Eletrobras Eletronuclear	**Relatório Técnico**	CLASSE **1**	Nº BP-U-UAS-190004

ASSUNTO/MOTIVO	
Resumo do Plano Preliminar de Descomissionamento da CNAAA com ênfase na Unidade de Armazenamento à Seco de Elementos Combustíveis Irradiados	PÁGINA **1/37** LOCAL/DATA Rio, 16-maio-2019 REDATOR Bruno Estanqueira Pinho U.O./TEL. SE.T/7938
REFERÊNCIA UAS	CÓDIGO ARQUIVO

Nº DE PÁGINAS	ANEXOS 0
37	1

Para ser providenciado
Para conhecimento

prazos

RESUMO

Este relatório apresenta um resumo do Plano Preliminar de Descomissionamento (PPD) da Central Nuclear Almirante Álvaro Alberto (CNAAA) [1] com maior detalhamento da Unidade de Armazenamento Complementar à Seco de Elementos Combustíveis Irradiados (UAS).

Este documento tem por objetivo prestar esclarecimentos suficientes ao IBAMA de forma a atender à exigência 7.2.1 do Parecer Técnico nº52/2018-DENEF/COHID/CGTEF/DILIC [2] do IBAMA de 14 de fevereiro de 2019 e também ao atendimento do Encaminhamento nº 2.1.1 da ata de reunião realizada entre a Eletronuclear e o IBAMA em 27 de fevereiro de 2019 [3].

Adicionalmente às informações contidas neste resumo, também seguem como **anexo 1** o relatório ACS.T 058.18 com PPD da CNAAA completo [1].

SUMÁRIO

ASSINATURAS		REV.	DATA	PÁG.	VERIFICADO/ APROVADO
BRUNO ESTANQUEIRA PINHO	HEITOR HITOSHI / LÚCIO FERRARI	1	16/05/19	11,26, 27,28	
AUTOR	VERIFICADO/APROVADO			27	
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Cód O&M 042/04

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1. Introdução

1.1. Descomissionamento de Instalações Nucleares

O Descomissionamento representa a fase final do ciclo de vida de uma instalação nuclear. Ele envolve todas as atividades empreendidas para a descontaminação e o desmantelamento das instalações com o envio dos rejeitos radioativos que não puderam ser descontaminados e liberados conforme critérios de liberação da norma CNEN NN 8.01 [4] para um repositório final de rejeitos radioativos e com a destinação adequada dos rejeitos não radioativos.

O objetivo final é que a instalação possa ser liberada totalmente ou parcialmente do controle regulamentar e que o sítio possa ser reutilizado para outros fins, de forma restrita (com restrições em função de nível de radioatividade remanescente) ou irrestrita (podendo ser utilizada para qualquer uso). Estas atividades exigem eficiente gestão, uma vez que envolvem processos complexos e multidisciplinares. Estes aspectos devem ter como base principalmente o estado da arte da tecnologia no momento e a experiência no desmantelamento de instalações semelhantes.

Ao longo da vida operacional de uma instalação, o que pode atingir várias décadas, o revestimento de pisos e paredes internas do prédio da contenção e da piscina, bem como dos sistemas auxiliares, estarão sujeitos à contaminação, como resultado da deposição superficial de material radioativo oriundo de corrosão de produtos de fissão e da penetração da contaminação, dentre outros. Além disso, pode ocorrer a ativação de materiais, como ocorre no vaso do reator (VR).

Todas as usinas de geração de energia, com geração através de carvão, gás natural, e nuclear, têm uma determinada vida útil a partir da qual não é mais economicamente viável a sua operação. De uma forma geral, antigamente, as plantas nucleares eram projetadas para uma vida útil de 30 anos, e algumas, mediante alterações e atualizações, conseguiram seguir operando por muito mais tempo. Os novos projetos de usinas são para 40 a 60 anos de vida útil. Ao final deste período, a usina precisa ser descomissionada, limpa e demolida de forma a deixar o "*site*" disponível para outro uso.

Especificamente para usinas nucleares, o termo descomissionamento inclui a descontaminação radiológica e o seu desmantelamento. De forma prática, e pela "*United States Nuclear Regulatory Commission*" U.S.NRC, o Descomissionamento de uma usina apenas se inicia quando o combustível nuclear já foi retirado da usina e os sistemas de refrigeração foram drenados, e termina quando se tem uma verificação da descontaminação da usina e de que todo o rejeito foi removido, quando sua licença pode ser terminada [5].

Até janeiro de 2018, mais de 105 reatores comerciais, 48 experimentais ou protótipos, mais de 250 de pesquisa e unidades de ciclo de combustível foram desligadas e algumas já desmanteladas. Grande parte de uma usina nuclear não fica com contaminação radioativa, ou fica com níveis muito baixos de contaminação. A maior parte do metal pode ser reciclada.

Dos mais de 150 reatores de potência comercial, incluindo os experimentais, pelo menos 17 já foram completamente desmantelados, mais de 50 estão sendo desmantelados, mais de 50 estão em Armazenamento Seguro (*Safe Storage*), 3 ficaram como sarcófagos ("*entombed*"), e para os outros, ainda não foram definidas as estratégias. [6].

No Brasil existem duas normas relacionadas ao descomissionamento de Usinas Nucleares que são as normas:

- CNEN NN 9.01 [7], que dispõe sobre Descomissionamento de Usinas Nucleoelétricas, de 2012 e revisada em dezembro de 2017, onde exige a obrigação da existência de um Plano Preliminar de Descomissionamento de Centrais Nucleares, que deve ser atualizado caso haja grandes modificações no seu escopo ou de 5 em 5 anos, especificamente a parte referente ao custo relativo ao descomissionamento.
- CNEN NN 9.02 [8], que dispõe da Gestão dos Recursos Financeiros Destinados ao Descomissionamento de Usinas Nucleoelétricas, CNEN NN 9.02, de 2016 e revisada em dezembro de 2017.

1.2. Objetivo

O objetivo deste relatório é o de descrever de forma específica o descomissionamento da UAS dentro do contexto da CNAAA de forma a atender à exigência 7.2.1 do Parecer Técnico nº52 do IBAMA [2] e também atender o encaminhamento nº 2.1.1 da ata de reunião realizada entre a Eletronuclear e o IBAMA em 22 de fevereiro de 2019 [3].

1.3. Plano Preliminar de Descomissionamento (PPD) da CNAAA

O objetivo do descomissionamento da (CNAAA) visa alcançar o estado final seguro do sítio, protegendo os trabalhadores envolvidos, a população e o meio-ambiente de forma sustentável, onde os resíduos radioativos e os combustíveis irradiados serão armazenados adequadamente sem impactar as futuras gerações.

O PPD fornece informações como descrição de responsabilidades, propriedade, descrição das instalações da CNAAA, prédios e sistemas, levantamento radiológico com definição das estruturas contaminadas, ativadas e não previstas de ter contaminação, histórico operacional com lista de acidentes e derrames, estratégia de descomissionamento e sua justificativa aplicada a CNAAA, planejamento resumido incluindo as principais fases do descomissionamento (Planejamento, Período de Transição (PT), Armazenamento Seguro, Descontaminação e Desmantelamento (D&D), Demolição e Recuperação do Sítio), Gerenciamento de Projetos, Lista de atividades e Estrutura analítica de projeto resumida das fases do descomissionamento, manutenção e vigilância, gestão de rejeitos, com inventário existente de rejeitos e projeção de rejeitos que serão produzidos até o final da operação das usinas, assim como os gerados pelo processo de descomissionamento, estimativa de custos e gestão do fundo financeiro para custear o processo, avaliação de segurança e principais riscos e perigos associados as atividades, Avaliação ambiental, proteção radiológica, Garantia da qualidade, Plano de Emergência, Plano de proteção física e Levantamento radiológico final.

O PPD da CNAAA, embora preliminar, evidencia a complexidade das atividades envolvidas no descomissionamento da CNAAA. Informações mais detalhadas serão apresentadas em revisões posteriores do PPD que devem ser realizadas periodicamente.

O PPD da CNAAA apresenta informações às autoridades competentes, visando mostrar que todas as partes do processo de planejamento foram consideradas e serão abordadas ou revisadas à medida que o plano seja atualizado. O PPD da CNAAA compreende as seguintes instalações principais:

1) Usina Nuclear de Angra 1 - Prédio do Reator (ERE), Edifício Auxiliar Norte (EAN), Edifício Auxiliar Sul (EAS), Edifício do Combustível (ECB), Edifício de Segurança (ESE) e Edifício da Turbina (ETG)
2) Usina Nuclear de Angra 2 - Prédio do Reator (UJA, UJB e UJF), Edifício Auxiliar (UKA), Chaminé de Descarga de Gás (UKH), Sala de Válvulas do Gerador Vapor (UJE) e Edifício da Turbina (UMA);
3) Usina Nuclear de Angra 3 - Prédio do Reator (UJA, UJB e UJF), Edifício Auxiliar (UKA), Chaminé de Descarga de Gás (UKH), Sala de Válvulas do Gerador de Vapor (UJE) e Edifício da Turbina (UMA)
4) Instalações/Edifícios de Suporte
    a) Centro de Gerenciamento de Rejeitos (CGR) e Prédio de Monitoração de Radiação (PMR)
    b) Depósito Inicial do Gerador de Vapor (DIGV)
    c) Laboratórios de Monitoração e Calibração (LCMR)
    d) Laboratório de Monitoração Ambiental (LMA)
    e) Unidade de Armazenamento a Seco (UAS) de Combustíveis Irradiados

O PPD da CNAAA baseia-se nas exigências das normas brasileiras [7] e [8] e em normas internacionais, seguindo a estrutura recomendada pelo Agência Internacional de Energia Atômica (IAEA) no seu guia "Standard Format and Content for Safety related Decommissioning documents, Safety reports series nº 45" de 2005 [9] e encontra-se com o seguinte sumário resumido:

1 INTRODUÇÃO
2 DESCRIÇÃO DO SÍTIO DA CNAAA
3 ESTRATÉGIA DE DESCOMISSIONAMENTO DA CNAAA
4 GERENCIAMENTO DE PROJETOS
5 ATIVIDADES DE DESCOMISSIONAMENTO
6 MANUTENÇÃO E VIGILÂNCIA
7 GERENCIAMENTO DE REJEITOS
8 ESTIMATIVA DE CUSTOS / MECANISMOS DE FINANCIAMENTO
9 AVALIAÇÃO DE SEGURANÇA
10 AVALIAÇÃO AMBIENTAL
11 PROTEÇÃO RADIOLÓGICA
12 GESTÃO DA QUALIDADE
13 PLANO DE EMERGÊNCIA
14 PROTEÇÃO FÍSICA
15 CARACTERIZAÇÃO RADIOLÓGICA FINAL

1.3.1. Estratégia de Descomissionamento da CNAAA

Os requisitos regulatórios brasileiros presentes na CNEN NN 9.01 [7] e nos relatórios e publicações da IAEA [9, 10] definem as principais estratégias de descomissionamento de plantas nucleares de potência. As estratégias de descomissionamento definidas pela IAEA são [10]

a) Desmantelamento Imediato: as operações de descomissionamento se iniciam tão logo possível após o desligamento permanente da planta. Equipamentos, estruturas, sistemas e seus componentes pertencentes às instalações e que apresentem contaminação por materiais radioativos são removidos e/ou descontaminados de maneira que os níveis de atividade radiológica se encontrem dentro dos limites estipulados. Desta forma pode ocorrer a liberação do sítio do controle regulatório para uso irrestrito ou uso restrito em novos empreendimentos.

b) Desmantelamento protelado: Nesta estratégia, após a remoção dos materiais nucleares da instalação, caso dos elementos combustíveis, toda a instalação ou partes desta que apresentem contaminação por materiais radioativos são processadas ou colocadas em estado seguro até que a mesma possa ser descontaminada ou desmantelada. O desmantelamento protelado pode envolver operações de desmantelamento prévias em algumas partes da instalação e o acondicionamento de alguns materiais produzidos, que devem ser removidos do local para uma instalação adequada. Tais operações constituem-se em tarefas preparatórias que viabilizam a colocação das instalações/partes remanescentes da planta em estado seguro.

