Note contributive pour la Commission Energie 2030.

Les solutions énergétiques d'origine nucléaire en Belgique.

Elément-clé d'un mix énergétique.

Prof. Ir J-M. Streydio Ir P. Tonon Prof. Ir P. Klees

Septembre 2006
Révision 2, May 2006

Contenu de la note.

Annexes : 3

(i) Note liminaire.

° L’absolue nécessité de recommander le choix, sans délai, d’une politique énergétique réaliste, c’est-à-dire fondée sur des options utilisant des systèmes éprouvés compte tenu de la limite de l’horizon temporel fixé à 2030, conduit à composer un bouquet énergétique diversifié, comprenant toutes les ressources d’énergie disponibles répondant aux critères d’une politique raisonnable et durable.

° Parmi ces ressources et tenant compte de l’échéance imposée ainsi que notamment des directives en matière d’émissions de gaz à effet de serre, nous sommes amenés à proposer pour la Belgique les solutions nucléaires qui sont disponibles à l’échelle industrielle.

° Les six critères que nous retenons sont les suivants :

- La contribution à l’indépendance énergétique, à savoir la capacité d’affronter une crise d’origine géopolitique ou accidentelle et d’une durée pouvant aller jusqu’à trois ans ;

- l’assurance d’une sécurité suffisante d’approvisionnement nécessaire au développement économique et social du pays en liaison ;

- le respect de nos engagements en matière de protection de l’environnement notamment selon le protocole actuel de Kyoto et son extension prévisible au-delà de 2012 (mesures Post Kyoto) ;

- le moindre coût total, y compris celui des externalités, à l’unité d’énergie produite ;

- la possibilité d’utiliser l’expertise internationalement reconnue de nos scientifiques, ingénieurs et techniciens, pour mettre en œuvre cette politique ;

- la sûreté et la sécurité des travailleurs professionnellement exposés, du public et de l’environnement tout en garantissant la longévité et la fiabilité des installations existantes.

(ii) Expertise nucléaire belge depuis 1952.

° En 1952 est créé le « Centre d’études pour les applications de l’énergie nucléaire (CEAEN) qui devient en 1957 le Centre d’études de l’énergie nucléaire (CEN●SCK) toujours en activité et installé à Mol.

° En 1956 la première réaction en chaîne contrôlée est réalisée, à Mol, dans le réacteur de recherche BR1 qui développe une puissance thermique de 4MW et est utilisé pour des recherches en physique du neutron, en physique de l’état solide ainsi que pour la mise au point de techniques de dosimétrie et la calibration de divers types de détecteurs. La Belgique est le troisième pays en Europe occidentale après la Grande Bretagne et la France à avoir obtenu la divergence d’un réacteur.

° La conception du réacteur à haut flux neutronique, le BR 2 débute en 1956 pour aboutir à une première divergence le 29 juin 1961, sur le site du CEN●SCK à Mol. Ce réacteur destiné à l’essai des matériaux à pour combustible de l’uranium enrichi à plus de 90%, il est modéré au béryllium et refroidi à l’eau légère. Il développe une puissance thermique de 50MW. Des campagnes d’irradiation y sont conduites pour différents types de matériaux de structure et de combustible. Le BR 2 produira des radioéléments à haute activité tels que le cobalt et l’iridium. Il y aura dans ce domaine plusieurs premières européennes et mondiales.

° L’industrie nucléaire est une des activités les plus surveillées au monde, soumise à des inspections régulières tant nationales qu’internationales. En 1957 est créé sous l’égide des Nations unies l’Agence internationale de l’énergie atomique (AIEA) et en 1958 l’Agence européenne pour l’énergie nucléaire devenue depuis 1972 l’Agence de l’OCDE pour l’énergie nucléaire. La première est connue pour son rôle d’inspection, la seconde est active en matière de sûreté et de radioprotection.
En Belgique l’Agence fédérale de contrôle nucléaire mise en place en 1994, agrée les contrôleurs des activités nucléaires en tant qu’organismes et leurs agents individuellement. Il existe trois organismes agréés : AIB-Vinçotte Nucléaire (AVN asbl), AIB-Vinçotte Controlatom (AVC asbl) et Techni-Test (sprl). Entités juridiques distinctes elles couvrent des domaines différents et complémentaires du secteur nucléaire.
AVN est spécialisée dans le contrôle des activités des centrales nucléaires alors qu’AVC est chargée des contrôles de radioprotection en dehors des centrales. Au plan réglementaire AVN assure le contrôle des quatre unités de Doel et des trois unités de Tihange. Elle intervient à tous les stades de la vie des unités : conception, construction, exploitation, démantèlement.

Elle collabore a de multiples projets internationaux et représente la Belgique lors de réunions techniques de l'AIEA ou de l'AEN.

AVC contrôle plus de 3.000 établissements allant des transporteurs de matières radioactives aux laboratoires de radiographie. Elle effectue la dosimétrie individuelle de près de 20.000 travailleurs exposés aux radiations ionisantes.
L'Agence Fédérale de Contrôle Nucléaire, appuyée par les organismes agréés, a permis de développer au sein des pouvoirs publics une expertise de haut niveau qui garantit le niveau de sûreté de toutes les installations nucléaires belges.

° En 1980 est créé l'Organisme national des déchets radioactifs et des matières fissiles (ONDRAF/NIRAS) chargé par les lois d'août 1980 et janvier 1991 de mettre au point des solutions pour la mise en dépôt définitive de l'ensemble des déchets de faible (A), moyenne (B) et haute activité (C). Dans ce cadre, ONDRAF/NIRAS a réalisé en collaboration avec le CEN le laboratoire pilote à 230m sous le site du CEN●SCK, HADES (High Acitivity Disposal Experimental Site) unique en son genre et propose l'argile de Boom comme site de dépôt définitif en profondeur pour les déchets radioactifs de catégories B et C.

° Notre pays compte en outre :
1) de nombreux établissements de recherches nucléaires comme le réacteur Thetis de l'Université de Gand ;
2) d'enseignement, de recherches et de formation dans les Universités et Hautes écoles ;
3) d'entreprises comme la Belgonucléaire experte dans la fabrication du combustible MOX ;
4) l'Institut national des Radioéléments à Fleurus ;
5) Synatom en charge de l'achat des matières fissiles, de la conversion et de l'enrichissement, et de la gestion des combustibles irradiés ;
6) Electrabel dont les activités de Maître de l'Ouvrage se déclinent selon le cycle de vie des unités : choix et conception, construction et licencing, démarrage et mise en service industriel, exploitation, arrêt et démantèlement ;
7) Tractebel Engineering (TE) principalement Architecte industriel du Maître de l'ouvrage de la construction à la déconstruction, selon une approche multidisciplinaire sur les marchés domestiques belgo-français et à l'exportation. En particulier TE se trouve en charge de la gestion des contrats de fabrication des éléments et combustibles, de l'établissement des plans de rechargement, des dossiers de sûreté des recharges et de la détermination des cycles en fonction des demandes de l'exploitant.
8) En outre, plusieurs entreprises industrielles localisées en Belgique participent activement à la maintenance et à l'entretien des unités (servicing). Parmi celles-ci citons : Axima, Alstom, ATEA, CEGELEC, CMI, Fabricom, Hamon, Intercontrôle, Polinorsud, Tecnubel, WATCO, Westinghouse …

(iii) Génération actuelle du parc électronucléaire.

° L'électronucléaire belge est une longue histoire performante basée sur la filière REP ou PWR. Nous sommes en effet le seul pays européen qui a produit de l'électricité nucléaire exclusivement au moyen du REP.
L'unité pilote en fut le BR3, réacteur de la 1^{ère} génération, d'une puissance développable de 11,5MWe, appelé le « Teapot » bien que jalon historique du nucléaire en Europe occidentale, a été importé des Etats-Unis et assemblé à Mol, au CEN●SCK pour être mis en service industriel et raccordé au réseau en 1962. Il fonctionnera durant un quart de siècle jusqu'en 1987 et parvient à démontrer que le recyclage du Pu dans les réacteurs à eau sous pression est une solution viable, fiable et d'avenir (combustible MOX).

° Le parc actuel de production nucléaire constitué d'unités de la deuxième génération est illustré au Tableau 1 tandis que la production de ce parc figure au Tableau 2.
Tableau 1 : la conception modulaire des équipements et des assemblages de combustible permet de suivre l'évolution technologique. Ceci représente un net avantage par rapport aux combustibles fossiles ou renouvelables dont les caractéristiques ne peuvent être modifiées durant la vie de la centrale.
Tableau 2 : ce tableau souligne la très grande stabilité de la production d'électricité d'origine nucléaire, stabilité essentielle pour l'approvisionnement en énergie du pays.
Il montre également que si l'arrêt est prononcé à l'échéance de 40 ans de vie, il n'y aura plus aucune production nucléaire à l'horizon du plan, soit 2030, alors qu'aujourd'hui plus de 50% de l'électricité est produite par le nucléaire.

On constatera à l'examen de ces documents :

- la stabilité et la sécurité dans le temps de production des unités concernées ;

- l'amélioration constante des performances grâce à la conception modulaire des équipements et du cœur permettant de bénéficier de l'amélioration permanente de leurs conception et fabrication ;

- le recours au caractère éprouvé de la filière permettant de disposer du retour d'expérience d'exploitation d'unités identiques ou similaires ;

  - la capacité des ingénieurs et techniciens belges de tirer un profit permanent de ces avantages.

(iv) Troisième génération éprouvée (type EPR ou AP 1000).

° Dans le monde, plusieurs modèles de réacteurs font l'objet d'études détaillées ou de premières réalisations :

- l'EPR d'Areva (France), (filière REP) ;
- l'AP 1000 de W/BNFL, (filière REP) ;
- l'ABWR de GE + Toshiba/Hitachi, (filière REB) ;
- l'ESBWR de GE, (filière REB) ;
- le SWR de Framatome ANP, (filière REB) ;
- les AES 91 et 92 de Atomstroyexport, (filière REP).

° Délais de construction et de mise en service.

Deux unités EPR sont en commande respectivement à OLKILUOTO pour TVO (Finlande) et à Flamanville 3 pour EdF (France).
L'AP 1000 est en cours de certification aux USA où la commande de plusieurs unités est envisagée d'ici 2008.
Le calendrier général de l'EPR finlandais et de l'EPR francais se présente comme suit :

	TVO	EDF
- Décision	mi 2002	fin 2004
- Contrat	déc 2003	mars 2006
- Préparation du site	début 2004	2006
- Premier béton	début 2005	2007
- Mise en service industriel	mi-2009	2012

Dès 2012 nous disposerons donc de la possibilité de contracter une unité nucléaire ayant doublement fait ses preuves et dont le délai entre le contrat et la mise en service industriel est de 6 ans.
Le retour de l'expérience acquise durant 40 ans sera optimum puisqu'il s'agit d'une exploitation continuée de la filière REP, intégrant le retour d'expérience des fournisseurs et des exploitants.

Le tableau 3 compare les paramètres principaux de l'EPR et ceux de D3/T4.

L'EPR est un réacteur évolutionnaire de grande puissance. Les évolutions technologiques correspondent au retour d'expériences d'exploitation. En utilisant des techniques industrielles éprouvées, il augmente le niveau de sûreté intrinsèque, la disponibilité et l'économie. Il produit un effet d'échelle par l'augmentation de puissance, améliore le rendement, l'utilisation du combustible et réduit le volume de déchets par unité d'énergie produite.

° Coûts.

- Le tableau 4 précise la compétitivité d'une unité EPR.

- L'AEN et l'AIE ont réalisé en 2005 une étude portant sur l'économie de la production d'énergie d'électricité à partir de différentes sources d'énergie. Le résultat est donné au tableau 5 et montre combien il est sensible au taux d'actualisation et aux prix prévisionnels du gaz et du charbon, les centrales utilisant ces combustibles étant beaucoup plus dépendantes des coûts de combustible que les centrales nucléaires.
  Nous avons vu qu'en service une centrale nucléaire présente des coûts de production stables. Le coût du minerai d'uranium ne constitue que 10% maximum de la totalité des coûts de l'électricité produite, de sorte qu'une augmentation sensible de son prix n'a pas une grande influence sur le coût de production de l'électricité
  Les hypothèses génériques pour les principaux paramètres comprenaient une durée de vie économique de 40 ans, un facteur de charge moyen pour les unités en base de 85% et des taux d'actualisation de 5 et 10%. Les coûts externes résultant des émissions résiduelles en ce compris les gaz à effet de serre ne sont pas intégrés dans cette étude, tandis que le coût du nucléaire intègre celui de la gestion des déchets et du démantèlement.

- Le tableau 6 visualise, en se basant sur les données de l'AEN et de l'AIE, l'effet « externe » que constitue la « contrainte carbone ». Plus un mode de production va émettre des gaz à effet de serre, plus il sera pénalisé dans le futur. (exigences Post Kyoto).

° Sûreté.

  - En matière de sûreté, il convient de rappeler qu'un accident comme celui de Tchernobyl, réacteur spécifiquement soviétique, est impossible en Belgique notamment pour trois raisons fondamentales : le REP est plus stable que le RBMK (les autorités de sûreté imposent au concepteur pour la réactivité, un coefficient négatif de température $\frac{d\rho}{dT} \leq 0$); le modérateur utilisé est de l'eau légère et non du graphite susceptible de s'enflammer et nos unités disposent d'une double enceinte de confinement totalement absente à Tchernobyl.

- Le concept de l'EPR est conforme aux critères EUR (European Utilities Requirements) développés par dix producteurs d'électricité européens dont Electrabel, EDF et les électriciens allemands E.ON, EnBW, RWE Power. Il a été validé par les autorités de sûreté françaises et allemandes.

  L'EPR répond également aux exigences des électriciens américains sous l'égide de l'«Electricity Power Research Institute » (EPRI).

