, after quantifying the problem, initiatives have been put in place integrating industry and university. International organizations like NEA [4] or IAEA [17] have issued several reports, supporting networking initiatives such as the World Nuclear University and the Asian Network for Education in Nuclear Technologies, and programmes on Nuclear Knowledge Management.

The specific European response, going beyond generic recommendations is the ENEN (http://www.sckcen.be/enen/) project, launched under the 5th Framework Programme with the main objective of producing a roadmap for the way ahead in nuclear engineering education in Europe and organizing pilot sessions. As an outcome of this project the ENEN Association was founded as a legal entity. Its members, universities and research centers, implemented together with a few training organizations and industrial partners the NEPTUNO project (http://www.sckcen.be/neptuno/) under the 6th Framework Programme.

The membership of the ENEN Association now consists of 35 universities members and 6 research centers. Supported by the 5th and 6th Framework Programme of the European Community, the ENEN Association established the delivery of the European Master of Science in Nuclear Engineering certificate. In particular, education and training courses have been developed and offered to materialize the core curricula and optional fields of study in a European exchange structure. Pilot editions of those courses and try-outs of training programmes have been successfully organized with a satisfying interest, attendance and performance by the students and the support of nuclear industries and international organizations. The ENEN Association further contributes to the management of nuclear knowledge within the European Union as well as on a world-wide level, through contacts with its sister Network ANENT in Asia (http://www.iaea.org/inisnkm/nkm/documents/trieste2006/29_ANENT(Kosilov).pdf), and by its participation to activities of the World Nuclear University [15].

The objective of the ENEN-II project (http://www.enen-assoc.org/en/activities/for-universities/enen-ii1.html) is to consolidate, the results and achievements obtained by the ENEN Association and its partners during the ENEN and the NEPTUNO projects and to extend and expand the activities of the ENEN Association. One of the objectives of the project is also to enlarge the effective membership of the ENEN Association by expanding into the new fields and nuclear disciplines, attracting universities and faculties active in those fields, and to increase the number of associated members by strengthening the cooperation with regulatory bodies, nuclear industries and waste management organizations.

*Consolidate* by implementing the education and training modules proposed and developed in the past few years and tested during the pilot sessions. “Consolidate” by applying the course evaluation criteria to the actual course and training performance, taking into account feedback from the participants and their companies, the end users and other stakeholders (see Figure 1). *Consolidate* by combining and organizing scattered web sites, data bases and course information in a well-designed and accessible communication and knowledge management system derived from the NEPTUNO communication system. *Consolidate* by testing in practice, and in collaboration with accreditation authorities, the developed mutual recognition schemes for academic education in nuclear disciplines.

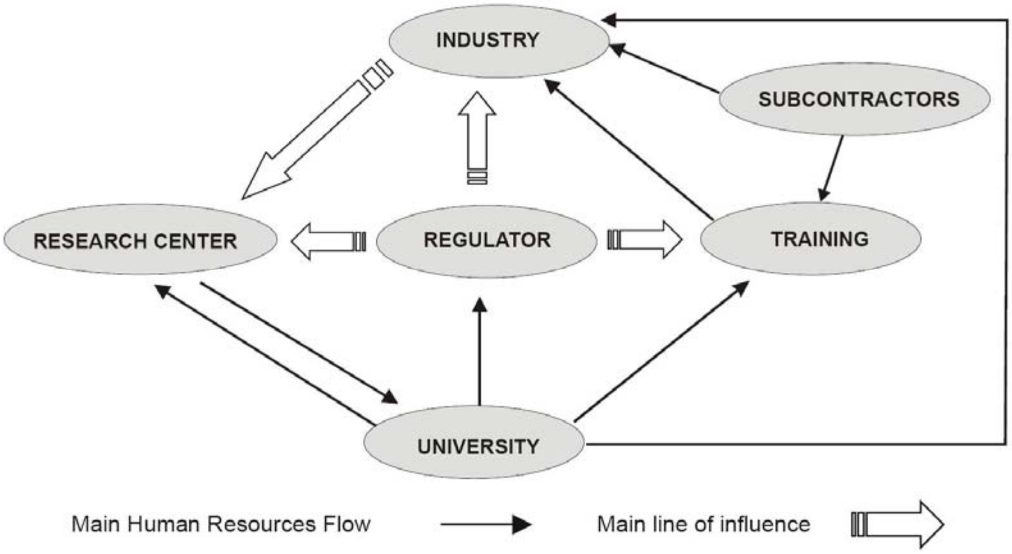


**Figure 1: Main players in nuclear education and training [15]**

*Extend* by moving outside the academic education area into professional and even vocational training, thereby strengthening the interactions and collaboration of universities, research centers, training organizations and industries to make training offers better respond to industry needs and enhance mutual recognition of professional qualifications across European countries. *Extend* to make a better use of and facilitate the access to EU tools to increase mobility of students and professors in nuclear disciplines. Testing of formulated best practices for mobility, accreditation and recognition of qualified licensed staff and in general all staff needing some form of education, schooling or training before operating in the nuclear industry. “Extend” by strengthening the links with nuclear education and training networks outside Europe, the World Nuclear University, and by developing a viable Erasmus scheme for Master of Science in Nuclear Engineering within the ENEN Association [15].