A estratégia de desmantelamento imediato deve sempre ser considerada como primeira opção uma vez que a mesma permite a recuperação do sítio no menor tempo possível [10]. No caso de uma Central Nuclear apresentar características específicas de múltiplas plantas, uma estratégia de desmantelamento protelado ou uma combinação das duas estratégias (desmantelamento imediato e protelado combinadas). Este é o caso da CNAAA, que possui múltiplas plantas (2 operacionais e 1 em estágio de construção).

Para definição da estratégia de descomissionamento de uma Central Nuclear, vários são os fatores que precisam ser analisados, sendo os principais mencionados a seguir: definição do estado final a ser alcançado, disponibilidade de instalações fora do sítio para armazenamento dos rejeitos radioativos de baixo e médio níveis, disponibilidade de instalações fora do sítio para armazenagem do combustível nuclear irradiado produzidos durante as operações comerciais das plantas Angra 1, Angra 2 e Angra 3, e interdependências existentes entre as plantas do sítio. Estes fatores foram discutidos no PPD da CNAAA [1] com mais detalhes, e foram analisados 3 cenários de estratégia, conforme abaixo:

I. Alternativa 1 – Desmantelamento imediato de todas as plantas

II. Alternativa 2 – Combinação das estratégias desmantelamento imediato e protelado

III. Alternativa 3 – Desmantelamento protelado de todas as plantas com referência a data de desligamento da última planta

Com base nas alternativas apresentadas, a Eletronuclear escolheu como estratégia de descomissionamento a alternativa 2, que combina o desmantelamento imediato com o desmantelamento protelado. Logo, de acordo com o descrito e ilustrado na Figura 1 da seção 1.3.3, as usinas Angra 1 e 2 serão descomissionadas conforme a estratégia de desmantelamento protelado enquanto a usina Angra 3 será descomissionada conforme a estratégia de desmantelamento imediato. 1

O estado final para a CNAAA após o desmantelamento é de uso irrestrito, ou seja, o site será liberado do controle regulatório da CNEN e, consequentemente, estará disponível para qualquer novo uso pela Eletronuclear ou sociedade.

A escolha do estado final foi feita com o objetivo de conduzir o processo de desmantelamento de modo a recuperar o sítio CNAAA com o menor impacto socioeconômico e ambiental possível.

1.3.2. Principais blocos de atividades do descomissionamento

O processo de descomissionamento é executado através de 5 tarefas principais brevemente descritas nas subseções seguintes. Estas tarefas devem ser executadas em qualquer estratégia escolhida (desmantelamento imediato, protelado ou uma combinação destas estratégias) seguindo normas, recomendações e estudos nacionais e internacionais sobre descomissionamento [1].

1) Planejamento e preparação

As tarefas de planejamento e preparação envolvem o levantamento das necessidades e recursos e a estruturação do cronograma do projeto, equipes e aspectos logísticos. No caso do descomissionamento se dar através da estratégia desmantelamento protelado, as principais tarefas de planejamento deverão ser divididas em duas etapas: a primeira referindo-se ao planejamento necessário para execução das tarefas que possibilitarão colocar a planta em estado de armazenamento seguro após seu desligamento permanente. A segunda referindo-se ao planejamento relativo à execução das tarefas de descontaminação, desmantelamento e recuperação do sítio após o término do período de estado seguro.

2) Período de Transição – Preparativos e modificações/adaptações após o desligamento permanente da planta

O Período de Transição inclui a remoção dos elementos combustíveis remanescentes da usina com a sua transferência para um repositório ou instalação, seu armazenamento, caracterização radiológica das áreas e de rejeitos, tratamento e disposição de rejeitos operacionais, modificação de sistemas e sua limpeza, estabelecendo novos limites operacionais e radiológicos durante o período de armazenamento seguro, enquanto aguarda o início do desmantelamento, remoção de alguns equipamentos, remoção de produtos químicos perigosos, adequação do programa de salvaguardas e proteção física, treinamento, reestruturação organizacional, etc. Este período deve ser precedido de forte planejamento e dura de 3 a 5 anos. O objetivo destas modificações é reduzir ou eliminar os riscos radiológicos e de acidentes industriais antes e durante o desmantelamento da planta.

Uma vez que não seja mais necessária, toda a infraestrutura da planta pode ser readaptada para acomodar oficinas para conduzir operações de desmantelamento, empacotamento e armazenagem dos rejeitos produzidos.

3) Período de Estado ou Armazenamento Seguro (Safe Storage Period)

O objetivo da estratégia de desmantelamento protelado é colocar a instalação nuclear em estado seguro pelo tempo que for necessário, reduzindo ainda as necessidades de manutenção da planta. Como consequência, a estratégia fornece tempo adicional para que certas condições na planta possam ser alcançadas viabilizando a realização de tarefas de descomissionamento antes do desmantelamento completo das instalações. Períodos de estado seguro com longa duração permitem a redução da exposição à radiação dos trabalhadores que executarão as tarefas de desmantelamento e/ou dos rejeitos radioativos de alto nível [7].

As atividades mais importantes deste período são: monitoramento, manutenção das estruturas e sistemas de suporte e adequação de edifícios quando necessário. O monitoramento tem por objetivo evitar a degradação das estruturas ao longo do tempo devido eventos externos e invasões/entradas não autorizadas ou até mesmo de animais ou aves. Por sua vez a manutenção previne infiltrações de água (da chuva, tubulações rompidas e água subterrânea) e fornece proteção contra eventos climáticos extremos e incêndios. O monitoramento radiológico por sua vez detecta emissões não previstas ou vazamentos de radionuclídeos. A adequação dos edifícios inclui a renovação das estruturas existentes de modo a torná-las adequadas para resistir a intempéries e infiltrações de água; inclui ainda a construção de barreiras de proteção nas áreas em que as mesmas se fizerem necessárias.

O monitoramento e a manutenção incluem ações que podem ocorrer em situações normais ou anormais, como na ocorrência de acidentes. Algumas destas ações são: confirmação da integridade da planta e seus edifícios, monitoramento da atividade radiológica, temperatura, umidade, corrosão, níveis de poluição atmosférica, segurança das instalações, drenagem e ventilação, condições das estruturas de aço, concreto e superfícies revestidas/pintadas/tratadas. A frequência das inspeções de rotina e monitoramento é de uma ou duas veze por ano, contudo podem ser diferentes de acordo com as condições da área ou local [1].

4) Descontaminação e Desmantelamento da planta (D&D)

As atividades durante este período incluem descontaminação e ou desmantelamento de todos os sistemas, equipamentos e materiais de plantas contaminados ou ativados. Estes serão removidos, separados, devidamente embalados e transportados para uma instalação de armazenamento final. Estas atividades têm duração de cerca de seis anos e incluem as tarefas críticas que exigem maior especialização para serem realizadas como: remoção de componentes internos do reator, do vaso de pressão do reator (RPV) e dos grandes componentes (como o gerador de vapor). A duração destas tarefas varia de dois a três anos e correspondem as tarefas mais dispendiosas e que exigem equipes especializadas para serem executadas adequadamente [1].

As atividades de D&D produzem grandes quantidades de material radioativo, como componentes do circuito primário, tubulações, válvulas, tanques, itens de proteção radiológica, racks de armazenamento de combustível irradiado, concreto contaminado, etc. Tais materiais devem ser cuidadosamente embalados e enviados para serem armazenados em locais apropriados e monitorados continuamente.

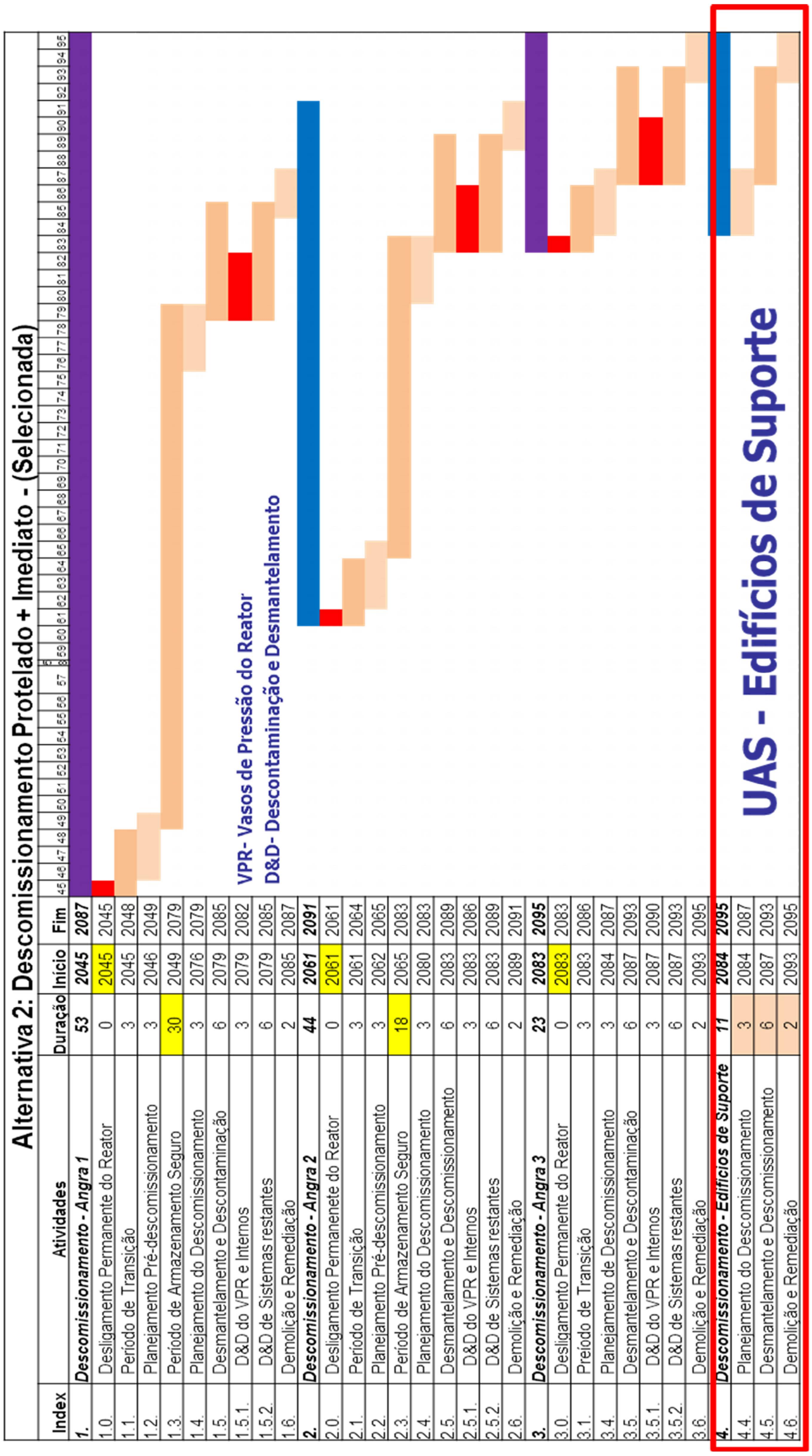
5) Demolição e remediação/restauração do sítio

As atividades deste período têm por objetivo permitir que o sítio alcance as condições definidas no plano de descomissionamento. O estado final define as condições que o sítio deve alcançar ao término do processo e estabelece os usos futuros que serão feitos da área, as tarefas de remediação que serão necessárias e a exposição futura dos usuários/população.

Este período também envolve operações de demolição convencional dos edifícios não contaminados ou que tenham sido descontaminados, a remoção de rejeitos convencionais, caracterização radiológica do sítio e a remediação das áreas necessárias. A duração destas tarefas varia de um a dois anos, conforme as condições finais desejadas para o sítio [1].