- Sa conception est basée sur une probabilité de fusion du cœur inférieure à 10^{-6}/réacteur an, réduite d'un facteur 10 par rapport à celle de la génération précédente (Génération II).
  Les délais de grâce en situations accidentelles sont augmentés par l'accroissement important du volume d'eau contenue dans le circuit primaire et les générateurs de vapeur.
  La fiabilité des systèmes de sûreté est accrue au moyen d'une quadruple redondance à 100% (concept des quatre trains) dont les technologies différenciées évitent les défaillances de mode commun.
  Les conséquences d'une fusion toute improbable du cœur sont limitées par la robustesse et l'étanchéité de l'enceinte de confinement, son compartimentage et la présence de recombineurs catalytiques d'hydrogène empêchant une concentration élevée de ce gaz et le risque de déflagration.
  Toute portion du cœur fondu serait recueillie, contenue et refroidie dans un compartiment situé à l'intérieur de l'enceinte de confinement.
  Celle-ci offre une protection efficace contre les agressions externes y compris les chutes d'avions militaires et gros porteurs civils et contre les risques sismiques. Sont également protégés, les bâtiments de sauvegarde de manière à conserver la quadruple redondance des systèmes, maintenant intactes les fonctions de sûreté.
  La protection radiologique des personnels d'exploitation et de maintenance est renforcée en divisant par deux la dose collective, en moyenne de 1 homme x Sievert/réacteur an observée actuellement dans les pays de l'OCDE.

° Externalités.

Déchets nucléaires et provisions pour démantèlement et gestion des matières fissiles irradiées.

- La décision de principe récente du Gouvernement Belge (26 juin 2006) de faire stocker en surface des déchets nucléaires de type A (ceux dont les caractéristiques radiologiques sont telles qu'ils peuvent être stockés en surface et qui sont souvent appelés déchets de faible activité et de courte durée de vie) sur le territoire de la commune de Dessel en Campine marque une étape importante dans la résolution d'un problème important qui handicape, du moins dans l'opinion publique, le secteur nucléaire. Il est important de souligner que, au-delà de l'étude technique de faisabilité d'un tel stockage, c'est la prise en compte de la dimension socio-économique du problème qui a permis, en impliquant les populations locales dans un processus de définition du projet, d'aboutir à l'acceptation de ce type de dépôt moyennant l'intégration de celui-ci dans un plan de développement local.

  L'évacuation définitive des déchets de type B et C, qui sont de loin en moindre quantité que les déchets de type A mais qui sont beaucoup plus actifs ou de plus longue durée de vie devra sans doute se faire en sous-sol mais aucune décision en la matière n'a encore été prise en Belgique. Pourtant notre pays est internationalement reconnu pour avoir depuis plus de 20 ans mené une recherche performante pour le stockage de déchets de haute activité dans des couches profondes d'argile. Ces recherches sont menées en concertation par l'ONDRAF-NIRAS et le CEN●SCK sur le site de Mol-Dessel ; elles sont soutenues par les producteurs belges de déchets (dont l'Etat Belge) et par la Communauté Européenne, ce qui entraîne une participation d'équipes étrangères et permet la validation des résultats sur le plan international. Des solutions techniques très performantes ont été développées et le comportement de l'argile sous irradiation est de mieux en mieux connu, si pas maîtrisé. La décision définitive de stockage de ce type de déchets passera sans doute également par un processus de participation et de négociation avec des autorités locales.

  En attendant, les déchets de type B et C qui proviennent du retraitement des combustibles usés sont stockés sur le site de Belgoprocess à Dessel et les combustibles usés et non retraités sont entreposés sur les sites de nos centrales nucléaires, à Doel et à Tihange, dans l'attente d'une décision sur la poursuite du retraitement.

Il y a lieu de noter que les déchets de haute activité doivent encore subir une phase « de refroidissement », le temps que leur activité soit suffisamment réduite pour qu'on puisse les stocker en profondeur sans dommage pour leur environnement. Cette période peut encore prendre 50 ou 60 ans.

Le financement de toutes ces opérations, qu'il s'agisse des actions de R&D ou de gestion des opérations courantes est assuré par les producteurs de déchets et différents mécanismes de financement ont été mis en place. Parmi ceux-ci, le Fonds à Long Terme mis en place par l'ONDRAF-NIRAS prévoit une réservation de capacité qui permet de définir le programme, des payements accompagnant la prise en charge des déchets, qui couvrent leurs coûts à long terme, et une garantie contractuelle qui impose aux producteurs de déchets de payer la partie fixe des coûts qui avaient été programmés pour leur participation, dans le cas où ils décideraient de mettre fin à celle-ci.

Le rôle de l'ONDRAF-NIRAS est explicité dans la note « Radioactive waste management in Belgium : current status by NIRAS—ONDRAF ». (annexe 1).

- Par ailleurs, la loi du 11 avril 2003 attribue à SYNATOM la gestion des provisions pour le démantèlement des centrales nucléaires et pour la gestion des matières fissiles irradiées dans les centrales belges. Cette loi a également organisé la constitution d'un Comité de suivi dont la mission est d'émettre des avis concernant les méthodes de constitution des provisions, la révision du pourcentage maximal des fonds que SYNATOM peut prêter aux exploitants nucléaires et les catégories d'actifs dans lesquels SYNATOM peut investir la part des fonds qu'elle ne peut prêter aux exploitants nucléaires, ainsi que de contrôler la constitution et la gestion des provisions. Comme indiqué dans la loi, les provisions constituées par la Société de provisionnement nucléaire SYNATOM recouvrent deux aspects : d'une part la provision pour la gestion des matières fissiles irradiées et d'autre part la provision pour le démantèlement des centrales nucléaires.

  L'évaluation de la provision nécessaire pour assurer la gestion du combustible irradié présent sur les sites des centrales passe par l'évaluation du coût de la gestion de la totalité du combustible qui sera déchargé au terme des quarante années de fonctionnement des centrales nucléaires.

  La loi du 11 avril 2003 prévoit que les provisions pour le démantèlement couvrent *« tous les coûts de la mise à l'arrêt du réacteur de la centrale nucléaire et de déchargement du com-*

bustible nucléaire, du démantèlement de l'installation nucléaire, d'assainissement du site et de gestion des déchets radioactifs qui en résultent » (Article 2, § 3). Un bureau d'études international a procédé à l'évaluation de ces coûts et différents scénarios ont été développés. L'ONDRAF-NIRAS a validé les hypothèses retenues dans cette étude et celle-ci a été validée par le CEN●SCK pour l'une des centrales prise comme exemple.

Le détail de la constitution de ces provisions est exposé dans la note « les provisions nucléaires » que l'on trouve en annexe 2.

La comparaison entre, d'une part, les estimations que l'ONDRAF-NIRAS a effectuées pour les coûts de l'évacuation finale des déchets radioactifs provenant des combustibles usés et du démantèlement des centrales qui auront été accumulés au terme de la période de fonctionnement de 40 ans retenue par la loi de janvier 2003 et, d'autre part, le mode et l'état de constitution des réserves financières qui seront nécessaires pour procéder en temps voulu à cette évacuation et au démantèlement des centrales montre que les provisions ainsi constituées seront à même de faire face aux échéances. Cela implique cependant que ces provisions continuent à être constituées et gérées en fonction de l'atteinte de l'objectif final auquel elles sont destinées.

- En matière de démantèlement, les ingénieurs de Tractebel Engineering ont en charge un contrat d'organisation majeur pour la centrale d'Ignalina en Lituanie et participent à l'exercice pilote du démantèlement du BR3 en cours d'achèvement au CEN●SCK.

  Là aussi, le temps venu, le modus operandi aura été largement éprouvé, non seulement en Belgique mais aussi internationalement. Il a débuté en 1964, lors du remplacement des pièces internes du réacteur de Chooz A.

  Le coût annuel de la déconstruction pour le retour au « green field » est évalué à 15% maximum de l'investissement initial. Cette estimation diminuera en fonction des progrès technologiques réalisés et de la courbe d'apprentissage d'ici la mise en œuvre des opérations.
  Régulièrement provisionné et actualisé, ce coût futur ne grève que d'une fraction de % le prix de revient du kwh.

° Protection de l'environnement.

- Les centrales nucléaires n'émettent aucun gaz à effet de serre ni de polluant atmosphérique (NO_x, SO_x, poussières).
  En particulier il s'agit d'une production d'énergie électrique « carbon free » par opposition à celle de centrales utilisant des combustibles fossiles et rejetant directement ces différents gaz dans l'atmosphère, ou de centrales dont on ne maîtrise pas le combustible (par ex. éoliennes) dont le faible coefficient d'utilisation (6,5h/j en moyenne) exige le recours à de l'énergie de substitution fournie par des centrales thermiques classiques émettrices de CO_2.

- Il est significatif de constater que la production d'énergie nucléaire permet au secteur électrique en France de diviser par 3,5 ses émissions de CO_2 depuis les années 1980, de sorte qu'aujourd'hui ses émissions de CO_2 rapportées au PIB sont les plus faibles d'Europe.
  Au demeurant, le Danemark, promoteur de l'énergie éolienne, se trouve être le plus important émetteur européen de CO_2 par kwhe produit : 676g CO_2 /kwhe pour une moyenne de 428g CO_2 /kwhe dans l'Europe des 15.

- Le Commissaire européen responsable de l'énergie et du transport de l'époque, Loyola de Palacio, a clairement résumé la problématique : *« Ou nous renonçons au nucléaire et nous ne respectons pas Kyoto, ou nous ne renonçons pas au nucléaire et nous respectons Kyoto. C'est aussi simple que cela et il faut le dire crûment pour que les gens le comprennent bien ».*

- Dans le cas de l'EPR, sa conception témoigne de progrès majeurs en terme de contribution au développement durable par rapport aux réacteurs du parc actuel :
  17% d'économie en consommation d'uranium au MWh ;
  15% d'actinides en moins générés au MWh ;
  14% de production d'électricité en plus pour un même niveau de rejets thermiques ;
  100% de capacité de chargement du cœur en MOX (UO_2 PuO_2).

(v) Faisabilité.

° Prolongation de la durée de vie de 40 à 60 ans du parc actuel.

- En Belgique, la loi ne prévoit pas de durée de vie prédéfinie pour nos centrales : tous les 10 ans, une réévaluation de sûreté, basée sur un « Decennal Safety Assessment Report » est soumise à l'approbation des autorités de sûreté.

  Les différentes composantes des réacteurs nucléaires sont soumises à un examen permanent et la culture de sûreté présente dans nos centrales impose une politique stricte de maintenance prévisionnelle et les composantes des centrales qui manifesteraient la moindre faiblesse ou interrogation sont irrémédiablement remplacées lors des périodes de révision prévues chaque année ou tous les 18 mois.

- La cuve est évidemment la composante cruciale du réacteur nucléaire et c'est elle qui fait l'objet de la surveillance la plus pointue, tant pour ce qui concerne la résistance mécanique des matériaux qui la composent que pour leur résistance à corrosion qu'elles soient soumises à des flux neutroniques importants ou à des contraintes thermiques susceptibles de déclencher les processus multiples et complexes qui gouvernent cette corrosion. Les méthodes d'examen sont validées sur le plan international et les résultats de ces examens sont communiqués en permanence aux autorités de sûreté.

  Une même attention est évidemment accordée aux autres parties du réacteur et la manière dont tout ce suivi est assuré est décrite dans le document en annexe 3 « Vessel issues that contribute to Nuclear Power Plant Life Management ».

  Il en ressort que le moindre incident ou doute entraîne une multiplication accrue du nombre des inspections, ce qui permet d'affirmer qu'aucun élément significatif de dégradation des matériaux n'a encore été observé et qu'aucune observation n'a jamais encore fait douter du maintien en fonctionnement de nos réacteurs ou de douter ni de leur durée de vie ni de l'extension de celles-ci de 40 à 60 ans.

  Il n'y a donc pas de raison technique ou scientifique de limiter cette durée de vie que seules les autorités de sûreté pourraient légalement interrompre.

- Il s'agit donc d'un processus éprouvé répondant aux exigences de sûreté et de sécurité qui permet de justifier économiquement la prolongation de la durée de vie du parc belge de 40 à 60 ans.
  Le tableau 2 reprend les dates de démantèlement des unités selon leur durée de vie.

° Construction de Doel V.

Le site de Doel permet, comme l'a démontré l'étude de l'implantation potentielle du projet N8 basé sur un réacteur REP de conception Framatome dit N4, l'installation d'une cinquième unité de grande puissance type EPR ou AP 1000.
Celle-ci peut donc être programmée dans le plan à moyen terme des producteurs d'électricité comme étant Doel V, par exemple dès 2015.

° Indépendance énergétique et sécurité d'approvisionnement.

- L'énergie nucléaire peut être assimilée à une source d'énergie domestique dans la mesure où les ressources en uranium sont largement réparties dans le monde et dans des pays politiquement stables et qu'en outre, le combustible peut facilement être stocké à des prix raisonnables. D'importantes ressources existent notamment en Australie, au Canada et aux USA de même qu'en Asie Centrale. Cette répartition garantit à la fois la sécurité et la diversité des approvisionnements. Ceci est particulièrement utile en cas de rupture inopinée d'approvisionnement en combustibles fossiles.

  Stratégiquement l'énergie nucléaire signifie pour l'Europe occidentale un facteur important de stabilité et donc d'indépendance énergétique, particulièrement en Belgique où l'on ne dispose pas de réserves fossiles. On se rappellera qu'à l'intérieur de l'Europe des 25, il existe également des réserves d'uranium qui pourraient être remises en exploitation selon l'évolution du prix de l'uranium.

- Le potentiel énergétique de l'uranium est considérable.
  Pour produire 100.000 kwhe il faut 35.000 kg de charbon, 25.000 litres de pétrole, 30.000 m³ de gaz naturel ou 400 gr d'uranium.
  La production d'une centrale nucléaire de 1.000 MWe pendant une année calendrier soit 8.760 h est de $8{,}76.10^9$ kwh ce qui correspond à un volume de 1.888.000 TEP ou 2.690.000 TEC.
  En Belgique, les 45 milliards de kwh d'origine nucléaire produits annuellement économisent 10,5 millions de tonnes de pétrole ou 14,7 millions de tonnes de charbon.