*Expand* by moving beyond the disciplines related to nuclear engineering for power plant design, construction and operation, into a broader area including nuclear engineering and other disciplines in support of reactor safety, radiation protection, radioactive waste management, radiochemistry, decommissioning and industrial applications of nuclear technologies. “Expand” by addressing the needs for education, training and skills development expressed by other groups of End Users in the framework of networks, such as ENETRAP, CETRAD, EUNDETRAF, etc. Of particular concern, to the EU Commission, authorities, industry and professional, university-based scientists are special skill-base deficits within nuclear radiological protection, radioecology and radiochemistry at masters and doctorate levels. It is contended that skills in these areas are of strategic, as well as immediate, importance for the maintenance of European nuclear operations and options within the evolving EU economy [15].

They are also important for meeting the challenges presented by unpredicted nuclear events (e.g., the Windscale fire, Chernobyl accident, terrorist and sabotage activities). In order to mitigate the effects of this decline the EURAC project identified remaining capabilities within the EU higher education sector, identified a need for about 100 trained specialists per year and proposed three European Masters courses that would meet the identified need. The ENEN-II project will expand education and training activities into those fields and mobilize the identified, existing fragmented capabilities to form the critical mass required to implement the courses and meet the radiological protection, radioecology and analytical radiochemistry postgraduate education needs of the European Union. In order to achieve the above it will be necessary to finalize a detailed syllabus for each of the proposed degrees and identify education institutions providing the course/module materials that are required to teach it, and having the laboratory facilities and equipment for practice training and research. Gaps in the curricula will have to be filled by developing, validating and having accredited the missing course modules [15].

Until now, education and training in waste management and underground storage were not addressed by these projects. Although the waste management is only a corner of the whole nuclear activities, the lack of commitment in this field is worrying, especially since the study of radioactive waste storage is a complex subject that requires an ever-increasing conjunction of different scientific disciplines. Moreover, difficulties exist of achieving scientific and technical consensus in this field. Indeed, growing environmental awareness lead to make difficult the social endorsement of any real waste storage solution without formal scientific demonstration of its safety. In this frame, available fundamental knowledge on numerous phenomena, particularly on coupled phenomena governing the behavior of the underground disposal has still to be improved and requires sustainable academic researches [15].

The need for an important educational effort directed towards increasing the research capacity is obvious however, as very little specific programmes are available in the European universities. Besides, the fall in the number of PhD students on the one hand and the rise of the average age of the faculty members on the other hand, leads us to anticipate imminent problems for the continuation and renewal of the skilled teams in several countries. Faced with this situation, the ENEN-II project will expand education and training activities and promote inter-university collaboration aimed at creating a common educational programme on the radioactive waste disposal, compatible with the European educational road map (Bologna declaration). The project will construct a common educational programme for radioactive-waste storage both by considering the diversity of the scientific issues involved and by anticipating the future needs of stakeholders in term of competence. As the long-term goal is to promote academic research, the courses encompassed in the programme will be targeted for delivery at the final year of Engineering and second year of Master (MS) degree, in order to arouse students' interest in pursuing radioactive-waste storage studies in third academic cycle (PhD level. The common educational programme will be tested by organizing pilot sessions in four of the universities adhering to the project. The methodology adopted for teaching consists in using multi-media facilities for broadcasting in live each lecture taught in one of the partner universities to the other partners. In this cost-effective way all the students will receive the same pedagogic programme independently of their geographic situation. Moreover, the outcome assessment of the pilot sessions will be facilitated by using the same evaluation criteria regardless to the specific constraints in each university [15].

Expand will thus include the development of networking within the ENEN Association to cover additional fields, e.g. reactor safety, and by establishing new networks. Expand by developing courses, workshops, seminars and training modules on new topics such as GEN IV, waste management, decommissioning, lifetime extension and other topics to be defined. Expand, finally, by developing a “think tank” functionality on a range of issues in modern societies where nuclear energy and applications are part of the possible options.

*Potential impact*

Due to the nature and scope of the ENEN-II project, the exploitation of its results affects virtually and effectively the whole European “nuclear” community. The project impact is in this respect huge. As for the NEPTUNO project in the past, the European universities, the students in nuclear fields, the nuclear professionals, training centers, nuclear operators, regulators and research institutions in each country, and the related international organizations are the potential customers and beneficiaries of the project achievements.