1.3.3. Cronograma previsto do descomissionamento

Considerando a estratégia escolhida no PPD da CNAAA[1], mencionada no capítulo 1.3.1 e as macro atividades descritas no capítulo 1.3.2 o cronograma geral considerado para o descomissionamento da CNAAA, onde a UAS está inserido no pacote de Edifícios Suporte segue conforme figura 1 a seguir:



Index	Atividades	Duração	Início	Fim
1.	*Descomissionamento - Angra 1*	53	2045	2087
1.0.	Desligamento Permanente do Reator	0	2045	2045
1.1.	Período de Transição	3	2045	2048
1.2.	Planejamento Pré-descomissionamento	3	2046	2049
1.3.	Período de Armazenamento Seguro	30	2049	2079
1.4.	Planejamento do Descomissionamento	3	2076	2079
1.5.	Desmantelamento e Descontaminação	6	2079	2085
1.5.1.	D&D do VPR e Internos	3	2079	2082
1.5.2.	D&D de Sistemas restantes	6	2079	2085
1.6.	Demolição e Remediação	2	2085	2087
2.	*Descomissionamento - Angra 2*	44	2061	2091
2.0.	Desligamento Permanenete do Reator	0	2061	2061
2.1.	Período de Transição	3	2061	2064
2.2.	Planejamento Pré-descomissionamento	3	2062	2065
2.3.	Período de Armazenamento Seguro	18	2065	2083
2.4.	Planejamento do Descomissionamento	3	2080	2083
2.5.	Desmantelamento e Descomissionamento	6	2083	2089
2.5.1.	D&D do VPR e Internos	3	2083	2086
2.5.2.	D&D de Sistemas restantes	6	2083	2089
2.6.	Demolição e Remediação	2	2089	2091
3.	*Descomissionamento - Angra 3*	23	2083	2095
3.0.	Desligamento Permanente do Reator	0	2083	2083
3.1.	Preíodo de Transição	3	2083	2086
3.4.	Planejamento de Descomissionamento	3	2084	2087
3.5.	Desmantelamento e Descontaminação	6	2087	2093
3.5.1.	D&D do VPR e Internos	3	2087	2090
3.5.2.	D&D de Sistemas restantes	6	2087	2093
3.6.	Demolição e Remediação	2	2093	2095
4.	*Descomissionamento - Edifícios de Suporte*	11	2084	2095
4.4.	Planejamento do Descomissionamento	3	2084	2087
4.5.	Desmantelamento e Descomissionamento	6	2087	2093
4.6.	Demolição e Remediação	2	2093	2095

Figura 1 – Cronograma Geral simplificado de atividades do descomissionamento da CNAAA com pacote incluída a UAS destacado em vermelho.

1.3.4. Gerenciamento de Rejeitos

A norma CNEN NN 9.01 [7] exige que não apenas a gestão dos rejeitos de descomissionamento seja tratada, mas também que seja estimada a quantidade de rejeitos que estará presente no final do período operacional. Para cumprir este requisito, ambos os tipos de rejeitos foram estimados no PPD da CNAAA.

Existem dois tipos de rejeitos associados à operação e descomissionamento de uma instalação nuclear. Estes são os rejeitos radioativos produzidos durante a operação (rejeitos operacionais) e os rejeitos produzidos durante o descomissionamento (nas etapas de desmantelamento e descontaminação).

No PPD é estimada a quantidade de rejeitos operacionais que serão gerados durante o período de operação das três usinas nucleares de Angra e o custo para a disposição desses rejeitos. Este rejeito será removido como parte da fase do Período de transição e o custo é considerado como um rejeito operacional. Uma estimativa da quantidade e do custo para a disposição final dos rejeitos de descomissionamento também é fornecida. O custo da disposição final desses rejeitos de descomissionamento está incluído na estimativa de custos de descomissionamento

As estimativas de rejeitos operacionais e de decomissionamento foram feitas considerando várias premissas que estão listadas no PPD da CNAAA [1], de onde são retirados os resultados a seguir.

1.3.4.1. Estimativa de Rejeito Operacional

A tabela 1 abaixo resume a estimativa de rejeito operacional considerado no PPD da CNAAA.

Tabela 1 – Resumo do rejeito radioativo operacional, m^3 [1]

	Unidade 1	Unidade 2	Unidade 3	Total
Nível baixo	1875,27	519,79	574,56	2969,62
Nível intermediário	4822,13	408,41	451,44	5681,98
Total	6697,40	928,2	1026	8651,60
Combustível irradiado (un.)	2095	2873	2845	7813

1.3.4.2. Estimativa de Rejeito de Descomissionamento

A tabela 2 abaixo resume a estimativa de rejeito de descomissionamento considerado no PPD da CNAAA.

O volume de rejeitos da UAS está considerado no volume de rejeito "limpo", sem contaminação ou ativação, na tabela 2.

Tabela 2 – Resumo do Rejeito de Descomissionamento, m^3 [1]

Tipo	Angra 1	Angra 2	Angra 3	Edifícios Suporte	Total
Nível baixo	7.343,3	12.923,9	12.822,1	635,9	33.725,2
Nível baixo de alta atividade	99,0	194,4	88,0	0	381,5
Nível baixo – container próprio	90,8	170,4	170,4	17,4	448,9
Intermediário – Alta atividade	29,3	7,3	227,4	0	264,1
Alto Nível	11,0	62,2	298,5	0	371,7
Limpo	312.939,9	428.145,0	428.145,0	65.701,6	1.234.931,4
Total	320.513,3	441.503,1	441.751,4	66.355,0	1.270.122,8

1.3.5. Programa de monitoramento ambiental

O programa de monitoramento ambiental monitora e avalia níveis de radiação em várias possíveis vias de ar, água e solo durante o período de descomissionamento. O programa define procedimentos de amostragem e instrumentos para monitorar o meio ambiente, métodos para redução de dados, validação e requisitos de relatórios. Os resultados anuais deste programa durante o descomissionamento das 3 unidades e instalações de suporte serão analisados e comparados com os resultados do período pré-operacional da CNAAA. Se o nível de radioatividade observado em amostras ou instrumentos no sítio da CNAAA exceder os níveis de notificação, eles serão reportados a CNEN. Se o nível de outros contaminantes perigosos for excedido, eles devem ser reportados ao IBAMA [13].

No caso da UAS não é considerada nenhuma contaminação radiológica.

As localizações atuais das estações de monitoramento dentro e fora do sítio são mostradas na Figura 2. O monitoramento de águas subterrâneas e de superfície, areia de praia, alga, precipitação e peixes também são realizados em locais mais distantes que não são mostrados nesta figura. O Manual de Controle Radiológico do Meio Ambiente (MCRMA) [14] relaciona a localização das estações de monitoramento radioativo no local na CNAAA, funcionando também para UAS. A quantidade e o número de estações de monitoramento em cada instalação serão avaliados e revisados, se necessário, antes do início das atividades de descomissionamento.

A Tabela 5 apresenta os tipos de sistemas de monitoração para efluentes líquidos e gasosos. Os seus limites de capacidade e detecção para o monitoramento do descomissionamento seguirão os requisitos estabelecidos para o funcionamento das usinas da CNAAA [14]. A frequência para monitoramento, coleta de amostras, substituição de filtros e dosímetros está descrita em [15]. Os procedimentos analíticos utilizados para coletar amostras e realizar medições são descritos nas Ref. [15] e [16]. As concentrações de fundo e base de radionuclídeos são apresentadas na Ref. [16].

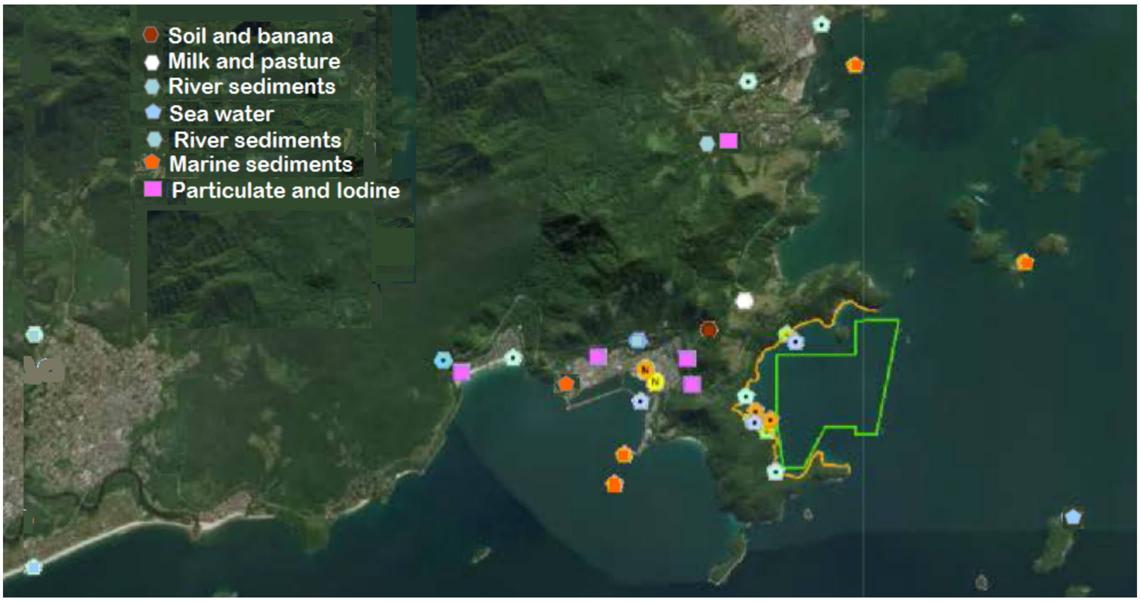


Figura 2 – Mapa que mostra o tipo de monitoramento ambiental dentro e fora da CNAAA [1].

2. Planejamento Preliminar do Descomissionamento (PPD) da UAS

O descomissionamento da UAS é parte do PPD da CNAAA [1] e mencionado na seção 2.3.4.2 da versão revisada do referido documento dentro do "pacote" de Edifícios Suporte, Relatório ACS.T 058.18 de 28/12/2018, anexo 1[1], que substitui a versão de 2014, enviada anteriormente ao IBAMA.

Não estão previstos impactos socioambientais associados ao descomissionamento da UAS do ponto de vista radiológico, uma vez que não está previsto qualquer tipo de contaminação da instalação em função das características de projeto da instalação. Seu escopo é constituído de uma demolição simples da UAS, com o envio do material retirado (entulho) para destinação comum, e os impactos socioambientais são equivalentes à uma atividade de demolição da instalação.

O início do processo de descomissionamento apenas ocorrerá após a transferência dos canisters para um depósito intermediário ou definitivo. Após esta etapa a UAS poderá ser descomissionada. No momento não há definição sobre quando haverá instalação para a disposição definitiva ou temporária dos ECIs.

Internacionalmente já existem projetos avançados de Depósitos Intermediário e finais conforme os exemplos a seguir:

i) Armazenamento consolidado Intermediário (CIS) – "HI-STORE CIS"

Liderado e projetado pela empresa Holtec, onde haverá uma coalisão de várias cidades para esta Instalação intermediária nos Estados Unidos.

Será utilizado a tecnologia subterrânea de armazenamento, chamada "HI-STORM UMAX. Certificada através do código da US.NRC 72-1040, com níveis de segurança sem precedentes e com capacidade para carregar 10.000 (dez mil) canisters. Este projeto está sendo desenvolvido para receber qualquer tipo de canister de quaisquer plantas nos EUA.