  - L'électricité nucléaire, dont le coût de combustible compte pour moins de 10%, contribue sensiblement à la sécurité des approvisionnements énergétiques en diminuant l'exposition à la volatilité des prix et aux tensions sur la production des combustibles fossiles.

Sur base des connaissances actuelles et selon l'OCDE, les réserves de pétrole devraient couvrir la consommation annuelle pour une quarantaine d'années, celles de gaz pour une soixantaine d'années et celles du charbon pour plus de 200 ans.

Les centrales nucléaires en service dans le monde consomment l'équivalent de 67.000 tonnes d'uranium naturel par an et les ressources d'uranium connues représentent environ 85 ans de consommation au niveau actuel (Livre rouge AEN, Uranium 2005).

Les réserves actuelles estimées à plus de 5 millions de tonnes, correspondent à celles qui ont été découvertes parce qu'elles ont été prospectées en ayant à l'esprit un amortissement économique à court terme. On sait toutefois que l'uranium est abondant dans l'écorce terrestre et que les ressources dites conventionnelles sont estimées à quelque 270 années de consommation au rythme actuel de la demande soit 10 millions de tonnes supplémentaires. Le retraitement du combustible usé et l'introduction du MOX dans les réacteurs permettent encore d'augmenter significativement ces chiffres. C'est la voie choisie par la France au travers de la loi de 2006.

° Impacts sociaux-économiques.

Le nucléaire en Belgique constitue un important patrimoine d'expertise mondialement reconnu dans les domaines de l'énergie, de la santé et de l'industrie.
Il en résulte que nos centrales sont des plus performantes et jouissent d'un palmarès envié en matière de sécurité et de sûreté, de protection de l'environnement et de stabilité de production comme de coût ; notre médecine nucléaire tant en diagnostics qu'en thérapies est appréciée internationalement (Bordet, Erasme, CHU Lg, UCL-Woluwé …) ; la production de radioéléments à des fins médicales ou industrielles par l'IRE est citée en exemple ; la présence d'IBA à l'exportation de cyclotrons et d'équipements de protonthérapie est remarquable, le contrôle non destructif de matériaux par Vinçotte se trouve à la pointe du progrès. Il existe au plan scientifique, à ceux de l'enseignement et de la pratique une synergie entre ces diverses activités qu'il importe de conserver et de développer.

(VI) Analyse comparée avec d'autres pays industrialisés.

° Hors Europe, les besoins croissants en énergie, la nécessité de limiter les émissions de gaz à effet de serre et la dépendance à l'égard des hydrocarbones conduisent aux situations suivantes :

- les USA prolongent l'exploitation des unités au-delà de 40 ans, la NRC ayant approuvé en 2003 neuf nouvelles prolongations de 20 ans des licences d'exploitation portant à 19 le nombre de réacteurs qui pourront être exploités pendant 60 ans. La construction de nouvelles centrales nucléaires type AP 1000 ou EPR est envisagée dont la tête de série devrait être mise en service industriel en 2012.

- Le DOE a proposé en 2000 la création du forum « Génération IV » organisant le développement des systèmes nucléaires futurs, à l'horizon 2040-2050 en respectant cinq critères fondamentaux : économie, sûreté, économie des ressources naturelles, recyclage et transmutations des actinides, réduction des risques de prolifération.

  L'accord international Génération IV a été signé en 2005. A ce jour, 7 pays : le Canada, les Etats-Unis, la France, le Japon, le Royaume-Uni, la Corée du Sud, la Suisse font partie de l'accord auquel s'est joint Euratom.
  Les candidatures de la Chine et de la Russie seront prochainement examinées et il serait souhaitable que la Belgique se joigne à ce forum dont les travaux joueront un rôle fondamental dans la politique énergétique du futur et spécifiquement dans la production de l'hydrogène.

- Le Japon, n° 3 mondial pour la production d'énergie nucléaire, après les USA et la France a trois tranches d'un total de 3.700 MWe en cours de construction et six centrales sont programmées de 2004 à 2010.

- La Corée du Sud, a deux réacteurs en construction et 8 planifiés d'ici 2018.

- Le Vietnam mettra 2000 MWe d'origine nucléaire en service d'ici 2017.

- La Chine a un programme nucléaire ambitieux. La duplication de centrales en exploitation a été décidée sur les sites de Ling Ao et de Qinshan le tout pour 3.200 MWe.
  Quatre tranches de la troisième génération (1000 à 1600 MWe) : (EPR ou AP100 ou VVER) seront installées respectivement sur le site de Sanmen et de Yangjiang.

- En Inde 9 centrales sont en construction en parallèle. La capacité nucléaire totale prévue à hauteur de 7.600 MWe en 2012 devrait atteindre 20.000 MWe en 2020. Cette vision indienne du développement du nucléaire est rendue nécessaire pour pallier le défaut de ressources énergétiques fossiles.

° Pour l'Europe nous avons traité ci-avant la situation en Finlande,en France et aux Pays-Bas.

- Aux Pay-Bas, l'EPZ Borssele a obtenu la prolongation de la durée de vie de la centrale du type REP de 40 à 60 ans, jusqu'en 2033. Tractebel Engineering y effectue les modifications liées à la révision décennale de sûreté.

- En Suède l'opérateur d'énergie a prévu d'investir 180 millions d'€ à court terme dans la rénovation des réacteurs existants et plus de 1 milliard d'€ dans les 15 prochaines années pour prolonger la durée de vie des unités jusqu'à 60 ans.

- En Allemagne les installations nucléaires du parc actuel généreront encore 260 milliards de kwhe ce qui permet aux centrales actuelles d'être exploitées au-delà de 2020.

- En Roumanie un deuxième réacteur CANDU sera mis en service en 2007 ; un appel d'offres pour 2 réacteurs complémentaires a été lancé en juin 2006.

- La Lituanie a fermé en 2004 Ignalina 1 (RBMK) et fermera Ignalina 2 (RBMK) en 2009 sur injonction de l'UE. Elle s'est associée à la Lettonie et l'Estonie pour le projet d'un nouveau réacteur REP à Ignalina qui devrait permettre de subvenir à une large part des beoins en électricité de ces trois Etats baltes.

- Au Royaume-Uni dont le parc de réacteur est de 27 unités, le gouvernement prépare la construction de nouvelles centrales REP de type AP 1000 ou EPR.

(VII) Recommandations

° Nous recommandons à la Commission de proposer au Gouvernement fédéral :

- de prévoir la prolongation de la durée de vie du parc nucléaire actuel jusqu'à 60 ans par unité ;

- de planifier la construction d'un REP de grande puissance de la troisième génération pour une mise en service industriel au plus tard en 2018.

° Ces deux recommandations répondent aux préoccupations gouvernementales relatives à la réduction d'émissions de gaz à effet de serre ainsi qu'à la limitation de la pollution atmosphérique, de même qu'à la stabilité et à la sécurité d'une fourniture d'électricité au moindre coût, au bénéfice des secteurs domestique et industriel.

° Nous demandons que les critères de choix et les solutions recommandées dans la présente note contributive figurent aux chapitres correspondants du rapport provisoire que la Commission Energie 2030 soumettra aux différents panels d'experts en octobre prochain.
Nous demandons également que la présente note contributive soit jointe aux documents supports de la Commission.

- . - . - . - . - . - . - . - . - .

TABLEAU 1

Parc nucléaire belge

Tranche Génération II	Mise en service industriel	Puissance développable à la MSI (MWe)	Puissance développable en 2003	Description projets
Doel 1	1975	392,5	392,5	-
Doel 2	1975	392,5	392,5	(2004) Remplacement GV + augmentation puissance
Doel 3	1982	900	1006	(1993) Remplacement GV + augm.puiss.(1994) Introd. MOX
Doel 4	1985	980	985	(1996) Remplacement GV
Tihange 1	1975	870	962	(1995) Remplacement GV et augmentation puissance + (1999) Remplacement couvercle cuve
Tihange 2	1983	900	1008	(1994) Introduction MOX + (1994) augmentation puissance + (2001) Remplacement GV + augmentation de puissance
Tihange 3	1985	1020	1015	(1998) Remplacement GV

Total	-	5.455	5.761	

TABLEAU 2

Production du parc nucléaire belge

	Energie brute produite (Twh)					Arrêt Durée de vie	
Tranche	2001	2002	2003	2004	Total depuis MS	40 ans	60 ans
Doel 1	3,3	3,4	3,2	3,2	93,2	2015	2035
Doel 2	3,3	3,3	3,3	3,1	85,8	2015	2035
Doel 3	8,5	8,1	8,3	8,5	168,2	2022	2042
Doel 4	8,6	8,3	8,3	8,0	150,6	2025	2045
Tihange 1	7,3	7,4	8,3	7,4	201,1	2015	2035
Tihange 2	7,3	8,1	7,9	8,9	162,3	2023	2043
Tihange 3	8,1	8,8	8,1	8,3	158,8	2025	2045
Total	46,4	47,4	47,4	47,4	1.020,0		
% de la produc élec.	57,4	55,3	55,4	55	-		

TABLEAU 3

Comparaison des principales caractéristiques EPR/D4-T3

	D4/T3	EPR
Puissance thermique MWth	3000	4500
Nombre de boucles	3	4
Puissance électrique nette MWe	1000	1650
Rendement global %	33	36
Nb d'assemblages de combustible	157	241
Taux de combustion GWJ/Tmu	43	65
Puissance linéique W/cm	165	155
Pression primaire/Pression de calcul bar	155/176	155/172
Température Branche Chaude max. °C	330	330
Débit primaire m³/h	24.000	28.000
Pression secondaire à 0% et 100% de Charge bar	82/75	90/78
Pression de calcul secondaire bar	89,7	97

Durée de vie de conception	an	40	60
Longueur de cycles	mois	12/18	12/18/24

ANNEXE 1

Radioactive waste management in Belgium: current status by ONDRAF/NIRAS

Radioactive waste management in Belgium is the responsibility of the Belgian Agency for Radioactive Waste and Enriched Fissile Materials [1] (ONDRAF/NIRAS), that was created by the law of 8 August 1980 and became operational in 1981 [2]. Placed under the supervision of the Federal Government through the Minister of Energy, ONDRAF/NIRAS also depends on the competent safety authorities for all aspects related to control and authorisations, namely the Federal Agency for Nuclear Control (FANC), which was created by the law of 15 April 1994 and became operational seven years later, under the Royal Decree of 20 July 2001 passed in implementation of the law. Radioactive waste management aims *"to deal with radioactive waste in a manner that protects human health and the environment now and in the future without imposing undue burdens on future generations"* [IAEA, 1995]. It can be divided into two time frames: short-term management and long-term management. *Short-term management* comprises various industrial operations that are well under control today and are performed routinely. They aim at transforming raw waste, which is heterogeneous and multiform, into a final product that is as compact as possible, that is chemically stable, and in which radionuclides are trapped. This product is contained in metallic packagings to form so-called "waste packages". According to plans, however, a large proportion of future dismantling waste will be conditioned directly in concrete caissons. *Long-term management*, on the other hand, comprises the interim storage of the waste packages in purposely designed facilities, and the subsequent implementation of an appropriate long-term solution. As decided by the Federal Government on 23 June 2006, this solution will be surface disposal for short-lived low-level and medium-level waste, or category A waste. According to the current timetable, surface repository construction would start in 2011. As for high-level and/or long-lived waste, or category B&C waste, the solution is assumed to be final disposal in a stable geological formation, Boom Clay being chosen as the reference host formation. It is still at the RD&D (research, development and demonstration) stage. ONDRAF/NIRAS subcontracts the industrial activities, studies and RD&D activities to third parties, ensures their overall coordination and takes care of the global integration of knowledge and understanding. The processing and conditioning of the radioactive waste produced in Belgium that is not processed by the producers on their own sites is subcontracted to Belgoprocess, its daughter company, as well as the interim storage of the conditioned radioactive waste. Studies and research projects are subcontracted to engineering companies such as Belgatom and research centres such as the Belgian Nuclear Research Centre (SCK•CEN), in Belgium and abroad. Large-scale demonstration projects in Boom Clay and in situ experiments are subcontracted to EURIDICE, a joint venture between ONDRAF/NIRAS and SCK•CEN.

After introducing the three major waste categories, this document focuses on the current status of ONDRAF/NIRAS' work programmes devoted to, respectively, surface disposal of category A waste and deep disposal of category B&C waste. It goes on

---

[1] Web sites of the Belgian organisations cited in the text:

ONDRAF/NIRAS: www.nirond.be
FANC: www.fanc.fgov.be
Belgoprocess: www.belgoprocess.be
SCK•CEN: www.sckcen.be
EURIDICE: www.euridice.be

[2] The mission and functioning of ONDRAF/NIRAS were first laid down by the Royal Decree of 30 March 1981. This was amended and supplemented by the Royal Decree of 16 October 1991 passed in implementation of the law of 11 January 1991, itself amended and supplemented by the law of 12 December 1997, and by the Royal Decrees of 4 April 2003 and 1 May 2006.

with an overview of the financing of ONDRAF/NIRAS' activities, in particular regarding long-term management. (For further details about short-term management activities and interim storage, the reader is referred to [ONDRAF, 2002].)

1. The waste to be managed in short

The radioactive waste to be managed can be considered from various angles. Hereafter follows a short introduction to what it is, how it is classified and where it comes from, an overview of the estimated total waste quantities to be managed, and an outline of the system used to ensure that the waste characteristics conform with the established acceptance criteria.

1.1. Waste classification and origins

The Belgian classification for the long-term management of conditioned radioactive waste is compatible with the major international classifications. The three main waste categories are as follows.

Category A waste is waste whose radiological characteristics are sufficiently low to allow the waste to be disposed of in a surface repository. In other words, it is radioactive waste whose activity level will decrease by natural decay at a rate such that it will reach a level comparable to that of natural radioactivity within a time frame that is compatible with monitoring possibilities after repository closure, namely about 200 to 300 years. Category A waste is short-lived low-level and medium-level waste, also sometimes called low-level short-lived waste for short.