The practical implementation of the project outcomes will result in the consolidation of a sustainable European Area of Higher Education and Training covering nuclear engineering, nuclear safety, radiation protection, analytical radiochemistry, radioecology, and radioactive waste management and disposal. It will contribute to the preservation of the nuclear knowledge in Europe and make it more accessible. It will facilitate the mobility of individuals, as well students as professionals, and enhance the mutual recognition of their diplomas and qualifications across the European Union. Through the mechanisms implemented within the project, it will be possible to achieve European certifications of an educational type, such as for the European Master of Science and for advanced courses on a variety of nuclear disciplines, and for the professional type, like training programmes or postgraduate courses to be imparted and recognized anywhere in Europe.

The European impact will be dependent on the extent of dissemination and the accessibility of the results, the participation of young professionals and students to the pilot sessions, and the involvement of the stakeholders.

Virtually the whole range of nuclear players will be represented: apart from the educational institutions themselves, the End Users, such as research institutions, the government institutions, the nuclear enterprises, the regulatory bodies and the nuclear learning societies will become involved in the project.

A higher level of networking of nuclear related organizations and industries at the European level will be obtained, in particular within the nuclear disciplines, such as engineering, radiation protection, analytical radiochemistry, radioecology, decommissioning, radioactive waste management and disposal, and between the academic institutions, the training organizations and the end-user associations. This will enhance the adjustment of curricula and training packages to the end-user needs, thereby improving the employment and career opportunities, and the qualifications of the young professionals. At the world-wide and intercontinental level, networking will enhance opportunities for European teachers and professionals to disseminate their expertise and produce added value by exporting the leading position of the European Union in nuclear power plant construction and other nuclear applications [15].

Non-overlapping education schemes in nuclear disciplines, an Erasmus curriculum for nuclear engineering and more transparent teacher and student mobility schemes will facilitate the certification of highly qualified specialists as well as the formation of young professionals with a broad view on nuclear applications, safety aspects and regulatory issues. Procedures and guidelines for advanced courses in nuclear fields will facilitate the organization of such courses, optimizing and coordinating the contents, collect practice in the joint organization of joint courses and enhance their quality.

Efficient communication tools established between academia and schools and the end-users, should result in a better gearing of short term research work, such as internships, master theses and postdoctoral work to the needs of nuclear industries, research centers and regulatory bodies. Mobility schemes for those student groups will become available. Dissemination of information on research results and socio-economic studies of relevance to the general public will be enhanced by respectively a major ENEN conference and the development of a “Think Tank” functionality within ENEN. At the same time, PhD students will have a forum for presenting their work and its relevance not only to a group of specialists in their own field, but also for meeting the challenge of transferring their essential message to the broader public.

All web sites related to the ENEN Association will be reachable through a single internet address, which will also link, with a semantic web structure with mutual recognition of authentication information, to other databases for nuclear applications. Contacts in the ENEN countries will be available ensuring regular verifications and timely updates of databases on education and training. The potential and role of the ENEN Association as a producer of outputs related to nuclear applications (books, CDROMs, E-learning modules, multimedia presentations, etc.) to the benefit of students, young professionals and the general public will be tested. Finally tools and instruments will be available to secondary schools and youngsters to get acquainted with nuclear applications, their often unknown impact on current societies and their perspectives for the choice of a career.

**IAEA Network of Centers of Excellence (COE) in Training and Demonstrations of Waste Disposal Technologies [18].**

Over the last thirty years many IAEA Member States have developed the methodologies for the disposal of radioactive wastes in underground "geological" repositories. Underground Research Laboratories have been set up and used for this purpose.

The *in-situ* laboratories in this network also provide the opportunity for hands-on training in waste disposal technologies for countries which do not have their own underground research facilities.

This group includes the following countries:

- Canada with the Underground Research Laboratory of Lac-du-Bonnet, Manitoba;
- Belgium with the Underground Laboratory in Mol, operated by EURIDICE;
- Switzerland with the Grimsel Test Site;

- Sweden with the Aspo Underground Research Laboratory, and the University of Kalmar;
- Wales, United Kingdom, with the Geo-Environmental Research Centre in Cardiff; and
- United States of America, with the WIPP facility near Carlsbad, New Mexico, the Yucca Mountain Project in Nevada, and Lawrence Berkeley National laboratory in California.