Abaixo segue Figura ilustrativa do HI-STORE CIS

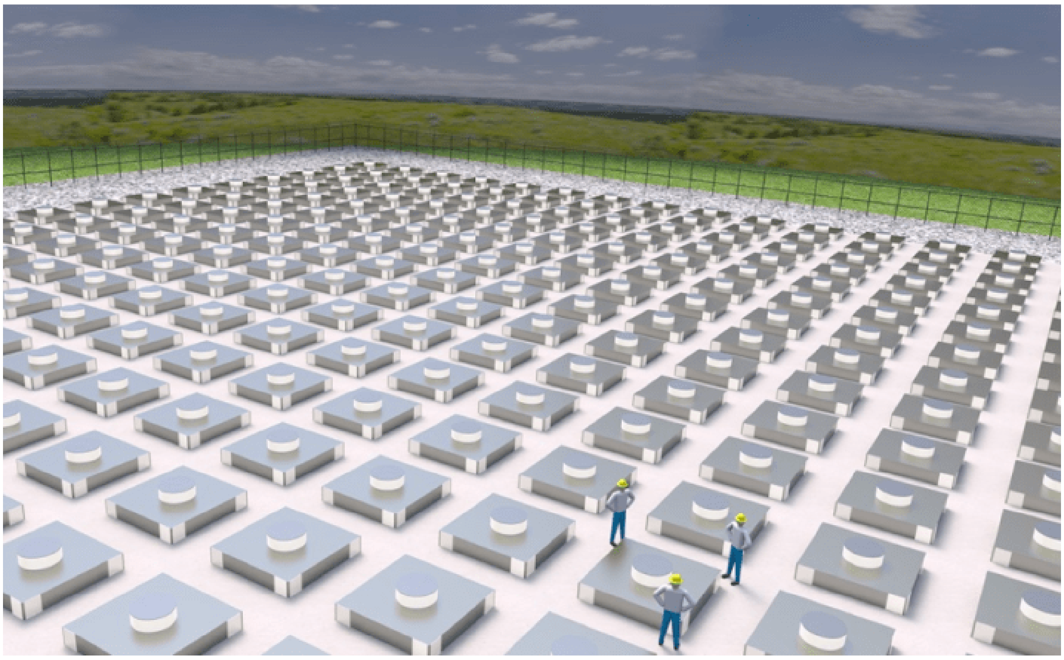


Figura 3 – Desenho ilustrativo da instalação HI-STORE CIS após construída [18].

ii) Instalação Intermediária de ECIs "Clab" – Central Interim Storage Facility for Spent Nuclear Fuel" – Suécia

Ficará a 25 km de Oskarshamn, e nesta instalação ficarão os ECIs suecos ficarão armazenados até a construção de uma Repositório Final de Armazenamento de ECIs. Será a 30 metros abaixo da superfície, conforme Figura 4 a seguir.

A instalação possui capacidade para até 11000toneladas de ECIs.

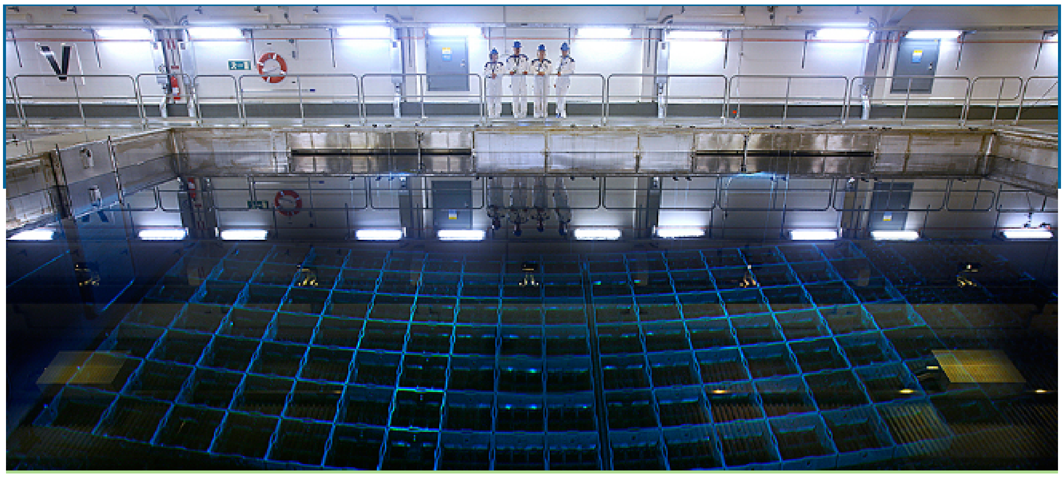


Figura 4 – Foto da Instalação Intermediária de Armazenamento de ECIs de Clab na Suécia [18].

iii) Repositório de combustível nuclear usado em Onkalo

É um repositório geológico profundo para a disposição final do combustível nuclear usado, o primeiro repositório desse tipo no mundo para resíduos de alto nível de radiação. Está atualmente em construção na Usina Nuclear de Olkiluoto, no município de Eurajoki , na costa oeste da Finlândia , pela empresa Posiva .

Baseia-se no método KBS-3 de enterramento de resíduos nucleares desenvolvido na Suécia pela Svensk Kärnbränslehantering AB (SKB). Terá a capacidade para 9.000 toneladas. A seguir segue a figura 5 ilustrativa.

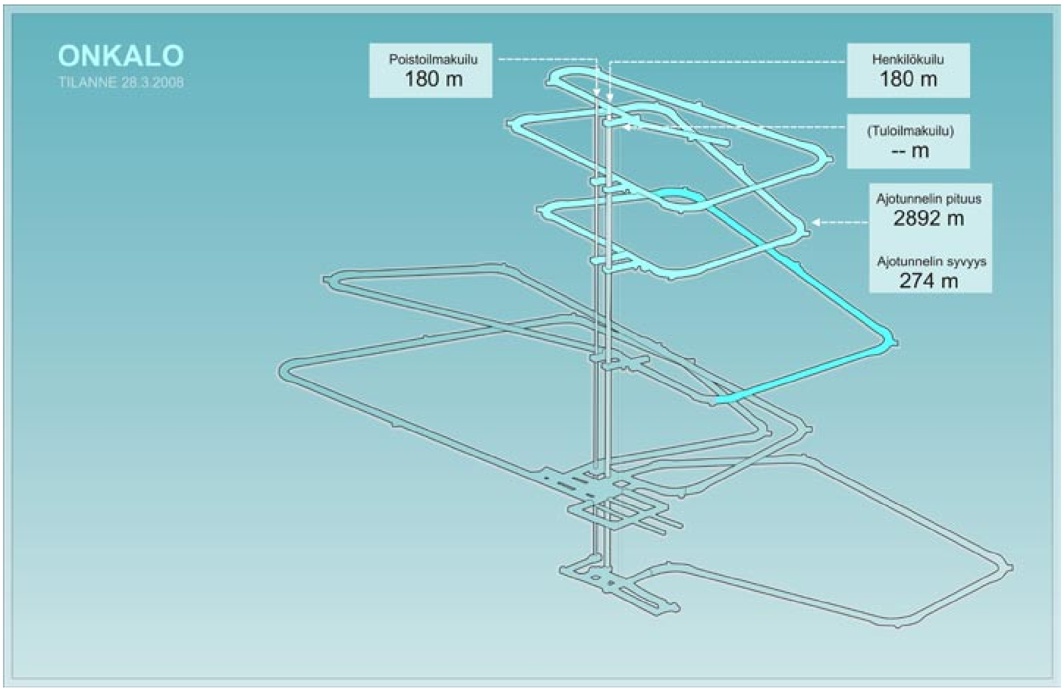


Figura 5 – Foto da Instalação Intermediária de Armazenamento de ECIs na Finlândia [19].

2.1. Responsabilidades e Propriedade

O atual proprietário da Central Nuclear Almirante Álvaro Alberto (CNAAA), abrangendo as plantas Angra 1 e Angra 2, que estão em operação, e a futura Angra 3, em construção, e as diversas instalações de apoio é:

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Eletrobras Termonuclear S.A. - ELETRONUCLEAR

- Endereço (Sede): Rua da Candelária, nº 65, Centro, CEP: 20.091-020 – Rio de Janeiro – RJ
- Endereço (Angra): Rodovia Procurador Haroldo Fernandes Duarte (BR-101) km 521,56 – Itaorna, CEP: 23.948-000 – Angra dos Reis -RJ

A UAS está em fase de projeto e construção e possui atualmente licença de local concedida pela CNEN no dia 14 de fevereiro de 2017, através da resolução nº 211 e uma Licença Parcial de Construção (LPC1) emitida pela CNEN no dia 18 de abril de 2019, através da resolução nº242.

A LPC1 é limitada à construção da laje para os 72 cascos, que corresponde ao pátio de armazenamento de concreto, sendo esta uma das principais estruturas, sistemas e componentes que compõe a UAS, conforme descrito no Relatório Preliminar de Análise de Segurança (RPAS) [20] da instalação.

2.2. Descrição da Unidade de Armazenamento Complementar a Seco (UAS)

No Brasil, o Elemento Combustível Irradiado (ECI) não é considerado resíduo e/ou rejeito, até que haja uma posição final do Governo Federal e da Comissão Nacional de Energia Nuclear (CNEN) sobre seu uso futuro, pois são considerados ainda recursos energéticos. Assim, os ECIs deverão ser armazenados de forma segura até que haja esta definição. O Relatório Nacional de Gerenciamento de Segurança de combustível Usado e Rejeitos Radioativos [25]em sua seção B1, informa que:

> "*A política adotada em relação ao combustível irradiado das Centrais Nucleares é mantê-los armazenados de forma segura, até que seja tomada uma decisão técnica, econômica e política sobre o seu reprocessamento e reciclagem, ou disposição final. Portanto destaca-se que, pela legislação federal Brasileira, o combustível irradiado não é considerado rejeito radioativo*"

A Unidade de Armazenamento Complementar a Seco (UAS) de Combustível Irradiado da Central Nuclear Almirante Álvaro Alberto (CNAAA) tem por objetivo geral promover o armazenamento a seco de elementos combustíveis irradiados (ECIs), acondicionados em Canisters inseridos no interior de Módulos de Armazenamento, visto que não existe hoje no país definição quanto à destinação final dos ECIs ou Local intermediário para armazenamento dos mesmos.

Como objetivo específico, os Módulos de Armazenamento associados às piscinas de estocagem interna das Usinas Angra 1 e Angra 2 (Piscinas de Combustíveis Usados - PCUs), incrementam a capacidade de armazenar os elementos combustíveis utilizados nos núcleos dos reatores das usinas que compões a CNAAA, cuja vida útil estimada é de 60 (sessenta) anos, para efeito de dimensionamento da instalação. Assim, o armazenamento complementar de combustível irradiado possibilitará a continuidade de operação da CNAAA.

A solução de Armazenamento Complementar a Seco é composta de sistema baseado em Canister, previamente licenciados pela norma americana U.S. NRC (United States Nuclear Regulatory Commission) 10 CFR Part 72 [26].

A solução de Armazenamento a Seco em "Canisters" é constituída das seguintes estruturas principais [24]:

1. **"Canister" (MPC-32ML e MPC-37):** Casco hermético, em aço inoxidável, que tem como objetivo o confinamento de todo o material radioativo em uma atmosfera de gás inerte (hélio). Contém estrutura reticulada ("basket") no seu interior, para o armazenamento seguro e controle de criticalidade dos ECIs. Os Canisters terão capacidade para 32 ECIs de Angra 2 (MPC-32ML) e 37 ECIs de Angra1 (MPC-37).

Figura 6 – Desenho ilustrativo do Canister

2. **Casco de Transferência (HI-TRAC VW):** "Sobre-embalagem" para proteção física e blindagem durante o processo de transferência entre as usinas e a UAS.

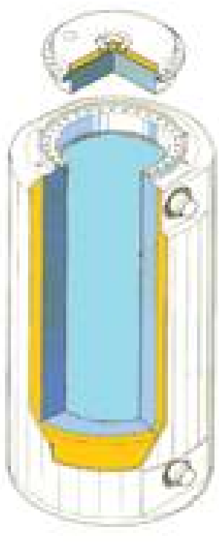

Figura 7 - Desenho ilustrativo Casco de Transferência

3. **Módulo de Armazenamento (HI-STORM FW):** Dispositivo de armazenamento dos "Canisters", em aço e concreto, projetado e licenciado para fornecer proteção física, dissipação de calor de forma passiva por convecção natural e blindagem contra radiação, durante o período de armazenamento.

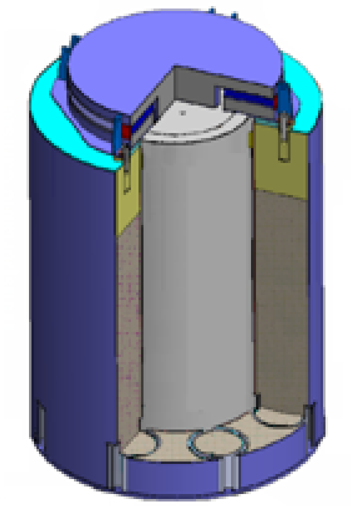

Figura 8 - Desenho ilustrativo do Módulo de Armazenamento

4. **Transportador (Cask Handling Machine ou Transporter):** Equipamento para manuseio e deslocamento dos módulos de armazenamento dentro PAD.