Category A waste has very diverse origins and, hence, very different natures. It comes from the production of electricity from nuclear origin by the nuclear power plants of Doel and Tihange, from the production and use of radionuclides for medical and industrial purposes, from research activities and from the dismantling of disused nuclear facilities. Examples of such waste are solid waste and liquid effluents from laboratories, protective clothing, residues from the processing of waste waters in nuclear power plants, filters, retired equipment, or dismantling waste such as concrete and metals.

Category B waste is low and medium-level waste contaminated by long-lived radionuclides in such amounts that it cannot be disposed of in a surface repository, but that does not generate enough heat to belong to category C. Category B waste arises mainly from the fabrication of nuclear fuel and from the reprocessing of spent fuel, but almost a quarter of it will be dismantling waste.

Category C waste is high-level waste, with large amounts of long-lived radionuclides. Most of this waste initially emits large amounts of heat which, with a view to deep disposal in clay at least, would impose a cooling-off period of minimum 60 years prior to disposal. This heat-emitting waste comprises fission products from the reprocessing of spent nuclear fuel, spent fuel itself (in case reprocessing is definitively abandoned by Belgium) and possible excess fissile materials. The remaining category C waste emits less heat and consists mainly of constitutive materials of fuel assemblies and reactor internals.

1.2. Waste quantities

The total volume of conditioned radioactive waste to be managed by the year 2070, namely by the end of the dismantling activities of all the existing and currently planned nuclear facilities, was estimated by ONDRAF/NIRAS in 2003–2004, on the basis of the inventory of 2003. This estimate takes account of the law of 31 January 2003 on the progressive phase-out of nuclear energy: it assumes that the seven existing nuclear power plants will be operated for 40 years. Given the uncertainty as regards the decision that will eventually be taken in relation to the current moratorium on spent fuel reprocessing, the waste inventory also takes account of the following two opposite hypotheses: full reprocessing of all spent fuel and definitive ban on reprocessing for all spent fuel.

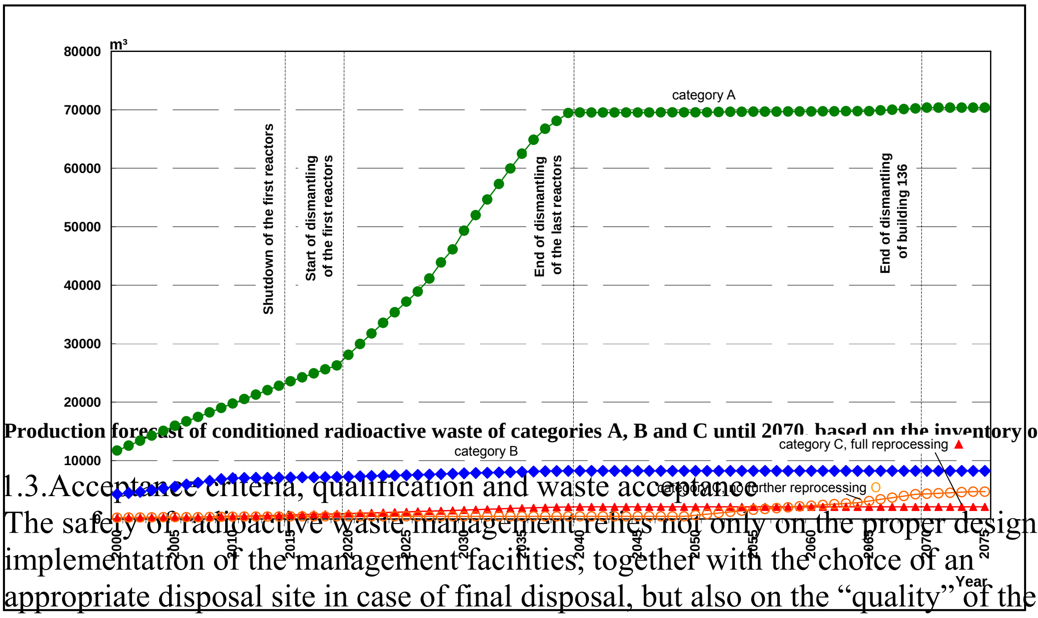
The results of the inventory are as follows (see also the table and the figure):

- *Category A waste*: 70 500 m^3, of which 13 495 m^3 were stored at Belgoprocess at the end of 2005.
- *Category B waste*: 8 700 m^3, of which 3 966 m^3 were stored at Belgoprocess at the end of 2005.
- *Category C waste*: 2 100 or 4 700 m^3, depending on whether the Government eventually decides to resume reprocessing for all spent fuel or to put a definitive ban on it. At the end of 2005, 253 m^3 of category C waste were stored at Belgoprocess.

According to the inventory, the total volume of category A waste will thus represent about 85% of the total volume of conditioned waste. Half of this category A waste is dismantling waste from nuclear power plants, a volume that does not depend on the duration of plant operation.

Production forecast of conditioned radioactive waste of categories A, B and C until 2070, based on the inventory of 2003, and conditioned waste volumes already in stock at Belgoprocess.

Waste category	Current stock [m^3] (end 2005)	Current estimates of total volume [m^3] (by 2070)	
A		**Nuclear power plants**	
		Operating waste	13 800
		Dismantling waste	35 300
		Others	
		Operating waste	4 900
		Dismantling waste	16 500
	13 495	**Total**	70 500
		if reprocessing resumes (for all spent fuel)	**if reprocessing does not resume**
B	3 966	8 700	8 700
C	253	2 100	4 700



Production forecast of conditioned radioactive waste of categories A, B and C until 2070, based on the inventory of 2003.

1.3. Acceptance criteria, qualification and waste acceptance

The safety of radioactive waste management relies not only on the proper design and implementation of the management facilities, together with the choice of an appropriate disposal site in case of final disposal, but also on the “quality” of the waste. The waste must have characteristics that are compatible with the requirements imposed by the next management steps, for instance transport, interim storage and, ultimately, final disposal. This compatibility can be ensured by a three-step process.

- The establishment, by ONDRAF/NIRAS, of the criteria with which non-conditioned and conditioned waste must comply for ONDRAF/NIRAS to accept them, and the establishment of the procedures setting the modes for the transfer of property of this waste from the producers to ONDRAF/NIRAS.

- The qualification, by ONDRAF/NIRAS, of all processing and conditioning processes and facilities, that is the confirmation that they are able to produce conditioned waste that complies with the relevant acceptance criteria, and the qualification of the methods for determining the radiological content of non-conditioned and conditioned waste.
- The acceptance of waste packages by ONDRAF/NIRAS after administrative and technical control that they comply with the relevant acceptance criteria.

The current acceptance criteria may need to be adapted later, as a result of certain requirements that might be imposed by the competent authorities in the framework of the licensing procedure for a disposal facility.

2. Work programmes on final disposal: current status

ONDRAF/NIRAS manages two disposal programmes: one devoted to category A waste, which is fairly well advanced, though it has not yet reached the implementation phase, the other devoted to B&C waste, which is a lot more complex and is still at the RD&D stage.

2.1. The category A waste disposal programme

The category A waste disposal programme [ONDRAF, 2006] has recently moved a significant step further, with the decision-in-principle by the Federal Government, on 23 June 2006, that category A waste will be disposed of in a surface disposal facility to be set up on the territory of the municipality of Dessel. This decision crowns 20 years of activities, which can be split up into two phases:

- a 12 year-long *exploratory project phase*, which enabled significant scientific and technical progress to be made regarding surface disposal, but which, through lack of consideration for the societal aspects, did not succeed in identifying a place in Belgium that was suitable for setting up the facility and where the waste would actually be accepted by the local people;
- an 8 year-long *preliminary project phase*, built on the previously acquired knowledge and experience, but thoroughly different in its approach from the previous phase in that it was based on two new ideas [Bergmans, 2005; NEA, 2004]:
    - the idea of local participation, on a voluntary basis, in the framework of partnership structures to be created between ONDRAF/NIRAS and interested municipalities;
    - the idea of integrating the disposal project under development at the local level, by giving local people the power to impact on its actual design and to make it match their values and concerns, through associating a range of conditions to it.

The local partnership approach led to the creation of three partnerships with, respectively, the municipalities of Dessel, Mol and Fleurus-Farciennes. The partnerships STOLA-Dessel in Dessel and MONA in Mol each developed an integrated surface disposal project and an integrated deep disposal project. These were approved by the general assemblies of the partnerships and subsequently approved by the local councils of the respective municipalities, prior to their submission to the Federal Government. The partnership PaLOFF also developed a preliminary integrated disposal project, but its activities were terminated by decisions of the local councils of Fleurus and Farciennes.

With the decision of the Federal Government to opt for the integrated project of surface disposal of STOLA-Dessel, the category A waste disposal programme has now entered the project phase, that is the phase that must bring the project from its current status to that of a project that is ready to be implemented. This can be expressed by the following two objectives, which, according to the current timetable, would be achieved within the next five years:

- obtaining a binding agreement between all the parties concerned specifying the modes of implementation of the integrated project and the rights and duties of the parties;
- obtaining the necessary licences and permits from the competent authorities to start construction works.
-

2.2. The category B&C waste disposal programme

The current status of the category B&C waste disposal programme is rather different than that of the category A waste disposal programme. It is less advanced, because it is a lot more complex. It also does not yet have a strong institutional basis: it relies on a number of work hypotheses, some of which are at the very basis of the whole programme, but these hypotheses have never been *formally* confirmed by a decision-in-principle at the federal level.

The two major hypotheses that underlie the B&C programme are, (1), that deep disposal in a stable geological formation is the reference solution for the long-term management of category B&C waste and, (2), that Boom Clay is the reference host formation. ONDRAF/NIRAS' choice for geological disposal is in line with the international recommendations, and Boom Clay, which is present under the SCK•CEN site in Mol and has been studied for some thirty years, seems to offer good potential for the safe disposal of B&C waste. According to the SAFIR report [ONDRAF/NIRAS, 1989] and the SAFIR 2 report [ONDRAF/NIRAS, 2001a and 2001b], which assessed the confidence in the safety and the feasibility of the disposal system under study, and according to the international peer review of the SAFIR 2 report by the Nuclear Energy Agency of the Organisation for Economic Cooperation and Development [NEA, 2003], Boom Clay would indeed not present any redhibitory flaws as regards safety and feasibility for the waste under study, namely mainly vitrified high-level waste from spent fuel reprocessing.

However, the implicit choices in favour of geological disposal and Boom Clay need to get legitimacy both at the societal and political level. Regardless of how sensible ONDRAF/NIRAS believes them to be, the fact is that they have not been submitted to any form of societal debate, which is a definite weakness in the B&C programme. This has been recognised by ONDRAF/NIRAS in the contextual document of the SAFIR 2 report [ONDRAF/NIRAS, 2001c] and by the experts of the NEA [NEA, 2003]. It has also been acknowledged in 2004 by the supervising minister of ONDRAF/NIRAS in a letter inviting ONDRAF/NIRAS to take the necessary steps towards developing a work programme with a societal dimension, aimed at involving the different stakeholders in a dialogue structure that has been agreed upon, towards the implementation of a stepwise decision-making process. This programme must involve a study of the various possible long-term management strategies, including the possible participative procedures.

As a result, and while pursuing its ongoing RD&D, ONDRAF/NIRAS is working out a three-fold work programme:

- the setting up of a new global plan for the long-term management of radioactive waste, known as the “Waste Plan”, as requested anyway by the Royal Decree of 30 March 1981;
- in keeping with the recent law of 13 February 2006, the setting up, as part of the Waste Plan, of a Strategic Environmental Assessment (SEA) report, which will in

particular include an analysis of the reasonable alternatives to geological disposal in a clay formation;

- the launch of a societal dialogue around the Waste Plan, and in particular around the long-term management of category B&C waste.

Together, the Waste Plan, the SEA and the societal dialogue should lend societal and political legitimacy to the B&C programme. As a minimum, they should result in a decision-in-principle by the Federal Government confirming the reference solution and expressing a clear position as regards the reference option. They should also result in a clear and widely supported reference decision-making process, which would be the thread of the further management of the programme.

3. Financing

The costs of managing radioactive waste are paid for at cost price by those who produce the waste, in line with the “polluter-pays” principle. The two main radioactive waste producers in Belgium are Electrabel, the operating company of the seven nuclear power plants, and Synatom, the *Société belge des combustibles nucléaires*, which is a daughter company of Electrabel. A third major contributor to the financing of the costs of radioactive waste management is the Belgian State, in its capacity as the party financially responsible for the liabilities. The cost share of the management of the other producers’ radioactive waste is marginal.

The costs of radioactive waste management can be split up into three headings — research and development, short-term management and long-term management — whose financing modes are different.

- The *financing of the research and development activities*, which focus primarily on long-term management, is ensured by agreements between ONDRAF/NIRAS and the waste producers on the one hand, and between ONDRAF/NIRAS and the Belgian State in its capacity as the party financially responsible for the liabilities on the other hand. In addition, several international organisations, such as the European Commission, have financed a sizeable share of the costs of the underground research facility HADES and have participated in *in situ* experiments.
- The *financing of the short-term management activities* is also ensured by the waste producers and the Belgian State, through contracts with ONDRAF/NIRAS. Since 1996, these contracts are based on a system of reservation of capacity, which implies that each waste producer commits itself to paying an agreed share of the fixed costs of the facilities and to paying the variable costs of the management of its waste as it is handed over to ONDRAF/NIRAS.
- Finally, the *financing of the long-term management activities* must cover the costs of the necessary technical operations and, in case of an integrated disposal project such as that for category A waste, the costs of the conditions associated with the implementation of the repository. These two aspects are to be covered respectively by the existing long-term fund (FLT) and by a dedicated mechanism yet to be developed.

  Under the legal provisions of the Royal Decree of 30 March 1981 defining the missions of ONDRAF/NIRAS and determining its operating modes, ONDRAF/NIRAS set up a tool, FLT, in order to ensure that it will have in time the necessary means at its disposal to finance the technical operations, including interim storage, which are needed to complete its long-term radioactive waste management mission. This means that future generations will not have to bear the consequences of activities from which they have not benefited. Taking the mechanism of a pension fund as a basis, ONDRAF/NIRAS has designed a funding system to which the waste producers and the Belgian State (in its capacity as the party financially responsible for the liabilities) contribute whenever they hand waste over to ONDRAF/NIRAS and of which ONDRAF/NIRAS accepts ownership. Such a transfer of ownership is subject to verification that the waste complies with the relevant acceptance criteria.