**University courses**

**Polytechnic of Milan, Italy – Permanent formation courses**

| **Faculty** | **Course Title** | **Description** |
|---|---|---|
| Dipartimento di Energia | Sicurezza industriale:<br>tecniche di valutazione del rischio | Le competenze necessarie per affrontare le complesse problematiche di sicurezza sono ormai permeate in tutti i settori dell'ingegneria ove l'analisi di sicurezza ha assunto un ruolo importante quale strumento di supporto alla progettazione degli impianti e mezzo insostituibile per la pianificazione dell'emergenza in situazioni incidentali. Oggi numerosi settori dell'ingegneria industriale ritengono indispensabile un approccio sistematico alla progettazione e gestione dei sistemi entro accertati limiti di sicurezza.<br>Inoltre, la valutazione della sicurezza e le conseguenti scelte operative fanno parte di precisi obblighi di legge che attengono al rispetto degli standard di emissione, alla Valutazione di Impatto Ambientale (VIA), alla stesura dei rapporti di sicurezza delle aziende a rischio previsti a seguito della Normativa Seveso, alla progettazione e operazione di componenti e sistemi.<br>La determinazione dei rischi associati ad una data attività industriale e la valutazione dell'efficacia delle protezioni preposte richiedono l'acquisizione di conoscenze relative al particolare impianto in esame e agli altri sistemi produttivi, ambientali e socioeconomici ad esso correlati. Pertanto, l'approccio alla sicurezza deve essere multidisciplinare al fine di:<br>• individuare le sorgenti di potenziale pericolo;<br>• analizzare le possibili situazioni incidentali, da un punto di vista qualitativo, per determinare l'evoluzione dell'incidente;<br>• valutare la frequenza di accadimento delle situazioni incidentali a partire dai dati di affidabilità dei componenti e sistemi di protezione coinvolti;<br>• analizzare le possibili situazioni incidentali da un punto di vista quantitativo per valutarne le conseguenze. |
| | Tecniche innovative per la valutazione dell'affidabilità' e disponibilità di impianti industriali | Il corso intende offrire adeguate conoscenze tecnico-scientifiche su problematiche critiche di affidabilità, disponibilità, diagnostica e manutenzione e fornire gli strumenti metodologici fondamentali per la loro trattazione, nonché indicare gli ambienti specialistici di supporto. Nel corso sono esposte le moderne metodologie di previsione statistica, di rappresentazione di sistema e di modellistica fenomenologica utilizzate per lo sviluppo di sistemi di monitoraggio e diagnostica e per le valutazioni<br>dell' affidabilità, disponibilità e manutenibilità di impianti complessi. |

**Polytechnic of Milan, Italy – Undergraduate courses**

| Faculty | Course | Hours | Credits | Professor | Contents |
|---|---|---|---|---|---|
| Aerospace Engineering | Safety of flight | 36 Lectures<br>16 Exercises | 5 | Morganti Guido | The Safety in flight operations. Its evolution in time. Typology of the events, Statistics and Accidents review. Structures connected to the Safety of flight. Preventive systemic analysis. Quality through probabilistic analysis. Methods for risk assessment. Accidents and Incidents Reporting. Systems. Prevention: safety of System and Safety of Flight. Accident Prevention Loop. Definition and management of Risk. Culture of Safety. Investigation of accidents: objects, procedures, responsibility and methods. Analysis of evidence, random factors and Recommendations. The Human Factor in accidents. The operating environment: the Air traffic control system. |
| Engineering of the environment and of the territory | Hydraulic protection of the territory 1 (prevention and protection from the hydraulic risk) | 32 Lectures<br>15Exercises | 5 | Rosso Renzo | Probabilistic methods of risk assessment and reliability. Risk assessment in hydrologic-hydraulic engineering: hazard, exposure vulnerability. Mapping of flooding risk. Methods of structural mitigation. |
| Chemical Engineering | Reliability and safety in process industry | 32 Lectures<br>24 Exercises | 5 | Biardi Giuseppe | Definition of risk. Toxicology and industrial hygiene. Source models. Dispersion in atmosphere. Fires and outbreaks. Protections. Identification and risk assessment. Normative organization. Prevention. |
| Civil Engineering | Technique and safety of the construction yards | 24 Lectures<br>16 Exercises<br>16 Laboratory | 5 | Berni Vanni | Normative and legislative organization in Italy and Europe. Machinery and general devices in construction yards. Operating techniques and provisional works. Management of safety and risk assessment. Reticular scheduling of jobs, techniques and analysis of criticality. Impact of jobs on environment: systems of mitigation and techniques of safeguard. |
| Electrical Engineering | Reliability and quality control | 28 Lectures<br>12 Exercises<br>16 Laboratory | 5 | | The quality concept. The norms. The certification. Quality and reliability in design (FMEA). Models of forecast of reliability. Maintenance and availability. Environmental compatibility. Robust design. |