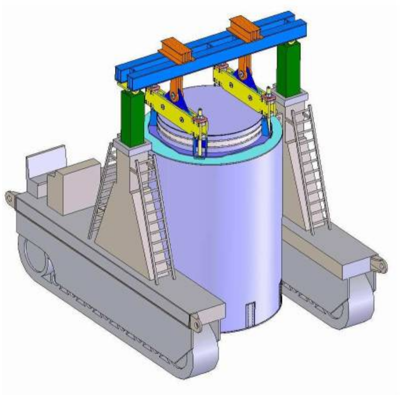

Figura 9 - Desenho ilustrativo do Transportador

5. **Casco de Transferência para externo à Central Nuclear (HI-STAR)**

Equipamento para transporte externo ao sítio das usinas, que será utilizado para envio dos Canister para destinação intermediária ou final.

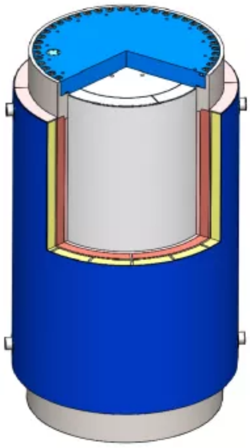

Figura 10 - Desenho ilustrativo do HI-STAR

Este transporte externo a CNAAA seguirá normativas de transporte conforme a seguir:

- 10 CFR Part 37 - Subpart D — Physical Protection in Transit
- 10 CFR Part 71 - Packaging and transportation of radioactive material
- 10 CFR Part 73 - Physical protection of plants and materials

6. **Instalação de Armazenamento Complementar – UAS:**

- Laje de concreto armado (PAD), onde são dispostos os conjuntos formados pelos Módulos de Armazenamento (44,2m x 49,4m)
- Cerca dupla para proteção física 1
- Guarita (10,55 x 15,94)
- Almoxarifado (24,00 x 31,50)

As figuras 11 e 12 a seguir mostram uma simulação 3D da instalação da UAS e o layout para ilustração respectivamente.

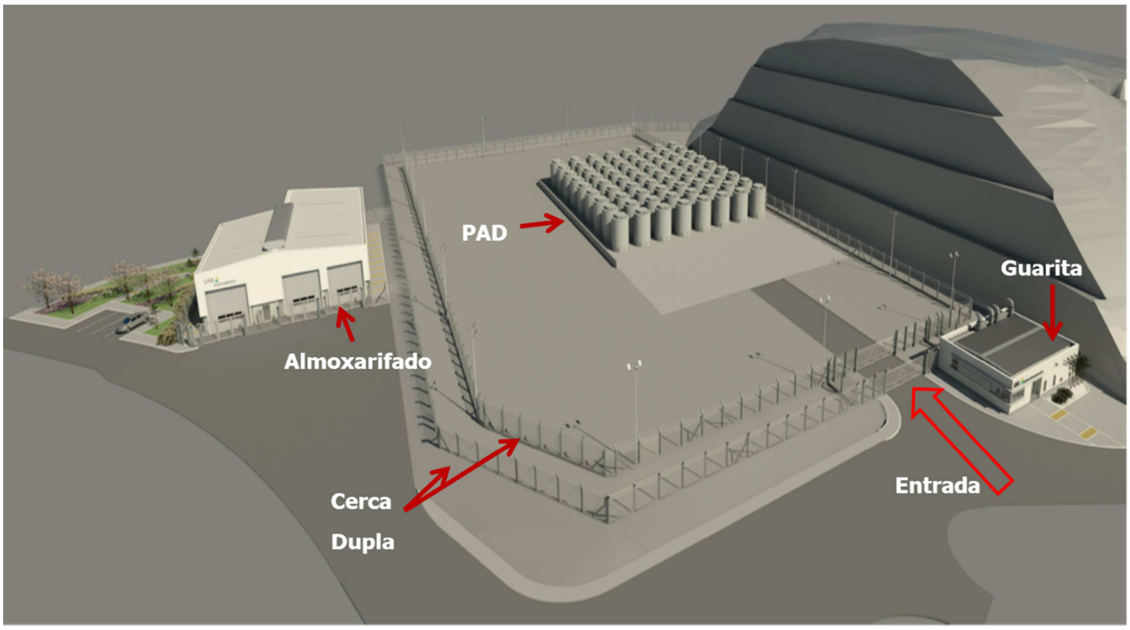

Figura 11 – Desenho Ilustrativo 3D da UAS com suas principais instalações

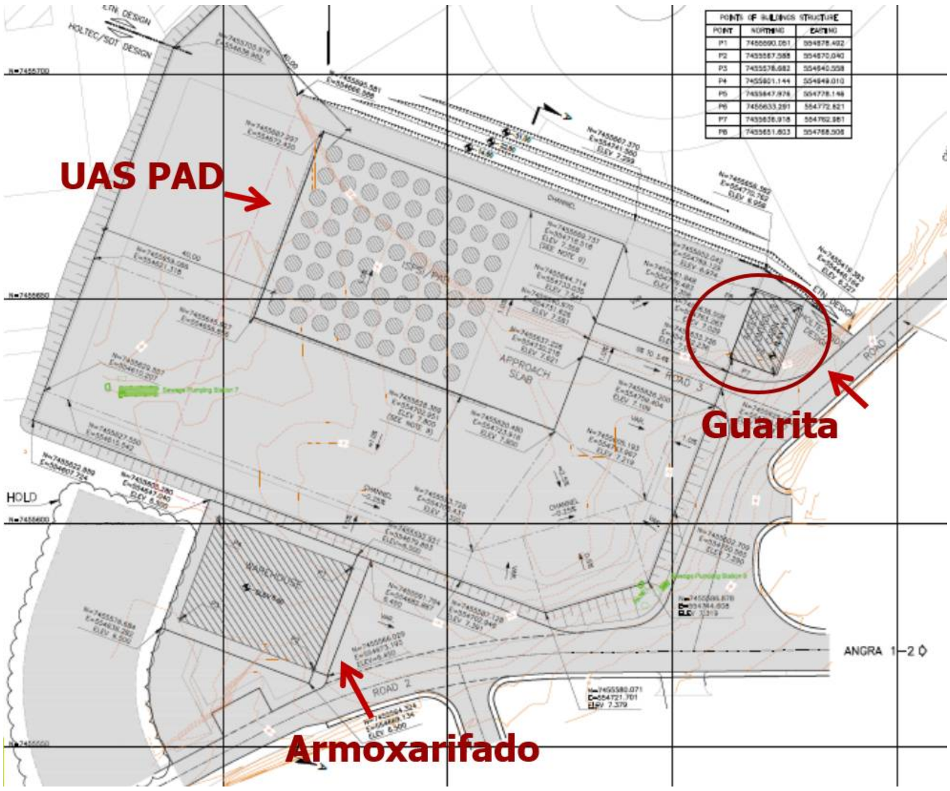

Figura 12 – Layout simplificado com as principais instalações da UAS

2

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A implementação da UAS, com armazenamento complementar à seco de inicial de 510 ECIs, 6 cascos para Angra 1 (com 37 ECIs em cada casco de armazenamento) e 9 cascos de Angra 2, (com 32 ECIs em cada casco de armazenamento), fora das PCUs de Angra 1 e Angra 2, permite a continuidade de operação da CNAAA por mais 05 ciclos (que atualmente corresponde a 5 anos), após a data estimada de esgotamento da capacidade de armazenamento das piscinas. A UAS tem capacidade para 72 cascos, equivalente a 25 ciclos de operação garantindo a operação da usina de Angra 1 por 60 anos e de Angra 2 por 40 anos. 1

2.3. Localização do empreendimento

A UAS será instalada próxima às fontes geradoras do combustível irradiado, as Usinas Angra 1 e Angra 2, que se encontram em operação, e a Usina Angra 3 em construção, dentro da área de propriedade do sítio da CNAAA, para maximizar o aproveitamento da infraestrutura necessária ao funcionamento das usinas, incluindo os recursos logísticos, técnicos e de mão de obra especializada, além de propiciar um transporte dos ECIs facilitado por estar dentro de uma mesma área. Na figura 13 a seguir do mapa da região está localizada a UAS e as principais instalações nos arredores.

Figura 13 - Mapa de localização da Unidade de Armazenamento Complementar a Seco de Combustível Irradiado (UAS) na CNAAA

2.4. Atividades Gerais previstas para o descomissionamento da UAS

Não é previsto qualquer tipo de contaminação da UAS conforme descrito no capítulo 13 do PSAR da UAS [20] devido ao Módulo de Armazenamento funcionar como uma contenção dos materiais radioativos não havendo possibilidade de contaminação do PAD.

Por isso, as atividades previstas para o descomissionamento da UAS são pertinentes à demolição/desconstrução do PAD que em resumo são:

1. Descomissionamento da UAS

1.1. Reaproveitamento e venda de equipamentos ou mobília, se possível

1.2. Contratação de empresa terceirizada para realizar a demolição e destinação dos resíduos

1.2.1. Almoxarifado

1.2.1.1. Reaproveitamento / Reciclagem de equipamentos e mobília e destinação final apropriada

1.2.1.2. Demolição do almoxarifado da UAS

1.2.1.2.1. Realização de Caracterização radiológica inicial

1.2.1.2.2. Desmantelamento e Demolição do almoxarifado

1.2.1.2.3. Realização de Caracterização radiológica final

1.2.1.2.4. Envio do Entulho para destinação final em aterro de lixo comum

1.2.1.2.5. Demolição da laje

1.2.1.2.6. Realização de Caracterização radiológica final

1.2.1.2.7. Envio de entulho para destinação final

1.2.2. Guarita

1.2.2.1. Reaproveitamento / Reciclagem de equipamentos e mobília e destinação final apropriada

1.2.2.2. Demolição da guarita

1.2.2.2.1. Realização de Caracterização radiológica inicial

1.2.2.2.2. Desmantelamento e Demolição do almoxarifado

1.2.2.2.3. Realização de Caracterização radiológica final

1.2.2.2.4. Envio do Entulho para destinação final em aterro de lixo comum

1.2.2.2.5. Demolição da laje

1.2.2.2.6. Realização de Caracterização radiológica final

1.2.2.2.7. Envio de entulho para destinação final

1.2.3. **Preparação final do terreno**

1.2.3.1. Preparação do terreno para retorno às condições originais e/ou acordadas na estratégia de descomissionamento (uso restrito ou não restrito) que estiverem válidas quando do descomissionamento. Atualmente é considerado como estado final de sítio o "uso irrestrito" conforme PPD da CNAAAA.

2.5. Descomissionamento dos equipamentos relacionados com a UAS

2.5.1. "Canister" (MPC-32ML e MPC-37) + Módulo de Armazenamento + ECIs

O destino final dos combustíveis irradiados está associado às usinas e não ao descomissionamento da UAS e estão considerados no PPD da CNAAA[1].

Os canisters com ECIs deverão ser enviados para destinação final assim que for selecionada a estratégia nacional para gerenciamento de ECIs, sendo enviados para reprocessamento ou para disposição final (quando houver um repositório de alto nível de atividade em operação no país)

São considerados custos e premissas relativos a esta destinação no DCE [5]

O destino final dos módulos de armazenamento também dependerá da estratégia escolhida pelo país para os ECIs, visto que podem ser enviados para um repositório final com ECIs ou descontaminados e devidamente descartados.

2.5.1. Carreta de Transporte modular e Transportador

Estes equipamentos também não têm previsão de contaminação, em função do Módulo de transporte e o módulo de armazenamento funcionarem como contenção para o material radioativo, conforme mencionado no capítulo 13 do PSAR da UAS [20] e também podendo ser reaproveitados e vendidos como equipamentos usados, vendidos como sucata ou descartados como lixo não contaminado após sua caracterização radiológica.