The funding mechanism for FLT will enable ONDRAF/NIRAS to cover its fixed costs under all circumstances and to cover its variable costs as they arise. It is based on the following three basic ideas:

- *reservation of capacity*, which means that each of the main producers notifies ONDRAF/NIRAS of its total waste production programme, enabling ONDRAF/NIRAS to share its fixed costs between the producers;
- *tariff payments*, which means that each producer pays FLT a contribution based on the total costs of the long-term management of the waste handed over to ONDRAF/NIRAS;
- *contractual guarantee*, which means that each of the main producers commits itself to paying FLT the balance of the fixed costs attributable to its waste that has not already been covered by the tariff payments.

The provisions according to which FLT must operate are set out in agreements between ONDRAF/NIRAS and the waste producers on the one hand, and between ONDRAF/NIRAS and the Belgian State on the other hand (in its capacity as the party financially responsible for the liabilities). These agreements also provide mechanisms to make advance payment, for the amounts of the contractual guarantee, of the funds necessary for the implementation of a disposal facility.

The working assumptions of ONDRAF/NIRAS and the contractual quantities announced by the producers are adjustable every five or ten years in principle, or earlier in the case of *force majeure*. Regarding category A waste, the main economic assumptions of the outstanding agreements are that it will be *disposed of on the surface, on one site only*. This assumption was confirmed by the Government's decision of 23 June 2006. Regarding category B&C waste, the main assumptions are that the seven existing nuclear power plants will be operated for 40 years, as imposed by the law of 31 January 2003 on the progressive phase-out of nuclear energy, that all the spent fuel will be reprocessed, and that category B waste will be disposed of as from 2046 onwards and category C waste as from 2073 onwards.

The assets of FLT are managed in line with the provisions of the Royal Decree of 1 May 2006, amending the Royal Decree of 30 March 1981. The Royal Decree of 1 May 2006 requires ONDRAF/NIRAS to invest its assets in EUR-denominated debt securities issued or guaranteed by a member state of the European Community, by its local public administrations or by international public organisations in which one or several member states take part.

On 31 December 2005, the total assets of the FLT for final disposal amounted to 88 MEUR_{2005}, that is 50 MEUR_{2005} for surface disposal and 38 MEUR_{2005} for deep disposal. These figures can be related to the estimated costs of, respectively, the construction, operation, closure and institutional control of the surface repository of STOLA-Dessel for category A waste and with the construction, operation and closure of the deep repository under development for category B&C waste. The undiscounted base costs and their respective margins for uncertainties lead to the following cost ranges:

- surface repository of STOLA-Dessel for category A waste: 360 to 490 MEUR_{2005};
- deep repository for category B&C waste (estimates based on the repository concept as described in the SAFIR 2 report):
  - in case of full reprocessing of all spent fuel: 890 to 1310 MEUR_{2005};
  - in case of a definitive ban on reprocessing for all spent fuel: 1250 to 2140 MEUR_{2005}.

4. Final considerations

The current challenges in radioactive waste management clearly concentrate on long-term management. Beside the obvious scientific and technological aspects, which still need sustained effort, especially as regards deep disposal, two potentially decisive aspects whose importance tends to be underestimated will receive much attention from ONDRAF/NIRAS in the coming years: the societal dialogue and the current lack of institutional policy for the long-term management of category B&C waste.

The category A waste programme will focus on the detailed studies that are still necessary to bring the integrated surface disposal project to the stage where it can actually be implemented, with a view to starting repository operation by 2016. This objective implies in particular the development of a dedicated mechanism for covering the costs of the conditions associated by STOLA-Dessel to its disposal project that cannot be covered by FLT. The existing participative approach will be maintained and extended according to need.

The priority for the category B&C waste programme, on the other hand, is to put an end to the current lack of policy. To this end, ONDRAF/NIRAS will engage in a societal dialogue around its Waste Plan with the aims, for the B&C programme, (1), to have its basis work hypotheses confirmed and, (2), to get a consensus on a clear, stepwise decision-making process. Once supported at a societal level, the decision-making process and the basis work hypotheses can be submitted to the Federal Government, for formal confirmation of the decision-making process, and for a decision-in-principle as regards the solution and option(s) to be investigated for the long-term management of category B&C waste. This decision-in-principle should be taken within the next few years if the deadline for the start of disposal of category B waste is to be met. According to the agreements between ONDRAF/NIRAS and the waste producers and between ONDRAF/NIRAS and the Belgian State (in its capacity as the party financially responsible for the liabilities), this deadline is 2046. By way of comparison, Finland has chosen geological disposal as solution for the long-term management of its spent fuel in 2001, with a view to starting repository operation in 2020, while France has decided in June 2006 that it will pursue its current work on the geological disposal of high-level and/or long-lived waste, with a view to starting repository operation in 2025.

References

Bergmans A. (2005), Van “de burger als beleidssubject” naar “de burger als partner”: de Belgische queeste naar een langetermijnoplossing voor het beheer van het laagradioactief en kortlevend afval, University of Antwerp, Faculty of Political and Social Sciences, PhD Thesis

IAEA (1995), The principles of radioactive waste management, IAEA Safety Series No. 111-F, Vienna

NEA (2003), SAFIR 2: Belgian R&D Programme on the Deep Disposal of High-level and Long-lived Radioactive Waste—An International Peer Review, OECD/NEA

NEA (2004), Dealing with Interests, Values and Knowledge in Managing Risk, Proceedings of the 4th workshop of OECD/NEA Forum on Stakeholder Confidence, 18–21 November 2003, Brussels, NEA No. 5301, OECD

ONDRAF/NIRAS (1989), Safety Assessment and Feasibility Interim Report (SAFIR), ONDRAF/NIRAS

ONDRAF/NIRAS (2001a), SAFIR 2—Safety Assessment and Feasibility Interim Report 2, NIROND 2001–06 E, ONDRAF/NIRAS

ONDRAF/NIRAS (2001b), Technical overview of the SAFIR 2 report—Safety Assessment and Feasibility Interim Report 2, NIROND 2001–05 E, ONDRAF/NIRAS (exists also in French and in Dutch, under respectively reference NIROND 2001–05 F and reference NIROND 2001–05 N)

ONDRAF/NIRAS (2001c), Towards a sustainable management of radioactive waste—Background to the SAFIR 2 report, NIROND 01–07 E, ONDRAF/NIRAS (exists also in French and in Dutch, under respectively reference NIROND 01–07 F and reference NIROND 01–07 N)

ONDRAF (2002), Vingt ans de gestion responsable des déchets radioactifs en Belgique — L'ONDRAF au service de tous, NIROND 2002–02 F, ONDRAF (exists also in Dutch, under reference 2002–02 N)

ONDRAF (2006), La mise en dépôt final, sur le territoire belge, des déchets radioactifs de faible et moyenne activité et de courte durée de vie — Rapport de clôture de l'ONDRAF relatif à la période 1985–2006, invitant le Gouvernement fédéral à décider de la suite à donner au programme de dépôt, NIROND 2006–02 F, ONDRAF (exists also in Dutch and in English, under respectively reference NIROND 2006–02 N and reference NIROND 2006–02 E)

Further reading

FANC, ONDRAF/NIRAS *et al.* (2006), Second meeting of the Contracting Parties to the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, National Report

ANNEXE 2

NUCLEAR PROVISIONS

NUCLEAR PROVISIONS

INTRODUCTION

Provision for managing irradiated fissile materials

Quantities of fissile materials used between 1982 and 1986

Before 1982, the costs of reprocessing fuel and the loans relating to recovered fissile materials were passed on to the companies producing nuclear electricity as they were incurred.

At the time, only the Doel 1 and 2 and Tihange 1 units were in service. The share of nuclear power in the consumption of electrical power was considerably smaller than now. Nevertheless, the sporadic nature of the actual costs and loans relating to irradiated fuel introduced significant variations in the selling price of electrical power.

From 1982, SYNATOM established provisions for costs relating to irradiated fuel in agreement with the Electricity and Gas Control Committee (*Comité de Contrôle de l'Electricité et du Gaz*, CCEG).

The establishment of provisions in step with the irradiation of fuel and the incorporation of corresponding subsidies in the selling prices of electrical power allowed short-term fluctuations in these prices to be eliminated.

Quantities of irradiated fissile materials after 1986

From the mid-1980s onwards, it emerged that the accumulation of quantities used in Belgian nuclear units, including the newly commissioned units, Doel 3, Tihange 2 then Doel 4 and Tihange 3, exceeded the accumulation of quantities covered by the reprocessing contracts signed with COGEMA.

For the new quantities used, no reprocessing or corresponding costs were planned before the end of the 1990s, i.e. not before the scheduled end of reprocessing under the COGEMA 80-89 contract. Consequently, a technique of establishing provisions on an updated basis was chosen, particularly since such a technique had been agreed with the CCEG for establishing, from mid-1985, provisions for decommissioning nuclear plants.

Provision for decommissioning nuclear plants

On 9 October 1985, an agreement on the decommissioning of nuclear units was signed by the State and the four companies present on the Belgian electricity market with interests in Belgian nuclear plants. This agreement provided for the creation of provisions for decommissioning and decontamination by each of the nuclear plants to cover the foreseeable costs of decommissioning and decontaminating the sites of the nuclear units.

The CCEG had been charged with ensuring, through its auditors, that each of the companies with interests in certain nuclear plants applied the rules of the agreement from 1 July 1985. From the outset the intention had been to carry out regular audits of the situation, in principle every five years. From 1990 onwards, the CCEG began assessing the decommissioning provisions to check whether the objective set was still realistic and whether or not the provisioning method had to be adapted. The result of these checks was translated into recommendations to be applied by the electricity companies.

1. LEGAL ASPECTS

The Act of 11 April 2003 entrusts SYNATOM with managing the provisions for the decommissioning of nuclear plants and for managing irradiated fissile materials in Belgian plants. This Act also organised the formation of a Supervisory Committee charged with issuing advices concerning the methods for establishing provisions, the revision of the maximum percentage of funds that SYNATOM can lend to nuclear operators, and the categories of assets in which SYNATOM may invest the part of the funds that it cannot lend to nuclear operators, as well as monitoring the establishment and management of these provisions.

This Act stipulates that in the six months following publication in the Belgian Official Gazette - which in this case occurred on 15 July 2003 - the nuclear services company and nuclear operators must submit to the Supervisory Committee a proposal for revising the provisioning method for decommissioning and for managing irradiated fissile materials. On 15 January 2004, a dossier containing the following elements was sent by SYNATOM to the Supervisory Committee:

- a scenario drawn up for decommissioning and for managing irradiated fissile materials;
- a detailed estimate of the costs involved, together with a schedule for the envisaged costs; and
- a calculation method for establishing provisions, according to discount and capitalisation rates corresponding to established techniques of financial analysis.

On 25 March 2005, the Supervisory Committee signalled its approval of the proposal submitted by SYNATOM. This approval, applied retroactively from 1 January 2004, of the methodology and financial parameters, was accompanied by a series of recommendations to be taken into consideration at the next three-year review on 15 January 2007.

During 2005, the Supervisory Committee issued two advices on the financial investments made by SYNATOM for the part of the provisions that could not be lent to the nuclear operators ELECTRABEL and SPE (that is at least 25%, from 15 July 2005, provided certain financial criteria were met, such as debt to equity ratio and the credit rating) and on the categories of assets in which SYNATOM may invest these funds. SYNATOM lodged an appeal against these advices with the Minister for Energy in accordance with the procedure provided for by the Act.

In compliance with the Act on nuclear provisions of 11 April 2003, the Belgian State, ELECTRABEL and SYNATOM entered into a tripartite agreement modifying the structure of the share ownership of SYNATOM and defining the solvency requirements and conditions for loans granted by SYNATOM to ELECTRABEL.

2. TECHNICAL ASPECTS

As indicated in the Act of 11 April 2003 and reiterated above, the provisions established by the nuclear services company SYNATOM cover two aspects: firstly the provision for managing irradiated fissile materials and secondly the provision for decommissioning nuclear plants.

2.1. Provision for managing irradiated fissile materials

The evaluation of the provision required to manage the irradiated fuel present on the nuclear plant sites involves evaluating the cost of managing all the fuel which will be discharged over the forty-year operational life of the nuclear plants.

Various scenarios for managing irradiated fuel have been examined: they refer to the management methods applied or envisaged world-wide by countries with nuclear power, namely either the reprocessing of the spent fuel or its disposal immediately after conditioning.

Firstly, reprocessing spent fuel is a proven technology, in particular to the company AREVA and waste-conditioning processes are well monitored; moreover, the recycling of fissile materials recovered during reprocessing, uranium and plutonium, is a proven technology in Belgium.

Secondly, the conditioning of irradiated fuel prior to its direct disposal was the subject of extensive conceptual studies and validation tests in the laboratory, but no industrial implementation has yet taken place.

Under these conditions, the scenarios drawn up envisage:

- on a temporal level
    - either immediate implementation (type-1 scenario);
    - or implementation deferred until 2017 (type-2 scenario).
      By 2017 ONDRAF should namely be in a position to confirm the capacity of Boom clay to accept the various types of hot waste. A type-2 scenario will not therefore start before 2017.

- on an operational level
    - either management based essentially on reprocessing (type-A scenario);
    - or management based essentially on conditioning the fuel without reprocessing (type-B scenario).

By combining these various options, three scenarios can be defined and assessed:

- scenario 1.A: Immediate Reprocessing: all the fuel is sent for reprocessing from 2007;
- scenario 2.A: Deferred Reprocessing: all the fuel is sent for reprocessing from 2018;
- scenario 2.B: Direct Disposal: all the fuel is conditioned from 2027 (detailed studies followed by the construction of a conditioning plant starting in 2017).