| Faculty | Course | Hours | Credits | Professor | Contents |
|---|---|---|---|---|---|
| Electrical Engineering | Electrical safety | 30 Lectures<br>20 Exercises | 5 | Zaninelli Dario | The safety of persons and systems. CEI regulations and the enforced legislation in electrical safety. Electric current effects on the human body and admissible voltages. Criteria of protection from direct and indirect contacts. Safety and breakdowns in the electrical net. Systems of filtering of noise and criteria of design of the filters. |
| Engineering of the materials | Protection of the environment and safety in the polymer industries | 18 Lectures<br>12 Exercises | 2.5 | | Risk Profile in the working environment of the technologies and the manipulations for the transformation and production of plastics. Impact of production activity on the territory. Risks for safety, risk for health. Evaluation of exposure to chemical and physical factors of risk. Toxicological characteristics of the substances, relationship dose adsorbed-effect on health. Criteria for prevention of accidents and pathologies. Indications for design and remediation: safety of machines. Filing the report "Risk analysis and assessment": the cognitive references, the legislative references, the institutional references. |
| Engineering of the environment and of the territory | Hydraulic protection of the territory | | | Rosso Renzo | Design of hydraulic works; hydrology and control of the fluvial floods; impact of the hydraulic works on the fluvial regimen; risk and reliability in the hydraulic design. |
| Civil Engineering | Technique and safety of the civil yards | | | Crispino Maurizio | Normative; machinery and plants; management of safety; impact of the jobs on the environment. |
| Nuclear and Chemical Engineering | Safety and risk analysis A | 80 Lectures<br>20 Exercises | | Zio Enrico | Definition of safety and risk analysis; safety: basic principles and quantitative evaluation methodologies; algebra of events and probabilistic calculus; reliability, availability and maintenance; the Monte Carlo simulation method; phenomenological analysis of accident evolution and of the impact on man and environment; techniques of computational intelligence in risk analysis. |
| Nuclear Engineering | Safety and risk analysis B | | | Ricotti Marco | Fundamental criteria of safety in the plants; risk analysis; introduction to the quantitative assessment of risk; classification of accidents; main protection and safety systems; accident and consequence modeling |

**University of Pisa, Italy – Undergraduate courses**

| Faculty | Course | Credits | Professor |
|---|---|---|---|
| Engineering of industrial and nuclear safety | Safety and risk analysis | 9 | Carcassi Marco Nicola Mario |
| Engineering of industrial and nuclear safety | Electrical safety | 9 | Moretti Alberto |
| Engineering of industrial and nuclear safety | Integrated systems quality-safety-environment | 9 | |
| Engineering of industrial and nuclear safety | Environmental impact evaluation | 6 | Mazzini Marino |
| Engineering of industrial and nuclear safety | Analysis of accidents in chemical plants | 9 | Cozzani Valerio |
| Engineering of industrial and nuclear safety | Management of quality | 6 | Vaglini Sergio |
| Mechanical Engineering | Industrial management of quality | 5 | Failli Franco |
| Chemical Enginnering | Reliability and safety in the industrial process | | Zanelli Severino |
| Electrical Engineering | Tests and electrical safety (v.o.) | | Moretti Alberto |
| Mechanical Engineering | Industrial management of quality | | Mirandola Roberto |
| Nuclear Engineering | Safety and risk analysis | | Carcassi Marco Nicola Mario |

**University of Pisa, Italy – Postgraduate courses**

| Faculty | Issued title | Year | Instructions |
|---|---|---|---|
| Department of Mechanical, Nuclear and Production Engineering | Specialist in ‘safety and industrial protection’ | First year | • High-risk industrial plants (Normative; Foundations of chemical plants; Industrial process systems; Thermo-electrical and nuclear plants).<br>• Evaluation of industrial impact (Normative; Methodology of VIA and applications).<br>• Chemical and physical aspects of accidents (Chemical aspects of accidents; Thermo-fluid-dynamic of accidents; Dispersion of pollutants in atmosphere; Dispersion of pollutants in water and on the ground).<br>• Measurements and instrumentation (basic instrumentation in industrial plants; Safety and control systems of plants).<br>• Risk analysis (Methodologies of safety analysis; Elements of reliability theory; Estimation of consequences of accidents). |
| | | Second year | • Safety and protection of the workplace (Normative; Safety of electrical systems; Safety of machines, of lifting equipment; Hygiene of the job).<br>• Measurements and instrumentation (Instrumentation and measurements of dangerous substances; Nuclear techniques and measurements for engineering applications).<br>• Emergency plans and monitoring networks (Emergency planning).<br>• Safety in the realization and operation of plants (Quality assurance in the nuclear technologies; Aspects of safety in the mechanical design of plants; Aspects of safety of chemical processes; Safety in the operation of high risk plants). |