2.6. Impactos socioeconômicos associados ao Descomissionamento da UAS

Do ponto de vista radiológico não há impacto previsto para o descomissionamento da UAS, pois não é considerado contaminação nas instalações da UAS.

Em relação às atividades de demolição simples, os impactos preliminarmente identificados para essa etapa são relacionados conforme a seguir:

- ✓ Alteração na Qualidade do Ar (devido ao trânsito de veículos leves e pesados envolvidos com as obras e desmanche, movimentação de terra e serviços de terraplenagem);
- ✓ Aumento da Poluição Sonora (devido a geração de ruídos decorrente do descomissionamento do empreendimento);
- ✓ Erosão (devido ao decapeamento e movimentação de veículos);
- ✓ Contaminação de Solo e de Água Subterrânea (devido a possibilidade de derramamento de substâncias químicas);

2.7. Gestão Ambiental

O descomissionamento da UAS seguirá os procedimentos do Programa de Monitoração Ambiental conforme descrito no PPD da CNAAA [1] no capítulo 10, e resumido neste relatório na seção 1.3.6.

3. Conclusões

O descomissionamento da UAS está contemplado dentro do "pacote" de Edifícios Suporte na seção 2.3.4.2 da versão revisada do Plano Preliminar de Descomissionamento da CNAAA[1] e será detalhado junto conforme a necessidade de atualização do mesmo segundo a CNEN NN 9.02 [8].

Não é considerado qualquer tipo de contaminação na instalação da UAS, conforme capítulo 13 do PSAR da UAS [20], pois o módulo de armazenamento (HI-STORM FW) é completamente vedado e funciona como uma contenção do material radioativo contigo no mesmo.

Na estratégia considerada atualmente na CNAAA, a UAS está sendo considerada como uma das últimas estruturas a ser descomissionada, em função de ser uma atividade que depende da premissa do país ter definido uma estratégia de Gerenciamento de ECIs conforme mencionado no capítulo 2.2 pela citação da seção B1 do "Relatório Nacional de Gerenciamento de Segurança de combustível Usado e Rejeitos Radioativos" [21] ainda sendo considerados fonte de energia e também por poder servir de base de apoio para alguma atividade ou armazenamento de resíduos do descomissionamento da CNAAA, caso já tenham sido retirados os ECIs para um destino final.

Os ECIs fazem parte do legado operacional das usinas da CNAAA e não fazem parte do escopo do descomissionamento da UAS, que considera que os ECIs já terão sido transferidos para sua destinação final.

Na seção 2.4 são listadas várias atividades gerais previstas para o descomissionamento da UAS, que serão executadas tão logo os ECIs sejam enviados par ao repositório final e conforme cronograma de estratégia do descomissionamento, sendo que as atividades serão basicamente de demolição simples e desconstrução do PAD, Almoxarifado e Guarita.

Como a UAS está inserida no PPD da CNAAA, assim como todas as outras instalações estará sujeita um plano de monitoração ambiental conforme mencionado na seção 1.3.6, e todos os procedimentos que serão preparados para execução do descomissionamento durante a fase de pré-planejamento das atividades de desmantelamento e demolição.

O PPD da CNAAA também terá um plano de comunicação das partes envolvidas que estará dentro do módulo 4 de gerenciamento de projetos do documento, mencionado de forma geral nas seções 3.2.2 e 8.1.2 do mesmo e também com maior detalhamento na referência [5] no capítulo 5.4 aplicado ao período de transição, que segue os mesmos moldes de comunicação de suas atividades em relação ao público.

Por fim, ressalta-se a importância do projeto UAS de forma a manter as usinas de Angra 1 e Angra 2 em funcionamento, garantindo empregos de funcionários e contratados, a economia da região e geração de impostos, muito dependente do funcionamento da CNAAA.

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Eletrobras Eletronuclear **RELATÓRIO**	CLASSE 2	Nº ACS.T.058.18
ASSUNTO/MOTIVO CNAAA PRELIMINARY DECOMMISSIONING PLAN		PÁGINA 1 / 165
		LOCAL/DATA Rio de Janeiro, 28/12/2018
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		U.O./TEL. ACS.T / 7938 / 7772
REFERÊNCIA CNEN NN 9.01 Standard		CÓDIGO ARQUIVO **ACS.T.058.18**

SUMÁRIO	Nº DE PÁGINAS	ANEXOS	(NOS RELATÓRIOS DE REUNIÃO INDICAR, INICIALMENTE, NO SUMÁRIO: LOCAL, DATA, COORDENADOR, PARTICIPANTES E DURAÇÃO)	Para ser providenciado Para conhecimento prazos
	165	2		

The Brazilian Nuclear Energy Commission (CNEN) through CNEN NN 9.01 [1] requires that a Preliminary Decommissioning Plan (PDP) be developed to lay the groundwork for the decommissioning activities for the Brazilian Nuclear Power Plants (NPP).

The PDP for the Central Nuclear Almirante Álvaro Alberto (CNAAA) is based on recommendations from the "Standard format and content for safety related decommissioning document nº45" [2] from International Atomic Energy Agency (IAEA). The PDP covers information on CNAAA description, decommissioning strategy, project management, decommissioning activities, surveillance and maintenance, waste management, cost estimate and funding mechanisms, safety and environmental assessment, health and safety, quality assurance, emergency planning, physical security and final radiological survey.

This document should be updated whenever there are major changes or every 5 years according to CNEN NN9.01 [1]. It will be detailed as the start of decommissioning activities approaches.

This document replaces the previous PDP, SN.T.001.14, sent to CNEN through letter SM.G-520/14 on November 2014.

ASSINATURAS	REV.	DATA	PÁG.	VERIFICADO/ APROVADO
AUTOR / VERIFICADO/APROVADO				
DISTRIBUIÇÃO (QUANDO FOR ENCAMINHADO SOMENTE O SUMÁRIO PARA CONHECIMENTO COLOCAR "PC") P; DT; DO; DA; SF.A, DPR.O, ALI.T				

Cód O&M 042/04-IN 13.01

This work was carried out jointly between Eletrobras Eletronuclear, a Brazilian Research and Development Institution represented by Universidade Federal do ABC and an international consulting company with experience in the subject represented by ENERCON.

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AAC – Auxiliary building - Controlled Access Ventilation

ABNT – Standards Brazilian Technical Association (Associação Brasileira Normas Técnicas)

AIEA – See IAEA

ANEEL – National Electrical Energy Agency (Agência Nacional de Energia Elétrica)

ALARA – As Low As Reasonable Achievable

AOI – Initial Operation Authorization (Autorização para Operação Inicial)

AOP – Permanent Operation Authorization (Autorização para Operação Permanente)

ASC – Control room, Fuel handling, Water intake service, Chlorination venting (Sala de controle, manuseio de combustível, serviço de entrada de água, ventilação de cloração)

AUMAN – Nuclear Material Use Authorization (Autorização para Utilização de Material Nuclear)

B – Energy transmission and Unit Auxiliary power supply (Transmissão de Energia e Fonte de Alimentação Auxiliar da Unidade)

CAON – Nuclear operations analysis committee (Comitê de Análise de Operações Nucleares)

CCCEN – Coordination and Nuclear emergency control center (Centro de Coordenação e Controle de Emergência Nuclear)

CGR – Waste Management Center (Centro de Gerenciamento de Rejeitos)

CNAAA – Central Nuclear Almirante Álvaro Alberto

CNEN – National Commission of Nuclear Energy (Comissão Nacional de Energia Nuclear)

CQV – Chemical products and volume control system (Sistema de Controle de Produtos Químicos e Volume)

DA – Administration and Financial board (Diretoria de Administração e Finanças)

D&D – Decontamination and Dismantling (Descontaminação e Desmantelamento)

DD – Decommissioning board (Diretoria de Descomissionamento)

DEP – Drainage equipment’s primary plant (Planta Primária de equipamentos de Drenagem)

DES – Drainage equipment’s secondary plant (Planta Secundária de equipamentos de Drenagem)

DIGV – Steam Generator Storage Building (Depósito Inicial dos Geradores de Vapor)

DO – Operations and commerce board (Diretoria de Operação e Comercialização)

DT – Technical board (Diretoria Técnica)

EAN – Angra 1 North Auxiliary Building (Edifício Auxiliar Norte de Angra 1)

EAP – Project of analytical structure (Estrutura Analítica de Projeto)

EAS – Angra 1 South Auxiliary Building (Edifício Auxiliar Sul de Angra 1)

ECB – Angra 1 Fuel building (Edifício do Combustível de Angra 1)

ECD – Decommissioning cost estimative (Estimativa de Custo de Descomissionamento)

ED – Electrical distribution (Distribuição Elétrica)

EGD – Decommissioning general contractors (Empreiteiras Gerais de Descomissionamento)

EIA – Environment impact report (Estudo de Impacto Ambiental)

EPI – Personal Protective Equipment (Equipamento de Proteção Individual)

ERE – Angra 1 Reactor Building (Edifício do Reator de Angra 1)

ESE – Angra 1 Safety Building (Edifício de Segurança de Angra 1)

ETG – Angra 1 Turbine Building (Edifício da Turbina de Angra 1)

ETN – Eletrobrás Termonuclear (Eletronuclear)

FA – Storage of fuel assemblies and other radioactive parts (Armazenagem de elementos combustíveis e outros itens radioativos)

FB – Handling of fuel assembly and other reactor core internals (Manipulação de elementos combustíveis e outros componentes internos do núcleo)

FGTS – Guarantee fund for service time (Fundo de Garantia por Tempo de Serviço)

G – Water supply and discharge (Suprimento e Descarga d`água)

GC – Demineralizing system (Sistema de Desmineralização)

GEU – Unit emergency group (Grupo de Emergência da Unidade)

GLP – Petroleum liquified gas (Gás Liquefeito de Petróleo)

HEPA – High Efficiency Particulate Arrestance

HVAC – Heating Ventilation and Air-Conditioning

IAEA – International Atomic Energy Agency

IBAMA – Environment and Natural resources Brazilian Institute (Instituto Brasileiro de Meio Ambiente e Recursos Naturais)

IBGE – Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística)

IM – Inspection and maintenance (Inspeção e Manutenção)

ILW – Intermediate Level Waste

ILW-HA – Intermediate Level Waste-High Activity

IPC – Costumer price index (Índice de Preços ao Consumidor)

ISDC – International Structure for Decommissioning Costing

IOE – Occupationally exposed individual (Indivíduo Ocupacionalmente Exposto)

HLW – High Level Waste

JD – Control and Shutdown elements (Dispositivos de controle e desligamento do reator)

JE – Reactor cooling system (Sistema de refrigeração do reator)

JM – Containment and Internals (Envoltório de contenção e estruturas internas)

JN – Residual heat removal system (Sistema de Remoção de Calor Residual)

KA – Component cooling system (Sistemas de refrigeração intermediária nuclear)

KB – Coolant treatment (Tratamento do refrigerante)

KJ – Cooling system (Sistemas de resfriamento)

KP – Radioactive waste processing (Processamento de Rejeitos Radioativos)

KPE – Solid radioactive waste storage system (Armazenagem de rejeitos radioativos sólidos)

KT – Nuclear collecting and drain systems (Sistemas nucleares de coleta e drenagem)

KU – Nuclear sampling system (Sistemas de amostragem de material nuclear)

LCMR – Radiation Monitoring and Calibration Laboratory (Laboratório de Calibração e Monitoração de Radiação)

LBG – Auxiliary steam system (Sistema de Vapor Auxiliar)

LCN – Auxiliary Steam Condensate Collect (Sistema de Coleta e Recirculação do Condensado do Vapor Principal)

LMA – Environmental Monitoring Laboratory (Laboratório de Monitoração Ambiental)

LLW – Low Level Waste

LLW-HA – Low Level Waste-High Activity

MCRMA – Manual of environment radiological control (Manual de Controle Radiológico do Meio Ambiente)

MDA – Minimum Detectable Activity

NEA – Nuclear Energy Agency

OECD – Organization for Economic Cooperation and Development

PE – Service Cooling Water System (Sistema de Refrigeração de Serviço de Segurança)