Whichever scenario is considered, the geological disposal of hot waste (canisters of vitrified residues or conditioned irradiated fuel) will begin at around the same time, since the time needed for them to cool on the surface prior to being placed deep underground is, in any case, around fifty years.

Therefore the geological burial of this waste should not begin before 2073 (2068 in scenario 2.B) and end around 2080, in other words a little more than 50 years after Doel 4 and Tihange 3 are shut down.

The total quantity of irradiated fuel discharged by the reactors until the end of the forty-year operational life of the nuclear plants is estimated at 4,550 tonnes, or 10,089 fuel elements based on current management, i.e. without taking account of a possible increase in the rate of irradiation on discharge.

2.2. Provision for decommissioning nuclear plants

The Act of 11 April 2003 stipulates that provisions for decommissioning shall cover *"all the costs of shutting down the reactor of the nuclear plant and of discharging the nuclear fuel, decommissioning the nuclear installation, cleaning up the site and managing the resulting radioactive waste"* (Article 2, § 3).

In 1995 and in 1999, ELECTRABEL commissioned NIS (a subsidiary of NUKEM GmbH, itself a subsidiary of the group ADVENT INTERNATIONAL since 1 April 2006), a research firm specialising in, among other things, the field of decommissioning plants, to produce a study on the planning of decommissioning activities and draw up a detailed estimate of the corresponding costs. The NIS study relates to the Doel 1 & 2, Tihange 1 and Tihange 2 units. For the other units (Doel 3 & 4 and Tihange 3), the cost estimates were extrapolated by ELECTRABEL and TRACTEBEL using the basic data developed in the NIS study for Tihange 2 together with the results of a sensitivity study developed by NIS. An order for a new study was placed with NIS in 2006 for the next evaluation of nuclear provisions, due on 15 January 2007.

Several scenarios were developed on the basis of the results of the NIS study. In the chosen scenario, namely immediate (or quasi-immediate) decommissioning once the reactor has been shut down (as opposed to deferred decommissioning, after 50 years and more), the nuclear units are assumed to be decommissioned in series. This involves decommissioning down to a "greenfield" state (as opposed to more limited decommissioning, allowing the site to be preserved as an industrial site). The choice of this strategy does not in any way foresee the actual options which will be adopted later, at the appropriate time.

The dates for shutting down the nuclear plants are fixed by the Act of 31 January 2003, which currently allows the units to operate for a period of forty years after their industrial commissioning.

The planning of the activities associated with the definitive shutdown and decommissioning of a nuclear plant can be broken down into three main periods:

- the definitive shutdown period, which runs parallel to the pre-planning phase and the drafting phase for the decommissioning file. During this phase, the operations carried out mainly concern the irradiated fuel and cleaning the unit: this phase is estimated to last between four and five years;
- possibly a waiting period for the Doel 1 & 2 and Tihange 1 units with a view to optimising the decommissioning work of a complete site (duration of this phase: around four years);

- the decommissioning period proper, which will last around seven years.

The infrastructures common to each site are used during the decommissioning of each unit and are therefore decommissioned as a continuation of the last unit on the site.

The costs of the decommissioning operations will be spread between 2015 and 2042.

The hypotheses taken into consideration in the NIS study were approved in advance by ONDRAF. The SCK-CEN carried out an expertise and audit mission aimed at verifying the acceptability of the hypotheses used in the study carried out for Tihange 1. The conclusions were that the code used by NIS is appropriate to the needs of the estimate made and that the hypotheses used seem reasonable and correspond to the "state of the art".

A sensitivity study was carried out on masses of activated parts, building masses, principal components, and contaminated equipment and systems.

3. ECONOMIC ASPECTS

3.1. Provision for managing irradiated fissile materials

Having addressed the envisaged scenarios in the preceding paragraphs, we will explain how the associated costs are assessed.

The calculation of the provision can be broken down into several components, each relating to a specific aspect of managing irradiated fuel. We will examine these with a view to highlighting the objective elements on which the economic assessment is based.

3.1.1. The cost of the additional storage of irradiated fuel

Each scenario for managing the back end aspects of the nuclear cycle is associated with a programme for managing the cooling ponds of nuclear units.

The programme allows the accurate determination of the number of transfers on site, the required number of storage containers for spent fuel and the dates on which additional installations must be constructed on the sites to allow the fuel to be managed until the last assemblies have left for reprocessing or conditioning.

The cost of the additional storage includes the following elements:

- the cost of purchasing the storage and transport containers (Doel site) and container-shuttles (Tihange site): it is based on the order placed with T.N.I. (TRANSNUCLEAIRE international, a subsidiary of AREVA);
- the cost of decommissioning these containers: the information is provided by T.N.I.;
- the cost of additional installations and their decommissioning: this is based either on that of similar installations present on the sites, or on studies backed up by figures carried out by the TRACTEBEL Engineering Office at the request of SYNATOM;
- the costs of operating the building for storing the irradiated fuel (SCG) at Doel and of transferring the irradiated fuel to the SCG: these costs are based on the experience of ELECTRABEL;

- the costs of operating the centralised spent fuel pool (DE) at Tihange and of transferring the fuels to DE: these costs are based on the current experience of ELECTRABEL;
- the cost of decommissioning the containers: the information is provided by T.N.I.

3.1.2. The cost of transportation

All the scenarios envisaged involve transportation of conditioned or unconditioned irradiated fuel and, where applicable, plutonium in the form of conditioned rough Mox.

Transportation of vitrified residues and irradiated fuel provides a reliable reference for assessing the cost of transportation from the sites to outside installations located in Belgium or abroad.

3.1.3. The cost of reprocessing

The cost of reprocessing used for the evaluation is based on a technico-economic analysis submitted by AREVA in 2002 for irradiated fuel reprocessing services.

The offer submitted by AREVA comprised:

- transportation of irradiated fuel from the Doel and Tihange nuclear plants to the La Hague reprocessing plant;
- discharge, storage and reprocessing of the fuel;
- delivery of vitrified waste and compacted waste to the storage site in Belgium;
- manufacture of the commercial Mox or rough Mox assemblies;
- recovered uranium will be made available in the form of UF6.

3.1.4. The savings in fissile materials

Scenario 1.A envisages the recycling of the plutonium recovered during reprocessing, with this being carried out in the initial period, in the form of Mox fuel.

Each Mox fuel element corresponds to a standard UO2 fuel element which does not have to be bought by SYNATOM. A saving is therefore made which the evaluation takes into account. It includes purchasing the uranium, its conversion and its enrichment as well as the actual cost of manufacturing the assemblies. The basic data are provided by the Supply Department of SYNATOM.

3.1.5. The storage and disposal of vitrified and compacted waste

The specific quantities of vitrified and compacted waste produced in the reprocessing scenarios (scenarios 1.A and 2.A) are those indicated in the delivery contract concluded between SYNATOM and ONDRAF in June 1997, which specifies the tariffs applicable to the storage and deep burial of reprocessing waste.

The delivery contract also specifies the annual revision formula for the tariffs applied by ONDRAF.

3.1.6. The cost of conditioning non-reprocessed fuel and rough Mox

The study carried out by BELGATOM from 1994 to 1998 on the feasibility of building a conditioning plant for spent fuel includes a detailed budgetary analysis of the cost of the investment and the cost of operating such a plant linked to a storage building capable of holding either 400 or 10,000 bottles. This basis was used in evaluating the cost of scenario 2.B.

Scenarios 1.A. and 2.A. make use of the results of the same study inasmuch as these make allowance for conditioning the plutonium which cannot be recycled in the form of Mox assemblies. Both consider that the plutonium is put into the form of Mox assemblies by AREVA which transports them to a plant working on a commission basis where they are to be conditioned into bottles. The cost of manufacturing the rough Mox fuel elements is included in the cost indicated by AREVA for reprocessing.

3.1.7. The storage and disposal of conditioned irradiated fuel and rough Mox

a) Storage

As with conditioning, the cost of constructing and operating a storage facility is based on the detailed technico-economic study carried out by BELGATOM as part of the evaluation of the open cycle, the capacity of the installation being adapted to the requirements of the scenario in question.

b) Disposal

As part of the technico-economic evaluation of the open cycle, an initial estimate of the cost of disposing of the irradiated fuel was carried out by ONDRAF; this allows us to evaluate the tariffs that would be applicable to the delivery of bottles of conditioned, irradiated UO2 or Mox fuel.

3.1.8. Safety margin

The various cost elements of the three scenarios envisaged were evaluated, as outlined above, on the basis of concrete data, resulting from the current experience of SYNATOM, current contracts or orders, specific studies requested from BELGATOM or, failing this, elements submitted by potential suppliers which correspond to the current market situation.

An analysis of the uncertainties was nevertheless carried out.

As regards scenario 2.B (Direct Disposal), the methodology developed by EPRI (ELECTRICAL POWER RESEARCH INSTITUTE) to determine project uncertainties and technological uncertainties was applied to the investments and the operation of facilities for conditioning non-reprocessed spent fuel or non-recycled Pu and storing the resulting bottles. It led to the application of a margin approaching 100% on these costs.

As regards scenarios 1.A and 2.A, as a precautionary measure, each component of the annual costs was increased by a safety margin of 15%.

3.1.9. Choice of reference scenario

Of the three scenarios (1.A, 2.A and 2.B) for managing irradiated fuel which were the subject of a technico-economic evaluation, it is not advisable to retain scenario 1.A - Immediate Reprocessing, since its implementation cannot be envisaged in the current political climate.

Scenarios 2.A (Deferred Reprocessing) and 2.B (Direct Disposal) have the advantage of not committing Belgium to a definitive orientation before 2017.

Furthermore, scenario 2.A has the following advantages:

- it is based on techniques and costs that are currently clearly understood, depending only very slightly on the conditioning cost and the tariff for burying fuel elements;
- the economic analysis tends to show that the cost of this scenario is greater than that of scenarios 1.A and 2.B, thus ensuring that the financial resources are sufficient whichever option is chosen by Belgium (1.A, 2.A or 2.B).

Scenario 2.B (Direct Disposal) is based on less familiar techniques from an industrial point of view and poses the problem of accurately assessing the costs and corresponding provisions as well as the uncertainty that currently exists concerning the specifications that will be drawn up for conditioning, the cost of conditioning and the cost of disposing of the conditioned irradiated fuel.

The chosen reference scenario is therefore scenario 2.A.

3.2. Provision for decommissioning nuclear plants

3.2.1. NIS estimates and schedules (Doel 1 & 2, Tihange 1 & 2)

The estimate of the decommissioning cost is based mainly on NIS estimates and schedules. Thus, the planning for decommissioning is subdivided into several “working steps” which represent the smallest unit in the cost planning. All these “working steps” are grouped together into nine “working packages” which cover all decommissioning operations. For each of these “working packages”, NIS defined the total amount of the costs during the decommissioning phase as well as their distribution over time. The total cost of decommissioning charges is the sum of the costs for all “working packages”.

3.2.2. Extrapolations for other Belgian nuclear plants

The decommissioning costs for the Doel 3 & 4 and Tihange 3 units were determined on the basis of an extrapolation of the costs for Tihange 2.

The estimates of NIS for the decommissioning of the nuclear plants were supplemented by their estimates for the decommissioning of certain equipment (such as the replacement steam generators and cover) and the site’s common buildings.

3.2.3. Potential savings and margin of uncertainty

The study carried out by NIS concludes that the estimates of the potential savings resulting from the grouping together by site of the decommissioning activities amount to more than 20%. ELECTRABEL/SYNATOM did not take all the potential savings identified by the NIS study into consideration when evaluating the chosen scenario. *Vis-à-vis* this study, the chosen scenario therefore takes account of a safety margin of 15%.

4. FINANCIAL ASPECTS

4.1. The make-up of provisions

SYNATOM is responsible for covering the costs of decommissioning nuclear plants and the costs associated with managing irradiated fissile materials. To this end, SYNATOM establishes provisions in its accounts in accordance with the new methodology and financial parameters approved by the Supervisory Committee.

The existing provisions for the decommissioning of the nuclear plants at ELECTRABEL and SPE have been transferred to SYNATOM.

4.1.1. Provision for managing irradiated fissile materials

The provision for managing irradiated nuclear fuel has the following characteristics:

- the calculation scenario used is a deferred reprocessing scenario in which the discharged fuel will be reprocessed and where the products produced by this reprocessing will be disposed of, in time, in a deep geological repository;

- the payments should run until 2044. By that point, the waste and the provision required to cover the cost of storage and deep disposal operations should have been transferred in full to ONDRAF. Based on the chosen scenario, the last waste would be buried in around 2080;

- the chosen financial hypotheses are the same as for the provision for decommissioning nuclear plants (discounting at 5%, including 2% inflation);

- additions to the provision are calculated on the basis of an average unit cost for all the quantities used until the end of the operational period of the nuclear plants and an interest charge on the existing provision at the end of the previous year is calculated at the rate used for discounting.

4.1.2. Provision for decommissioning nuclear plants

The provision for decommissioning nuclear plants is made up as follows:

- the amount of the principal is determined on the basis of the costs estimated per nuclear plant, based on a study carried out by external consultants;

- a rate of inflation of 2% is applied until the end of decommissioning to determine the future value of the commitment;

- a discount rate of 5% (including 2% for inflation) is applied to determine the net present value of the obligation (NPV). The nominal discount rate of 5%, approved by the Supervisory Committee at the beginning of 2005, is based on an analysis of the evolution and the average long term reference rate (rate of Belgian OLO 30-year linear bonds, 30-year "benchmark" rate in euros and 30-year interbank swap rate). The nominal variation, during the 2005 financial year, of these reference rates was not significant enough or sufficiently perennial for the best estimate of the provision to be considered as being globally affected, taking other factors of uncertainty into account;

- the decommissioning work is supposed to begin five to eight years after the definitive shutdown of the units in question, taking into account an operational life of forty years after commissioning;

- the present value of the obligation at the time of commissioning represents the initial amount of the provision with, in return, an asset of an identical amount included in the tangible assets concerned of ELECTRABEL. This asset is depreciated over a period of forty years from the date of industrial commissioning;

- an annual addition to the provision, corresponding to the interest charged on the existing provision at the end of the previous year, is calculated at the discount rate.