**Polytechnic of Turin, Italy - Undergraduate courses**

| Faculty | Course | Hours | Credits | Professor | Contents |
|---|---|---|---|---|---|
| Engineering<br>of the environment<br>and of the territory | Safety of the temporary<br>and/or mobile yards | 40 Lectures<br>15 Exercises | 5 | Clerico Marina | |
| Engineering<br>of the environment<br>and of the territory | Safety and risk analysis A | 20 Lectures<br>15 Exercises | 3 | Carpignano Andrea | |
| Engineering<br>of the environment<br>and of the territory | Foundations of<br>occupational safety | 40 Lectures<br>15 Exercises | 5 | Patrucco Mario | |
| Engineering<br>of the environment<br>and of the territory | Safety and risk analysis B | 10 Lectures<br>15 Exercises | 2 | Gecchele Giulio | |
| Engineering<br>of the environment<br>and of the territory | Technique of environmental<br>safety | 30 Lectures<br>30 Exercises | 5 | Piccinini Norberto | Instruments in order to characterize the dangers in the various activities and to define organizational procedures, in order to meet the safety objectives; risk assessments in decisional processes for correct design and careful management of the entrepreneurial or environmental risks. |
| Engineering<br>of the environment<br>and of the territory | Plants in process industry /<br>Technique of environmental<br>safety | 100 Lectures | 10 | Sassi Guido<br>Piccinini Norberto | Dangers in the various activities and procedures to achieve safety objectives; risk assessments in decisional processes. |
| Engineering<br>of the environment<br>and of the territory | Occupational safety and<br>environmental protection/<br>Safety and risk analysis | 100 Lectures | 10 | Gecchele Giulio<br>Carpignano Andrea | Problems of safety on the job and environmental protection; the risks connected with the safety on the job and important incidents; norms for the safety on the job. |
| Engineering<br>of motor-vehicles | Hygiene and occupational<br>safety | 18 Lectures<br>2 Exercises<br>12 Laboratory | 2 | Oggero Simona | D.Lgs. 626/94, general aspects, introduced innovations, regulation put into effect and recent modifications. |

| Faculty | Course | Hours | Credits | Professor | Contents |
|---|---|---|---|---|---|
| Chemical Engineering | Safety and environmental protection of the industrial processes | 25 Lectures<br>23 Exercises | 4 | Piccinini Norberto | |
| Chemical Engineering | Safety and hygiene of the job | 20 Lectures<br>15 Exercises | 3 | Mazzeo Giuseppe | |
| Chemical Engineering | Electrical safety in the industrial processes | 20 Lectures<br>15 Exercises | 3 | Tommasini Riccardo | |
| Chemical Engineering | Technique of environmental safety | 40 Lectures<br>60 Exercises | 10 | Piccinini Norberto | Instruments in order to characterize the dangers in the various activities and to define organizational procedures, in order to meet the safety objectives; risk assessments in decisional processes for correct design and careful management of the entrepreneurial or environmental risks. |
| Chemical Engineering | Industrial chemistry II / Safety and environmental protection in the industrial processes | 60 Lectures<br>60 Exercises | 10 | Ferrero Franco<br>Piccinini Norberto | Analysis of the chemical processes evidencing the availability of raw materials, the technological chemical-physical factors and the criteria of safety and environmental impact. |
| Chemical Engineering | Fire Safety Engineering | 90 Lectures<br>15 Exercises | 10 | Gecchele Giulio | Theoretical elements of the physical-chemical phenomenon of fire and basic elements for proper design accounting of the fire safety criteria for the protection of the persons and the control of the damages. |
| Chemical Engineering | Safety of the job and environmental defense | 90 Lectures<br>15 Exercises | 10 | Patrucco Mario | Problems of analysis and construction of the safety on the job in industrial environment and in civil shipbuilding with respect to the operative methods and the equipments used, and of the protection of the external environments from pollution. |
| Civil Engineering | Quality and safety | | 4 | | |
| Building Engineering | Safety in the yards buildings | 20 Lectures<br>60 Laboratory | 5 | Ceste Carlo | |

| Faculty | Course | Hours | Credits | Professor | Contents |
|---|---|---|---|---|---|
| Electrical Engineering | Electrical safety | 50 Lectures | 5 | Carrescia Vito | |
| Electrical Engineering | Technique of electrical safety | 50 Lectures<br>45 Exercises | 10 | Carrescia Vito | Electrical Safety: ways to safely handle electric power. Effects of electric current on the human body; systems of protection against direct and indirect contacts; safety of command circuits, of sectioning, of places with explosion outbreak danger, of non-ionizing radiations. |
| Energetic Engineering | Safety and environmental impact of the energy systems | | | | |
| | Management of quality and safety | 40 Lectures<br>15 Exercises | 5 | | |
| | Technique of environmental safety | 50 Lectures<br>45 Exercises | 10 | Carrescia Vito | Dangers in the various activities and procedures to achieve safety objectives; risk assessments in decisional processes. |
| Nuclear Engineering | Safety and risk analysis | 70 Lectures<br>30 Exercises | 10 | Del Tin Giovanni | Safety analysis of complex systems through the use of probabilistic and deterministic methodologies for system design, management of transport systems, accounting for the relative environmental compatibilities, and emergency planning in accidental situations. |
| Engineering of protection of the territory | Large territorial risks | 20 Lectures<br>30 Exercises | 4 | | |
| Engineering of protection of the territory | Plans of civil protection and mapping of the areas of risk | 50 Lectures<br>30 Exercises | 7 | Gatti<br>Estella | |