PCB – Biphenyl polychlorinated (Bifenilpoliclorado)

PCU – Spent Fuel Pool (Piscina de Combustível Usado)

PDP – Preliminary Decommissioning Plan

PEL – Local emergency plan (Plano de Emergência Local)

PFD – Final Decommissioning Plan (Plano Final de Descomissionamento)

PGV – Steam Generator blowdown (Gerador de Vapor Blowdown)

PMBOOK – Project Management Book

PMR – Waste Monitoring Building (Prédio de Monitoração de Radiação)

PGQ – Quality Assurance Program (Programa da Garantia da Qualidade)

PRORET – Tax regulatory procedure (Procedimento de Regulamentação Tarifária)

PUS – Biocide Treatment for Cooling Water (Sistema de Tratamento com Biocida da Água de Refrigeração)

PWR – Pressurized Water Reactor

QK – Chilled Water System (Sistema de Água Gelada)

RCR – Residual Heat Removal (Remoção de Calor Residual)

RH – Human Resources (Recursos Humanos)

RPV – Reactor Pressure Vessel

SAP – Primary sampling (Amostragem Primária)

SEC – Containment spray (Spray de Contenção)

SESMT – Labor medicine and security engineering specialized services (Serviços Especializados em Engenharia de Segurança e Medicina do Trabalho)

SEV – Steam extraction (Vapor de Extração)

SR – Workshop, stores in controlled area (Workshop, Lojas, em Área Controlada)

SRB – Boron recycling (Reciclagem de Boro)

SRC – Cooling component (Componente de Resfriamento)

SRR – Reactor cooling system (Sistema de Resfriamento do Reator)

SVP – Steam main system (Sistema de Vapor Principal)

TRG – Gaseous wastes treatment (Tratamento de Resíduos Gasosos)

TRL – Liquid wastes treatment (Tratamento de Resíduos Líquidos)

UAS – Complementary Dry Storage Unit (Unidade de Armazenamento a Seco)

UJA/UJB/UJF – Angra 2 and Angra 3 Reactor Buildings (Edifícios dos Reatores de Angra 2 e de Angra 3)

UJE – Angra 2 and Angra 3 Main Steam and Feedwater Valve Compartment (Compartimento de Válvulas do Vapor Principal e Água de Alimentação de Angra 2 e de Angra 3)

UKA – Angra 2 and Angra 3 Reactor Auxiliary Buildings (Edifícios Auxiliar do Reator de Angra 2 e de Angra 3)

UKH – Angra 2 and Angra 3 Vent Stack (Chaminé de Descarga de Gases de Angra 2 e de Angra 3)

UMA – Angra 2 and Angra 3 Turbine Buildings (Edifícios das Turbinas de Angra 2 e de Angra 3)

1 INTRODUCTION

The goal of the decommissioning of the ''Central Nuclear Almirante Álvaro Alberto'' (CNAAA) - as presented in this Preliminary Decommissioning Plan (PDP) – aims at safely reaching the final state regarding the site, while protecting the workers involved, public and the environment. The Preliminary Plan for the decommissioning of the CNAAA presents information to the regulatory authority to show that all portions of the planning process have been considered and will be addressed or revised as the plan is reviewed and updated in the future. The final aim is to decommission the CNAAA at the end of its lifetime in a way that is environmentally sustainable. The radioactive waste and spent fuel will be disposed properly without impacting future generations and the CNAAA site will be recovered for future uses by society.

1.1 Responsibilities and ownership

The current owner of the ''Central Nuclear Almirante Álvaro Alberto" (CNAAA) encompassing the Angra 1 and Angra 2 plants, which are under operation, the future Angra 3, under construction, and support facilities is:

Eletrobras termonuclear S.A. - ELETRONUCLEAR

Address:

Rua da Candelária, 65

Centro

Rio de Janeiro - RJ

ZIP 20091-906

The operating and radiological licenses for the nuclear power plants and the waste management center of the CNAAA are listed in Table 1.1.

Table 1.1 – Operating and radiological licenses issued to the CNAAA nuclear power reactors and waste management facilities.

Angra 1 NPP	• Construction Licence - Licença de Construção – Ofício CNEN nº 82/74, 02.05.74. • Nuclear Material Use Authorization AUMAN – Autorização para Utilização de Material Nuclear – Portaria nº 185, de 31.07.1997. • Initial Operation Authorization - AOI - Autorização para Operação Inicial – Portaria nº 18/87, de 23.12.1987. • Renewal of Permanent Operation Authorization - AOP – Renovação da Autorização para Operação Permanente – Ofício nº 124/10-CGRC/CNEN, de 09.08.2010.
Angra 2 NPP	• Construction Licence - Licença de Construção – Resolução nº 16/81, de 31.11.1981. • Nuclear Material Use Authorization - AUMAN – Autorização para Utilização de Material Nuclear – Resolução nº 18/99, de 16.09.1999. • Initial Operation Authorization - AOI - Autorização para Operação Inicial – Resolução nº 007/00, de 24.03.2000. • Permanent Operation Authorization - AOP – Autorização para Operação Permanente – Resolução nº 106/11, de 15.06.2011.
Angra 3 NPP	• Construction Licence - Licença de Construção – Portaria nº 077/10, de 25.05.2010.
Waste Management Center (CGR)	• Waste Storage Unit 1 and 2A Operation Authorization - Depósitos 1 e 2A - Autorização para Operação Ofício nº 164/01 – CODRE/CNEN de 08/11/2001 e Ofício CNEN nº 124/10, de 09/08/2010. • Waste Storage Unit 2B Permanent Operation Authorization Depósito 2B - Autorização de Operação Permanente - Ofício n° 018/2009-CGRC/CNEN, de 15/01/2009. • Waste Storage Unit 3 Permanent Operation Authorization Depósito 3 - Autorização de Operação Permanente - Ofício n° 018/2009 – CGRC/CNEN, de 15/01/2009. • Waste Monitoring Building Construction Licence - Prédio de Monitoração – Autorização para Construção – Ofício nº 121/14-CGRC/CNEN, de 04.08.2014. • Steam Generator Storage Building Permanent Operation Licence - Deposito Inicial dos Geradores de Vapor (DIGV) Autorização de Operação Permanente - Ofício n° 006/2009-CGRC/CNEN, de 05/01/2009.

ELETRONUCLEAR is also the main organization responsible for the decommissioning process for nuclear plants, waste management center and the support facilities.

The previous owner of the CNAAA was Furnas Centrais Elétricas S.A. and operated CNAAA until 1997. ELETRONUCLEAR was created in 1997 after the merging of Nuclen (Nuclebrás Engenharia SA) and the nuclear division (Diretoria Nuclear) of Furnas Centrais Elétricas, and since then it operates the CNAAA.

ELETRONUCLEAR is a state-run brazilian company, subsidiary of the Eletrobras group (Centrais Elétricas Brasileiras SA – Eletrobras), a holding company that has its shares negotiated in the national (Bovespa) and international stock exchanges. The Eletrobras group was created in 1962 and currently the Brazilian Federal Government owns the majority (52%) of its shares and controls the company.

Today, both Furnas and ELETRONUCLEAR are subsidiaries of the Eletrobras group. The address of the Central Nuclear Almirante Álvaro Alberto is:

Rodovia Procurador Haroldo Fernandes Duarte - BR101/RJ, S/N

km 521,56 - Itaorna

Angra dos Reis - RJ

ZIP 23948-000

1.2 Preliminary Decommissioning Plan Context

This Preliminary Decommissioning Plan (PDP) for Almirante Álvaro Alberto Nuclear Station (CNAAA) is based on the CNEN NN 9.01 Standard issued through resolution no. 133 [1] and on recommendations from IAEA SRS nº45 standards [2]. This PDP replaces the PDP presented to CNEN in 2014 [3] and aims at providing a consolidated set of information describing the process that will be used by ELETRONUCLEAR for planning and performing the decommissioning. The plan provides information such as strategy, cost and radioactive inventory associated with decommissioning and the end state planned for the site after decommissioning. This document, although preliminary, demonstrates the complexity of the activities involved in CNAAA decommissioning. More detailed information will be presented in later revisions of the PDP which should be performed periodically [1].

The plan describes how ELETRONUCLEAR will be organized to perform the decommissioning, the methodology that will be adopted to plan and perform the decommissioning, and the main steps and activities expected to be performed. The plan also covers the possibility of an unexpected early permanent shutdown of the facilities before the planned shutdown dates.

2 CNAAA SITE DESCRIPTION

The purpose of this Chapter is to provide sufficient detail to allow an understanding of the extent of the decommissioning project, the types of facilities, systems and material involved.

2.1 Facility description

The CNAAA is a multi-plant site that has two pressurized water reactors(PWR) in operation, a third PWR plant under construction and support facilities that are part of this decommissioning project. In this section, we describe the facilities that will be decommissioned, that are, those facilities containing or potentially containing radioactive material or dealing with contaminated materials. All areas containing or potentially containing radioactive material are considered within the decommissioning project scope.

Decommissioning activities involve dismantling of systems and equipment, demolition of structures and transportation of radioactive waste. Thus, the start of decommissioning activities in one of the CNAAA plants may interfere in the commercial operation activities of the other plants. This matter is one of the main concerns of this decommissioning project.

2.2 Site location and description

The Central Nuclear Almirante Álvaro Alberto (CNAAA) is located in the Cunhambebe district in the Angra dos Reis municipality, State of Rio de Janeiro. The distances of the CNAAA from the cities of Rio de Janeiro, RJ; Belo Horizonte, MG; and São Paulo, SP; are 133 km, 343 km and 216 km, respectively [4-6].

In the CNAAA site, there are two basic topographic provinces: the Coastal Plain (Planície Costeira) and the Serra do Mar. The climate is tropical with frequent rains, plenty of sunlight, high humidity, moderate wind speed and occasional summer storms. The temperatures are high during summer and mild in winter. The rivers in Angra dos Reis have short gradients flowing like waterfalls and draining directly into the sea. The rivers of greater water flow, with 10 km in length, are the Rio Mambucaba and Rio Bracuí [4-6].

Road infrastructure in the region is characterized by the Rio–Santos highway, BR-101. There are two major road junctions. One of the junctions is located approximately 35 km south-west (SW) from CNAAA, in the city of Paraty and enables the connection with the city of Cunha, State of Sao Paulo, through the RJ-165. The other junction is in the city of Angra dos Reis approximately 16 km - in the east/southeast (ESE) direction - from Angra 2 enabling the connection with the Rio Claro municipality.

There is only one railway line in the vicinity of CNAAA connecting the cities of Barra Mansa and Volta Redonda to Angra dos Reis. This railway line runs parallel to the RJ-155 and is associated with the Angra dos Reis Port (from which the steel production from Volta Redonda is shipped), at 17 km from the CNAAA site in the Easterly (E) direction. This railway system may be considered as one possible alternative for transportation of material and wastes during the decommissioning project, but access to it must be done by means of trucks on highways. There are no railways to the CNAAA. However, material could be transported by barge from the CNAAA site to the port, loaded on railcars and shipped to the final disposal site.

2.2.1 Exclusion area

ELETRONUCLEAR has legal control over any activity within the CNAAA exclusion area. The exclusion area for the CNAAA, shown in Figure 2.1, defines the boundary for the release of effluents of the facilities which shall not exceed the dose limits established by CNEN NN-3.01 Standard [7]. Besides ELETRONUCLEAR's employees, only employees of its contractors and subcontractors can work inside the exclusion area. The access for visitors is controlled and restricted.