4.2. The management of funds corresponding to nuclear provisions

The Act of 11 April 2003 stipulates that SYNATOM is charged with managing the funds that make up the exchange value of the provisions for decommissioning and the management of irradiated fissile materials.

As of 15 July 2005, SYNATOM can lend the nuclear operators (ELECTRABEL and SPE), at the market rate applied to industrial loans, the exchange value of the nuclear provisions, up to a maximum of 75% of the total amount of the provisions and provided certain financial criteria are respected, such as the debt to equity ratio and the credit rating. This information must be periodically sent to the Supervisory Committee, which may reduce this percentage and request partial or full repayment of the loans in question.

That part of the provisions that cannot be lent to the nuclear operators, namely at least 25% of the total of the provisions, is invested by SYNATOM in assets outside the nuclear operators, ensuring the investments are sufficiently diversified and spread to minimise the risk. In July 2005, SYNATOM invested a sum of MEUR 808.4 in two tranches of a loan to ELIA SYSTEMS OPERATOR.

SYNATOM also has to retain sufficient cash (included in the 25%), in the form of treasury accounts or cash, to be able to finance all the costs associated with decommissioning and the management of irradiated fissile materials for the next three years of operation. Since 2004, SYNATOM has managed a portfolio of European bonds with a rating of AA or AAA which amounts to MEUR 78.4 (situation at end of 2005).

The table showing the status of provisions as at 31 December 2005 can be found in annexe 1.

4.3. Miscellaneous considerations

4.3.1. Availability of provisions

Belgian lawmakers have put a mechanism in place to ensure that the entire provision will be available within SYNATOM:

- SYNATOM must periodically send information to the Supervisory Committee (including the quarterly debt to equity ratio and the annual credit rating) which should flag up well in advance any cash-flow problems among the nuclear operators;
- the amounts that can be lent to ELECTRABEL and SPE vary according to a gradual scale and these may be reduced to 0% if the debt to equity ratio exceeds 75% or if the credit rating drops to a level below BB (Moody's);
- the law stipulates that a general preferential claim on the personal assets of

the nuclear operators, in favour of SYNATOM, applies as soon as the Supervisory Committee imposes on the nuclear services company the partial or full repayment of the loans in question. This preferential claim guarantees the repayment of the loans in question at the repayment amount fixed by the Supervisory Committee;

- SYNATOM must retain sufficient cash at all times to be able to finance the costs of the next three years of operation;
- the Act on nuclear provisions stipulates in Article 11, § 3 and 4 that "*if during decommissioning operations (or for the management of irradiated fissile materials), the provisions prove to be less than the decommissioning cost, the nuclear operators shall pay SYNATOM the amount required to cover the excess cost of decommissioning at the time this is due*".

4.3.2. Guarantees

The mechanism put in place by Belgian lawmakers offers guarantees to ensure that the provisions are available immediately for managing irradiated fissile materials and at the time operations start on decommissioning the nuclear plants. These guarantees concern the following elements:

- the Supervisory Committee is composed of Senior Representatives of the Belgian State and may call on ONDRAF and the AFCN (Belgian Federal Agency for Nuclear Control), whose directors take part, with rights of discussion only, in meetings of the Supervisory Committee. The nuclear operator is not represented in the Supervisory Committee;
- the Supervisory Committee may, in the performance of its duties, request the advice of national, foreign or international institutions or of specialised centres of competence;
- the Belgian State has a golden share in the capital of SYNATOM and two Belgian Government representatives in the Board of Directors of SYNATOM who have a right of appeal;
- the full provisions are not lent to the nuclear operators and loans are granted subject to certain financial criteria being observed, such as the debt to equity ratio and credit rating. The Supervisory Committee may review the maximum percentage of the funds which SYNATOM can lend according to developments in the borrowing capacity of the borrower in line with a graduated transparent scale established in the tripartite agreement between the Belgian State, ELECTRABEL and SYNATOM;
- a general preferential claim on the personal assets of the nuclear operator applies as soon as the Supervisory Committee imposes on SYNATOM the repayment of loans granted;
- the loans granted by SYNATOM to ELECTRABEL and SPE contain a "negative pledge" clause by virtue of which ELECTRABEL/SPE refrain from mortgaging their property assets or other securities on their financial debt, except with the prior written approval of SYNATOM (given after the approval of the Supervisory Committee or by granting an equivalent security to SYNATOM);
- the maintenance of liquidities by SYNATOM corresponding to the costs of the next three years of operation;
- the final responsibility of the nuclear operator if the amounts provisioned prove too low.

4.3.3. Externalisation of nuclear provisions

In Western Europe, nuclear provisions are managed either by the nuclear operators ("internal management") or by a mechanism of one or more funds managed by the authorities or a public body ("external management").

Based on a report on the use of financial resources intended for the decommissioning of nuclear plants (*), the European Commission intends to present a recommendation asking the Member States to take the necessary measures to:

- guarantee that financial resources will be built up during the operational period of nuclear plants to maintain a high level of nuclear safety during decommissioning operations;
- guarantee that the resources built up in this way will be available and adequate to meet, at the appropriate time, the costs of decommissioning operations;
- guarantee that these resources will be used for the purposes for which they were created and will be managed in a completely transparent manner.

The system put in place in Belgium satisfies these requirements and consequently the externalisation of funds in Belgium seems pointless, for the following reasons:

- the modifications to the share ownership in the Group have no impact on the guarantees set down in the Act of 11 April 2003;
- a transfer of provisions without the nuclear operator being released from its responsibilities in the field is unacceptable;
- the guarantees of a preferential claim on the personal assets of the nuclear operator and the "negative pledge" should be eliminated (with an increased risk of the funds not being available);
- any externalisation solution will yield less than funds managed by the Sector, under current financial market conditions;
- the increase in constraints could alter the perception of the borrowing capacity of Electrabel and its ability to secure financing on the markets;
- there is no sense in entrusting the provisions to ONDRAF as this body has a technical rather than financial management mission and this would lead to the risk of a conflict of interest.

(*) COM/2004/0719 of 26/10/2004.

Annexe

Status of nuclear provisions as at 31 December 2005 (in MEUR).

SYNATOM Nuclear services company		
Loan to Elia	808.4	
Short-term investments	78.4	
Synatom financing requirements	261.1	
Sub-total	1,147.9	26.7% of the total
Loan to Electrabel	3,119.9	
Loan to SPE	34.9	
Sub-total	3,154.9	73.3% of the total
General total	4,302.8	
Provisions		
Provision for decommissioning	1,448.3	
Provision for irradiated fuel	2,854.4	
Provisions total	4,302.8	

* Synatom annual report 2005

ANNEXE 3

Vessel issues that contribute to Nuclear Power Plant Life Management[3]

Eric van Walle, SCK•CEN, Boeretang 200, B-2400 Mol
July 2005

Lifetimes

The lifetime of a nuclear power plant (NPP) can be a misleading concept as in reality we can talk about multiple lifetime definitions. The *design* lifetime of a NPP depends upon the original conceptual estimations of crucial components that make up the plant. For an older generation of NPP's it was set to 30 years (in Belgium Doel I/II), for later generations it became 40 years (in Belgium Doel III/IV, Tihange I/II/III).

For some countries like the USA, the design lifetime equals the *license* lifetime and the so-called End-Of-Life time (EOL) is, in the case of a 40 year design lifetime, set equal to 32 years of full operational power (80% of 40 years).

For other countries, like Belgium, no EOL definition exists and a license is granted each time for 10 years on the basis of a decennial Safety Assessment Report (SAR). This explains the terminology of Plant Life Extension (USA) versus Plant Life Management (Europe). The USA needs extention of the design life, Europe doesn't need it because of the different lifetime definition and approach.

Besides the design and license lifetime one defines the *technical* lifetime that is determined upon technical considerations and the *commercial* lifetime that depends upon socio-economic issues.

Components

A nuclear power plant is made of different main components that can be classified according to different degrees of importance towards safety considerations. Many components are not considered to be crucial to threathen the life of the NPP. The safety culture within the power station includes a strict policy of precautionary maintenance and during the annual or 18 months revision periods of the NPP many parts are revised or unconditionally replaced. Moreover, serious investments for large components, the best example is the steam generator, can be made upon technical and economic considerations and can be executed in an almost routinely manner.

One of the most crucial parts of the NPP is the reactor pressure vessel (RPV). This vessel is a structure of some 15 meters high with a diameter of about 5 meters and a wall thickness of 20 cm and is made of low carbon steel. It contains the core of the reactor loaded with nuclear fuel that heats the water inside the vessel and that is the source of energy production. The vessel of a so-called Pressurized Water Reactor (PWR), the only type of reactor we have in Belgium, operates at some 300°C under an internal pressure of about 150 bar. The vessel is part of the primary circuit of the NPP and forms the primary barrier in a series of barriers towards the outside world. Although many large components like, as mentioned before, steam generators can be replaced, it is generally accepted that the RPV is irreplacable. It is therefore considered to be the most crucial component to determine the plant life and becomes the most important item in Plant Life Management of the NPP.

---

[3] **Introduced by J.-M. Streydio**

The vessel wall, especially at the height of the core, is continuously bombarded by neutrons that escape from the core and the surrounding water, and that in their path, cause damage inside the structural vessel material: this is the phenomenon of material embrittlement. Methodologies that follow-up the possible embrittlement of the material are implemented and assure that the vessel is at all times safe against brittle cracking.

The vessel is welded to the primary cooling circuit. The weldings at nozzle height (inlet and outlet of the vessel) are made by dissimilar welds: welds between different kinds of material. The same type of welds can be found in the so-called vessel penetrations that serve for feedthrough systems of instrumentation or control rods. The feedthroughs are made of different material than the vessel material. We need to distinguish between top and bottom penetrations: the top penetrations go through the removable lid of the vessel, the bottom penetrations go through the bottom part of the main structure of the vessel. Internationally (see later) there has been evidence that some of the materials together with the welds have been subject to cracking (from inside to outside). All these welded areas are not subjected to large neutron flux, but can suffer from internal stresses that are transmitted on the main materials that are exposed to the primary coolant. The presence of these internal stresses depends on the stress-relieve heat treatment that was given to these welds. Most of them were stress-relieved with the vessel at the time of vessel manufacturing, but some repair welds did not undergo that same treatment. When the cracking occurs, it is a very slow process that proceeds along the grain boundaries withing the material and is therefore defined as InterGranular Stress Corrosion Cracking or IGSCC. In some situations, however, it has not been clear whether the cracks are pre-existing (from the period of manufacturing) or appeared during service. Non-destructive testing methodologies are used to follow the (non)-evolution of these cracks.

Another component of interest to plant life management is the internal part of the pressure vessel. The internals are mainly built out of stainless steel and they make up the base structure that contains the fuel elements. Here the neutron flux, that hits these internal structures, is at its highest intensity. Initially the attitude of NPP owners towards the internal parts of the RPV has been a policy of replacement. However, the main internal structures that cannot be replaced that easily, will be affected by corrosive type of degradation through a combination of environmental conditions (temperature, primary coolant, irradiation, stresses...), material condition and irradiation time. This is so-called irradiation-assisted stress corrosion cracking or IASCC.

Some internal parts receive in 40 years of irradiation time a neutron dose that can be up to 1000 times higher than the integrated dose at the vessel wall. Typically one expresses this in a so-called dpa-unit. Dpa stands for 'displacements per atom' and in a PWR vessel wall, after 40 years of operation, one collects 0,1 dpa for the vessel wall, versus ~100 dpa for some internal parts. In other words: after 40 years of operation, one out of ten atoms has been displaced by neutronic bombardment/ interaction in the vessel, whereas in the internal part every atom has been displaced one hundred times.

Component Safety Life Management

Degradation by neutron embrittelemt

The integrity of the pressure vessel must be assured at all times. In Belgium we mostly follow the US regulation, although some exceptions exist where we follow French regulation.

For pressure vessel integrity issues under neutron bombardment (what we called the material embrittlement before) the United States Nuclear Regulatory

Commission, USNRC, has put down rules in the 10CFR50 Appendix G&H documentation. To follow-up possible problems of neutron embrittlement of the vessel, surveillance programmes have been installed according to ASTM E185. These programs consist of introducing a number of surveillance capsules against the inner vessel wall of the reactor at core height. These capsules contain specimens that are made of identical or representative material of the vessel. The irradiation history of these specimens follows the irradiation of the vessel beltline region (the central portion of the vessel structure that 'looks' directly at the reactor core) which receives most of the neutron irradiation. As the capsule is more close to the core than the vessel wall to the core, the capsule will receive a higher neutron fluence in a given time. Usually this 'lead' factor is of the order 3: or 6 years of irradiation in a surveillance capsule represents 18 years of vessel irradiation.

Periodically, capsules are removed from the reactor and the specimens are mechanically tested according to standardised procedures. In Belgium, Tractebel / Electrabel, has contracted this analysis and testing out to the Nuclear Research Centre, SCK•CEN. This evaluation allows to follow-up ahead of time the degradation of the vessel material due to neutron irradiation and also allows to make prediction curves for the evolution in time of the degradation of each reactor vessel. The legislative methodology used at present was developed in the early 1980's and is based on a semi-empirical procedure that measures indirectly the fracture toughness of the material via the so-called Charpy test. The overall methodology is known to be in most cases overconservative. At this time we have this type of data, that represent more than 40 years of exploitation time of the vessel, for all 7 Belgian NPP's. These 'toughness values', that are a measure for the (remaining) strength and ductility of the material, are input parameters for an integrity analysis of the vessel. Within this integrity analysis, one assumes the existence of a crack with a considerable depth and size in the vessel structure and one looks at the possible evolution (growth) of such a crack under normal and accidental conditions. The method can either be applied in an deterministic manner or based on probabilistic safety analysis (PSA). At all times (in PSA terms: one thru wall cracking has a probability of 10^{-6}/year), it must be assured that the material toughness is high enough to prevent brittle cracking, which is the case for all Belgian reactor pressure vessels up to 40 years and more. It must be said that the pre-supposed crack is taken in a very conservative way and that non-destructive measurement techniques have by far never found a crack of this size (only very small pre-existing and non-evoluting flaws have been detected in reactor pressure vessel structures). Moreover, almost half of the NPP's in the USA already obtained a license extension for 20 years (60 years of total license) under the existing legislation.