**University of the Studies of Rome “La Sapienza” - Undergraduate courses**

| **Faculty** | **Course** | **Hours** | **Credits** | **Professor** | **Contents** |
|---|---|---|---|---|---|
| Engineering of the Safety and of the Protection | Statistics and probability for risk analyses | 4 h/week | 5 | | Statistics. Probability and frequency. Distributions of probability. Rare events. Aleatory variables and functions in the time and space domain. Basics of the theory of the reliability. The risk concept. |
| Engineering of the Safety and of the Protection | Safety Regulation | 4 h/week | 5 | Lepore Michele | Introduction to the European Union Directives on safety and protection. Critical analysis of the national regulation in the field of the safety of the job. Profiles of responsibility of the various actors in the field of the safety. |
| Engineering of the Safety and of the Protection | Physics applied to the safety | 4 h/week | 5 | | The basis for the acquaintance and understanding of the physical phenomena that govern the Sciences and Engineering of the Safety and Protection. |
| Engineering of the Safety and of the Protection | Geology applied to safety | 4 h/week | 5 | Sappa Giuseppe | The basic information for the understanding of the role of the natural factors which can originate or amplify the risks for the people and for the environment. |
| Engineering of the Safety and of the Protection | Laboratory of measurements and instrumentation for the safety | 4 h/week | 5 | | Fundamental principles of measurements of physical quantities. The theory of errors and the propagation of errors. Instrumentation. Equipments and safety systems. |
| Engineering of the Safety and of the Protection | Industrial and environmental hygiene | 4 h/week | 5 | | The response of the human organism to the risks of the working environment. The biological risk. The units of measure used in order to guarantee the sanitary damage from the various agents of biological risk. Vigilance and sanitary surveillance. |
| Engineering of the Safety and of the Protection | Reliability of the materials | 4 h/week | 5 | | Defects of the materials. Non destructive analyses. Mechanics of fractures. |
| Engineering of the Safety and of the Protection | Electrical engineering and safety electrical worker | 4 h/week | 5 | | Circuits and networks in continuous current. Circuits in alternating current. Three-phase systems. Elements of electrical measurements. Theory and application of electrical machines. Devices of maneuvering and protection of plants. Safety in the electrical applications. |

| Faculty | Course | Hours | Credits | Professor | Contents |
|---|---|---|---|---|---|
| Engineering of the Safety and of the Protection | Risks in the yards and the excavation works | 4 h/week | 5 | | Constituent and organizational elements of yard works and the associated risks. Typology of yards and factors of risk. Consequences on the territory of anthropic activity. Impact of the engineering works on the territory. Methods of analysis of risk for the yards and the territory. Examples of calculation of the risk. |
| Engineering of the Safety and of the Protection | Machines and safety | 4 h/week | 5 | | Cinematic chains. Mechanisms. Lubrication. Connections. Organs of transmission. Operator machines and engines machines. Components of fluid systems (pumps, valves, compressors, blowers, turbo-machines). Machines design. The mechanical risk and the Directive Machines. Criteria of programmed maintenance and safeguards. |
| Engineering of the Safety and of the Protection | Fire safety | 4 h/week | 5 | | Basic phenomenological concepts and chemistry of the combustion. The response to fire of structures and materials; passive systems of protection. Reference accident scenarios. Analysis of consequences. General criteria of safety in industrial and civil applications. Safety regulation of oil, methane, GPL thermal systems etc. Regulations for the control of combustion. |
| Engineering of the Safety and of the Protection | Safety in the industrial plants | 4 h/week | 5 | Fedele Lorenzo | Aspects of safety in the planning, management and maintenance of mechanical industrial systems. Statistics on the accidents and injuries, definition and classification of the risks. The identification of the job environments. Risk analysis: mechanical, electrical, physical and health risk,. Formulation and execution of measurement campaigns for the identification of the levels of risk. Types of intervention in order to limit the levels of risk in the various fields. |
| Engineering of the Safety and of the Protection | Safety instrumentations and controls | 4 h/week | 5 | | The measure of the process parameters in industrial systems. Typology and choice of the sensors for the various quantities to measure. Basics of theory of automatic control. The basic controllers (P, I, D, PID, etc.). Basics on the main devices for regulation of fluids and electric quantities. Devices of protection of fluid systems. |
| Engineering of the Safety and of the Protection | Risk analysis in the industrial plants | 4 h/week | 5 | Caira Marco | Definition of risk. The quantification of the consequences of accidents. Advanced instruments of calculation of the consequences in the case of releases, in atmosphere, of dangerous substances. Methodologies of risk analysis: HAZOP, analysis cause-consequences, fault-tree, event-tree. The analysis of risk as a decision making tool in engineering design. Examples of risk calculations. |

| Faculty | Course | Hours | Credits | Professor | Contents |
|---|---|---|---|---|---|
| Engineering of the Safety and of the Protection | Reliability and safety of the structures | 4 h/week | 5 | Ruta Giuseppe | Survey on the existing constructions. Masonry constructions: measures “in situ”, examination and classification of typical disarrangements. Constructions in steel: control of the bolts, location of eventual phenomena of damaging for corrosion and fatigue; control on compressed elements. Constructions in concrete: detection of the cracking phenomena. Assessments on the state of conservation of armors. |
| Engineering of the Safety and of the Protection | Geotechnics and safety of territorial infrastructures | 4 h/week | 5 | | |
| Engineering of the Safety and of the Protection | Management of quality | 4 h/week | 5 | | The assurance of quality (the regulations of series ISO 9000) and the Total Quality Management. The organization and the governance of the business processes. The Quality System. The management of the resources. The quality in the planning. The qualification of the processes. The quality in the production. The business quality and the other subsystems: the management of the emergency and the environmental management of enterprise. |
| Engineering of the Safety and of the Protection | Management of the safety in yards and infrastructures | 4 h/week | 5 | | Regulations for the management of the Safety in the works of Engineering. Technical-economic feasibility of excavation works, the extractive activities, the civil constructions and territorial infrastructures. Dimensioning elementary and complex job tasks. Planning of the activities, the technologies and the equipments for digging and construction. Planning in compatibility and environmental safety conditions. Optimization of the surveying programs and interpretation of the measures. Design criteria and safety factors. Analysis of the Factors of Risk. Monitoring. Optimization of the interventions for the reduction of risk. Risk assessment. Emergency plans. |
| Engineering of the Safety and of the Protection | Safety proof and remediation of job environments | 4 h/week | 5 | | Stage in the topics of disciplinary groups, with development and writing of plans or analysis of case studies. |

| Faculty | Course | Hours | Credits | Professor | Contents |
|---|---|---|---|---|---|
| Engineering of the Safety and of the Protection | Safety and emergency plans in industry | 4 h/week | 5 | | Analysis of the norms for systems. The classification of high-risk industries. The writing of the safety report. The methodologies of risk analysis. Consequences analysis. Elaboration of internal plans of safety. Planning external safety. Guidelines of planning. Expeditive methods for the temporary programming of the safety plans. Problematics of evacuation. The information to the public. |
| Engineering of the Safety and of the Protection | Fire safety planning | 4 h/week | 5 | | General criteria of fire safety. Inflammable substances. Typology of fires and outbreaks. Safety systems for monitoring and surveying explosions and fires. Systems of fire extinction and systems of protection of the equipment: Ventilation and smoke evacuation. Technical standardization and insurance aspects. |
| Engineering of the Safety and of the Protection | Integrated systems and technologies of safety | 4 h/week | 5 | | Introduction to the safety: safety and security. Physical safety and electronic security. Systems anti-intrusion and burglar alarms. Systems of access control. Systems for video-surveillance. Automatic systems for the detection fires, toxic gases and explosives. Integrated systems of emergency (SIS). Systems of monitoring, control, supervision. Safety control rooms. Systems of safety communication. Systems of protection and tracking of moving transportation means. Metal detectors. X-ray scanners. Electronic sniffers for the detection of explosives, narcotic substances, chemical and bacteriological toxic agents. Security systems for the protection from environmental interceptions. |
| Nuclear Engineering | Protection and safety in the nuclear systems | | 5 | | |
| Nuclear Engineering | Risk analysis | | 5 | | |
| Engineering of the environment | Monitoring and protection for Environmental Engineering | | 5 | | |

**Faculty of Engineering, Uni versity of Studies of Bologna: Master of Second Level**

| Faculty | Course | Hours | Credits | Professor | Contents | Web site |
|---|---|---|---|---|---|---|
| Engineering | Design and Management of Advanced Nuclear Systems | 1 Year | 70 CFU | Prof. Marco Sumini (Director) | Aim of the Master: prepare and train technicians for the companies in the field of nuclear energy, able to deal with the fundamental themes of design, licensing and management of nuclear fission reactors, i.e. neutronics, plant engineering and safety. | http://masternucleare.ing.unibo.it/ |

## Bibliografia


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[2] SCK•CEN, "Training courses on integrated safety assessment modeling for waste repositories", http://www.sckcen.be/en/Our-Research/Scientific-Reports/Scientific-Report-2006/Education-Training-Communication/Training-courses-on-integrated-safety-assessment-modeling-for-waste-repositories.

[3] E. Zio, F. Cadini, D. Avram, T. Girotti, "Perfomance Assessment:modellazione dei fenomeni di dispersione di contaminanti attraverso le barriere protettive di un deposito di rifiuti radioattivi e metodologia di analisi probabilistica del rischio associato alla costruzione ed operazione del deposito stesso", CIRTEN CERSE - Polimi RL 1140/2008, Milano 2009.

[4] NEA 2000, "Nuclear Education and Training: Cause for concern?".

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[15] ENEN project, "Consolidation of European Nuclear Education, Training and Knowledge Management", April 2007 (http://www.enen-assoc.org/en/activities/for-universities/enen-ii1.html).

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[18] http://www.iaea.org/NewsCenter/Features/UndergroundLabs/Grimsel/repositories.html