Recently, a new measurement technique, the so-called Master Curve, has been worked out and substantially validated throughout the world. This methodology allows to determine the fracture toughness of the pressure vessel surveillance material, the capsule specimens, in a direct way (versus the indirect manner that is in the legal evaluation methodology). For almost all Belgian vessels these direct fracture toughness data exist for their 'limiting' surveillance materials (limiting = most susceptable to neutron embrittlement). This is an unicum in the world and indicates the good practice of the Belgian NPP owners towards safety assessment and in investing state-of-the-art concepts. All data demonstrate the overconservative legal procedure and allow in the integrity analysis of all Belgian NPP's a continued lifetime (up to 60 years of operation and higher) for the Belgian pressure vessels.

Within Germany and the USA, changes in the legislation to adopt to the new methodology have been worked out and are under consideration by the rulemakers. Belgium would automatically adopt this new ruling. It should also be mentioned that enormous efforts by USNRC to improve methods based on probabilistic safety analysis to evaluate the vessel integrity under accidental conditions have been developed and are under initial rulemaking: the available computing power (they analysed up to 180.000 cases that could possibly lead to an accidental event) and the existance of data/information from actual power plants allows also on this side to reduce the conservatism within the actual legislation.

Besides effects of embrittlement by neutrons, people have also contemplated that the pressure vessel, being during operation continously at about 300°C, could embrittle due to thermal ageing (of course the areas where neutrons are around would be subject to the sum of the two phenomena and the embrittlement measured would be the sum). To check this possible phenomenon one has thermally aged materials (without being subjected to neutron bombardment) up to 40 years of operation: up-to-now no significant effects of material degradation have been seen.

It must also be written that a large effort has been and is being devoted to the understanding of radiation embrittlement of pressure vessel materials: a large number of scientific issues have been resolved. We understand the main causes of the embrittlement and worldwide efforts are being conducted to underpin the radiation damage mechanisms that have been identified to cause the embrittlement. Here, the SCK•CEN is also an important international player.

In conclusion, one can state that neutron embrittlement of the pressure vessel as a probable cause for vessel fracture can almost surely be ruled out within reasonable NPP lifetimes.

Degradation through IGSCC or IASCC

The phenomenon of corrosion is very complicated as it involves many parameters: material, stress, temperature, environment, irradiation... It is clear that when the material is subjected to irradiation that the corrosion related cracking of the material is enhanced. The reason is complicated but can be generalised to two phenomena: (i) irradiation degrades the bulk of the material and causes hardening and loss of ductility; also, irradiation enhances diffusion or segregation processes of certain alloying elements towards the grain boundaries of the material; (ii) irradiation drastically changes the environment with which the material is in contact: radiolysis of the primary coolant results in the presence of rather aggressive species and a higher dissociation rate of the coolant into elements that will be present at the coolant-material interface where the corrosion phenomena occur. A material under stress (external load, thermal stress or stresses, originating from differential swelling of conatcting components) or at higher temperature (from the nuclear heating) has the tendency to crack faster.

From the legislative viewpoint, things are not as clearly regulated as in the case of vessel embrittlement . All components are subject to regulated (usually ASME) in-service inspection within the normal maintenance plan: these inspections occur at regular (or imposed) times during the normal outage period of the power plant. Moreover, recent corrosion related cracking events that occurred internationally (not in Belgium, except for the steam generators that have been systematically replaced) led USNRC and other organisations, like EdF who detected the 'first' events, to come up with prediction formulae for crack growth rates in materials subject to the above mentioned types of corrosion.

As indicated before the primary circuit structure is subject to the phenomenon of intergranular stress corrosion cracking: no substantial irradiation level, when compared to other parts of the reactor system, is present. The places where this type of corrosion has been detected are the feedthrough systems and the nozzles (inlet, outlet and emergency injection). These places contain Inconel 600 base metal and/or Inconel 182 welds, materials that have demonstrated cracking when being internally stressed due to welding. The areas were the phenomena occur are also primary barriers to the outer world. When cracks appear, however, they are slow-growing when compared to cracking that might occur in a pressure vessel due to vessel embrittlement (years versus milliseconds).

The first upper feedthough cracking was observed in France and resulted in a systematic replacement of the vessel heads with new vessel heads. The new lids contain Inconel 690 for the feedthoughs; a material known not to be subjected to cracking (from research on steam generator degradation). In Belgium, the phenomenon of upper feedthrough degradation was detected via non-destructive monitoring on Tihange 1, which resulted in a replacement of the vessel head in 1999. Until now, no effects of this type of cracking on the upper feedthroughs of other Belgian plants have been detected during non-destructive inspections.

The bottom penetrations of an NPP cannot be replaced that easily and a cracking event was recently detected in the South Texas plant in the USA. In Belgium, this type of bottom penetrations is present in all reactors but they are at lower temperature (which reduces the risk of cracking) than in the US case. The bottom penetrations for Doel 2 (the second oldest reactor in Belgium) have been subject to extra ASME in-service inspection and no irregularities have been found. Doel 1/2 also has safety injection nozzles that contain dissimilar materials. They are also at low temperature and have not been subject to cracking.

The inlet and outlet nozzles of the later generation of Belgian reactors have also been called to inspection after degradation effects were detected in the hot leg nozzle at the VC Summer and Ringhals reactors abroad. In Belgium detailed stress and defect tolerance analyses were performed. A ranking of the most sensitive locations was made and the inspections program was enhanced accordingly. One possible location was found in a cold nozzle but construction evidence and multiple follow-up suggest that it might concern a pre-existing flaw that shows no evolution. The safety consequence is anyhow that the number of inspections have been increased.

The internal parts of the PWR reactor, mainly elements of the structures that support the core, can be subject to irradiated stress corrosion cracking. The risk here is not connected to an outer world barrier, but a concern of deformation of the core structure that might prevent control bars to enter in a correct way. This corrosion phenomenon has a clear threshold and starts to occur in a PWR at a fluence that is about ten times higher than for boiling water reactors (BWR, no reactors in Belgium are of this type). As such the research on this phenomenon for PWR reactors is rather new, but can to certain extent profit from the BWR experience. The materials used for these internals mainly belong to the stainless steel family and are as said before subjected to very high levels of irradiation. Some of these materials components can and have been replaced in time, but others, like for example the core bottom plate or the baffle formers cannot be replaced that easily. Although, the stress level is rather low in these components, other phenomena like swelling might occur after long time exploitation (>60 years).

In Belgium, typical examples of IASCC were the baffle bolts in Tihange 1: these bolts are subject to high fluence and, at some spots inside the bolt, to high stresses. At the spots of high stress concentration corrosion cracking occurs. Many of these bolts have been replaced with less corrosive materials and intensive research projects have been conducted to explain the corrosion phenomena and ameliorate the corrosion properties.

At this time a lot of research effort is put into these corrosion phenomena. It is for sure that these phenomena will govern to a large extent discussions of future plant life management of the nuclear power plants. On the other hand, they are at this time not considered to be life threathening for the NPP and mitigation methodologies are established or are the focus of present research.

Conclusion

This brief is intended to give an overview of phenomena that are taken into consideration for Life Management of the reactor pressure vessel structure(s) of Nuclear Power Plants in Belgium. The phenomena relate to Pressurized Water Reactors as this is the only type of commercial power reactors we have in Belgium.

The reactor pressure vessel is considered to be the central part of the NPP and is irreplacable. As it also forms a primary barrier to the outer world, its integrity needs to be guaranteed at all times for safe exploitation of the NPP. An immediate consequence is that if the safety of this component can not be guaranteed, the NPP needs to be taken out of service: Nuclear Power Plant Life Management is to a large extent determined by the integrity of reactor pressure vessel.

Two phenomena of degradation of the vessel structure need permanent follow-up: radiation embrittlement of the central part of the pressure vessel and corrosion phenomena that occur in areas of the vessel that are not subjected to neutron embrittlement. Moreover, internal to the vessel, one needs to cope with the effect of irradiation assisted stress corrosion that can affect the internal parts of the PWR.

On the embrittlement of the vessel due to irradiation, the actual legislation allows to operate the Belgian NPP's for 40 years and more without problems. Moreover, a new more physically-justified methodology up for legislation, can assure a lifetime of 60 years and higher.

On the corrosion issues of the Belgian NPP's: the cover of Tihange 1 was replaced in 1999 due to corrosion cracking of a top feedthrough. This type of corrosion was not detected during inspection of the other Belgian NPP's. On the bottom feedthroughs no corrosion cracking was detected either. Multiple checks of the nozzle areas was performed on the NPP's and besides one indication of a small crack, but suspected to be a original flaw and confirmed to be without evolution, no effect was seen. On the internals, baffle bolts have been replaced and other core components are followed-up. As a normal safety precaution the number of inspections on estimated crucial areas have been increased. At this time, no lifetime limitations have been set due to these events.

Tableau 4

Estimations de coûts en €/MWh pour la construction d'une nouvelle centrale EPR (durée de vie de 60 ans) selon le Ministère français de l'industrie (2005)

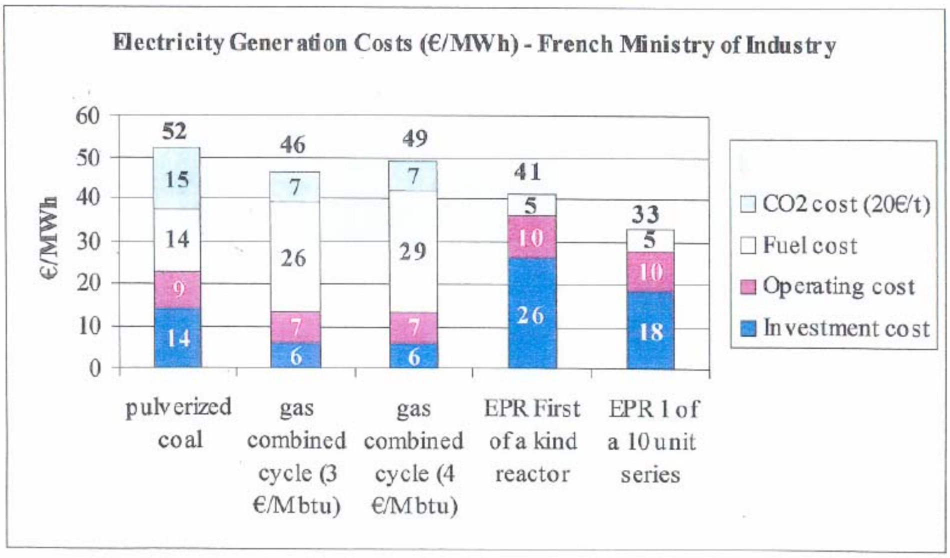
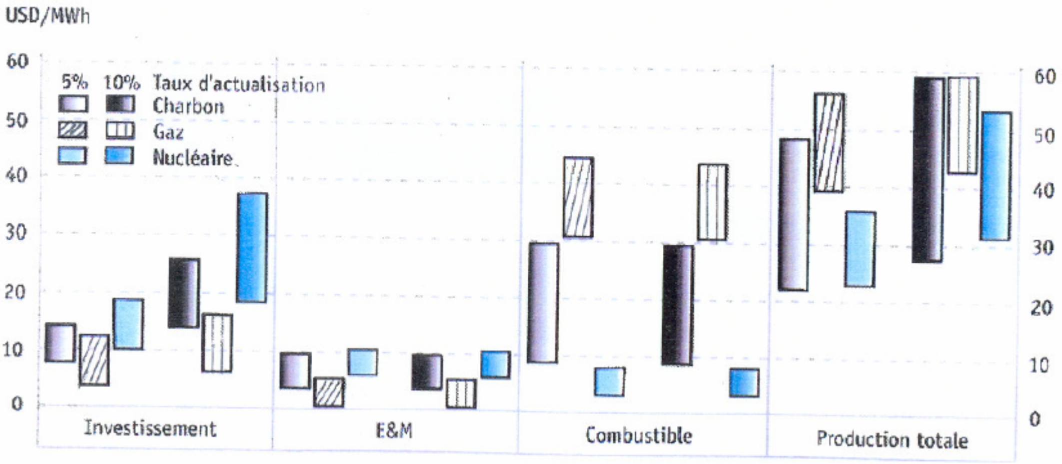


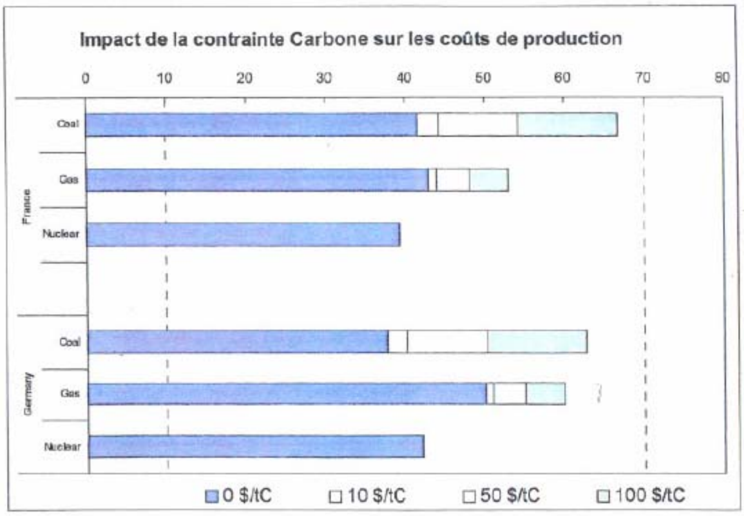
Tableau 5

Fourchette des coûts actualisés pour le charbon, le gaz et le nucléaire (USD/MWh)



Source : OCDE/AEN (2005). *AEN Infos*. Vol. 23, n° 1, page 27.

Tableau 6



Base = données AEN et AIEA