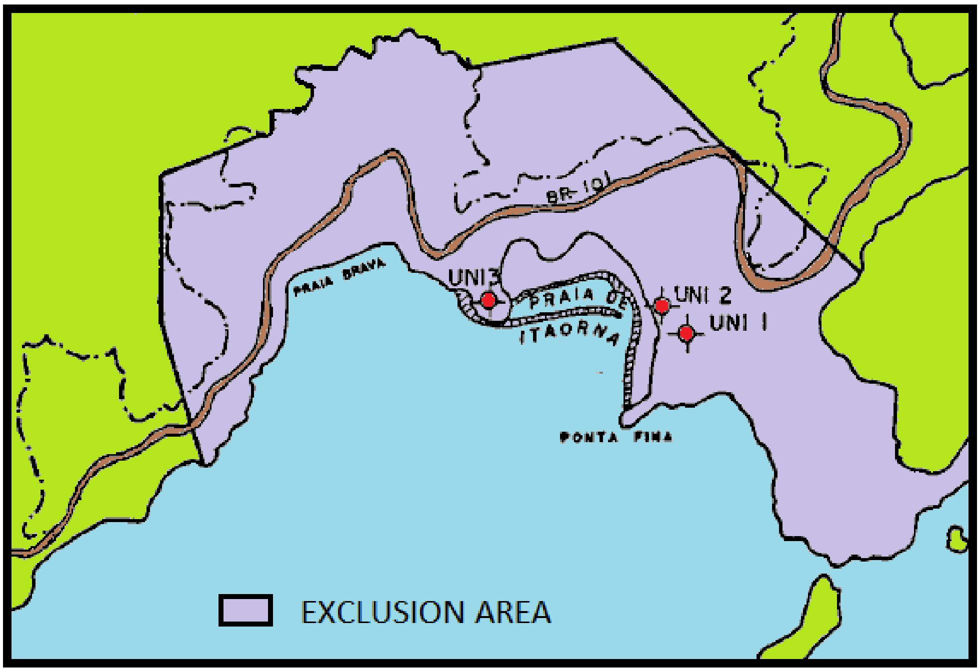


Figure 2.1 – Exclusion area for the CNAAA. Adapted from Ref. [4].

2.2.2 Population spatial distribution

The population concentration areas closest to CNAAA are Parque Mambucaba and Frade in the districts of Mambucaba and Cunhambebe respectively, both in Angra dos Reis. In the city of Paraty, the closest population is from Tarituba district. Figure 2.2 illustrates the location of these districts and Table 2.1 provides the amount, distance and direction of the population in the districts near the CNAAA site.

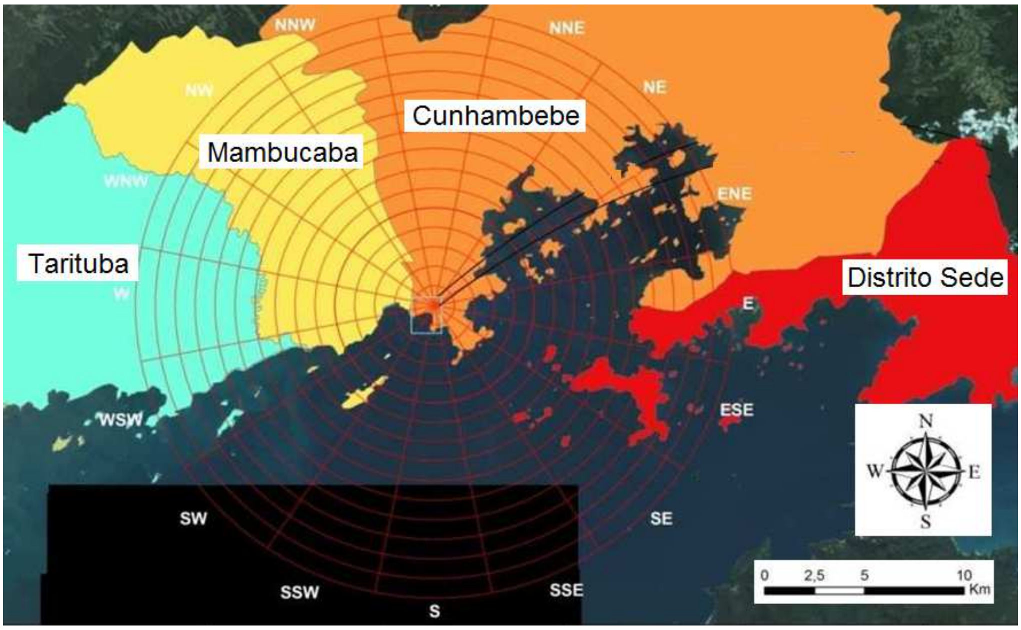


Figure 2.2 - Localization of Cunhambebe and Mambucaba districts and Angra dos Reis Headquarters District and Tarituba.

Table 2.1 - Populations near the CNAAA site, 2010 [8].

District	Population	Distance (km)	Direction
Cunhambebe	74.809	5-10	NE
Mambucaba	22.205	6-8	W
Tarituba	3.683	6-14	WS W
Total	**100.697**	-	-

Source: http://www.sidra.ibge.gov.br. Acess 11/21/2013

Residential population distribution projections for the period from 2010 to 2050 in the areas of CNAAA influence are based on Census data, 2010, prepared by the Brazilian Institute of Geography and Statistics (IBGE) [8, 9]. The results, by census sector (territorial unit of collection) are consolidated in Table 2.2.

The distribution of current population and projected by circular sector, was defined from the projections made for the census sector.

Table 2.2 - Projection and radial distribution of the resident population in the area of CNAAA direct influence [8, 9].

Distance (km)	2010	2020	2030	2040	2050
	Population	Population projection	Population projection	Population projection	Population projection
0 - 1	0	0	0	0	0
1 - 2	837	839	844	782	707
2 – 3	867	931	1053	1105	1071
3 – 4	226	288	372	533	593
4 – 5	1672	2014	2482	3514	3885
5 – 6	8622	11112	13931	19833	22915
6 – 7	11903	15453	19987	26316	39066
7 – 8	8661	11251	14595	19081	28949
8 – 9	1135	1398	1750	2488	2828
9 – 10	5268	6788	8482	12165	13527
10 – 11	2900	3727	4646	6657	7401
11 – 12	3072	3935	4900	6998	7754
12 – 13	2011	2585	3222	4203	5124
13 - 14	3949	5129	6640	8724	13022
14 - 15	10113	13137	17026	22322	33578
Total	61236	78587	99936	134721	180420

Source: Population Radial Projection in the Area of Direct Influence of Angra 2 Nuclear Power Plant - conducted by the UERJ Engineering School Research Centre - CEFEN 2012

2.3 Buildings and system description

The CNAAA has an area of 12,494,200 m² with three Pressurized Water Reactors (PWR), two of which are in operation and the third under construction [5]. The PDP includes these nuclear power plants and the support facilities. Figures 2.3 to 2.6 show (in yellow) parts of the site which will be object of decommissioning. The areas outside the yellow region are currently considered conventional facilities and are not part of this decommissioning plan.

The facilities included in the PDP are:

a. Angra 1 including Reactor Building (ERE), North Auxiliary Building (EAN), South Auxiliary Building (EAS), Fuel Building (ECB), Safety Building (ESE) and Turbine Building (ETG);

b. Angra 2 including Reactor Building (UJA, UJB & UJF), Auxiliary Building (UKA), Gas Discharge Chimney (UKH), Main Steam Valves Room (UJE) and Turbine Building (UMA);

c. Angra 3 including Reactor Building (UJA, UJB & UJF), Auxiliary Building (UKA), Gas Discharge Chimney (UKH), Main Steam Valves Room (UJE) and Turbine Building (UMA);

d. Radiation Monitor Calibration Laboratory (LCMR);

e. Waste Management Center (CGR) that includes Waste Storage Unit 1, Waste Storage Unit 2 and Waste Storage Unit 3, the Waste Monitoring Building (PMR) and the Steam Generator Initial Storage (DIGV);

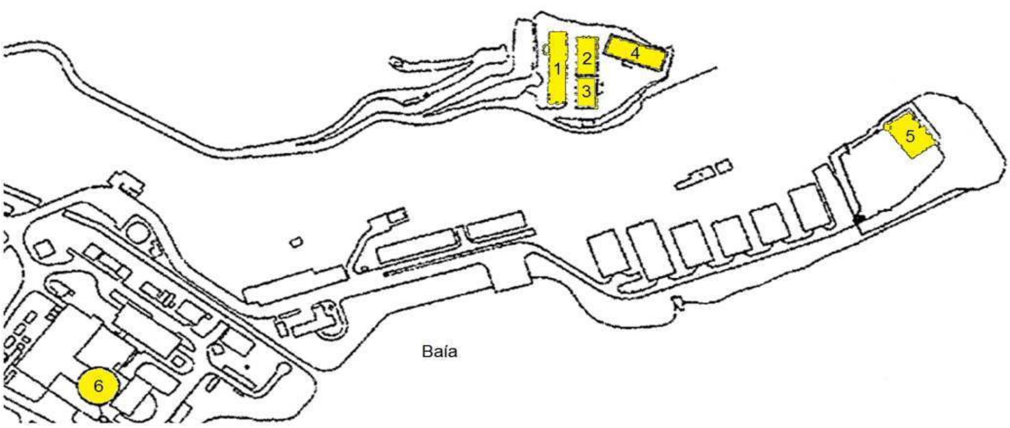
f. Environmental Monitoring Laboratory (LMA); and

g. Complementary Dry Storage Unit (UAS).

The turbine buildings are included because of their attachment to the Auxiliary Buildings and to allow access to areas containing activated or contaminated material.

1 - Angra 1 Reactor Building
2 - Angra 1 Reactor Auxiliary Building
3 - Angra 1 Fuel Building
4 - Angra 2 Reactor Building
5 - Angra 2 Reactor Auxiliary Building
6 - Angra 2 Gas Discharge Chimney
7 - Angra 2 Mainsteam Valves Room
8 - Angra 2 Turbine Building
9 - Angra 3 Reactor Building
10 - Angra 3 Reactor Auxiliary Building
11 - Angra 3 Gas Discharge Chimney
12 - Angra 3 Mainsteam Valves Room
13 - Angra 3 Turbine Building

Figure 2.3 - Central Nuclear Almirante Álvaro Alberto site, with the affected facilities indicated in yellow. Source: adapted from [5].



1 - Storage unit 1
2 - Storage unit 2 - module A
3 - Storage unit 2 - module B
4 - Storage unit 3
5 - Storage DIGV
6 - Angra 1 NPP

Figure 2.4 - Location of the Radioactive Waste Management Center. Source: adapted from [4].

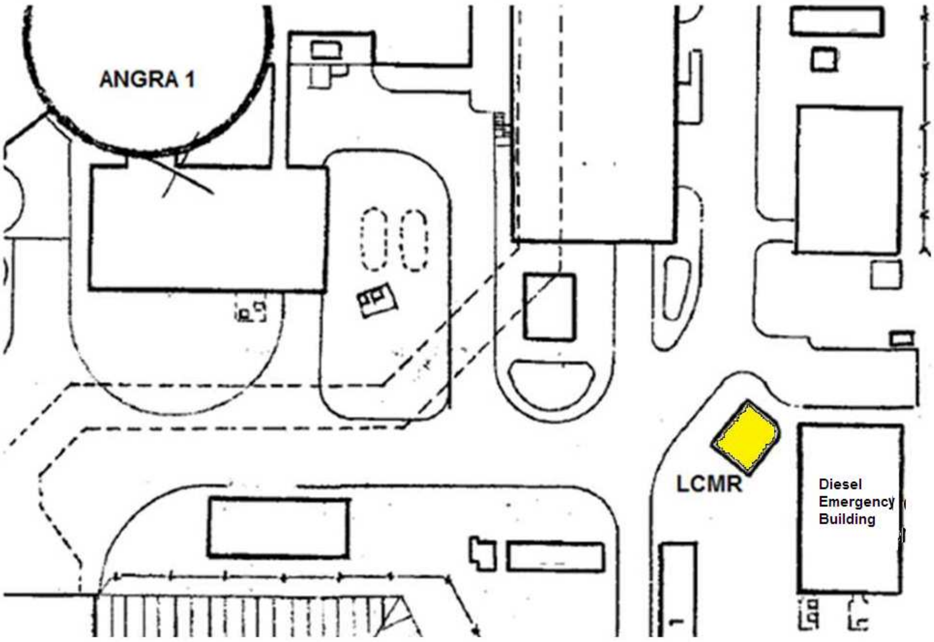


Figure 2.5 - Localization of the Radiation Monitor Calibration Laboratory (LCMR). Source: adapted from [4].

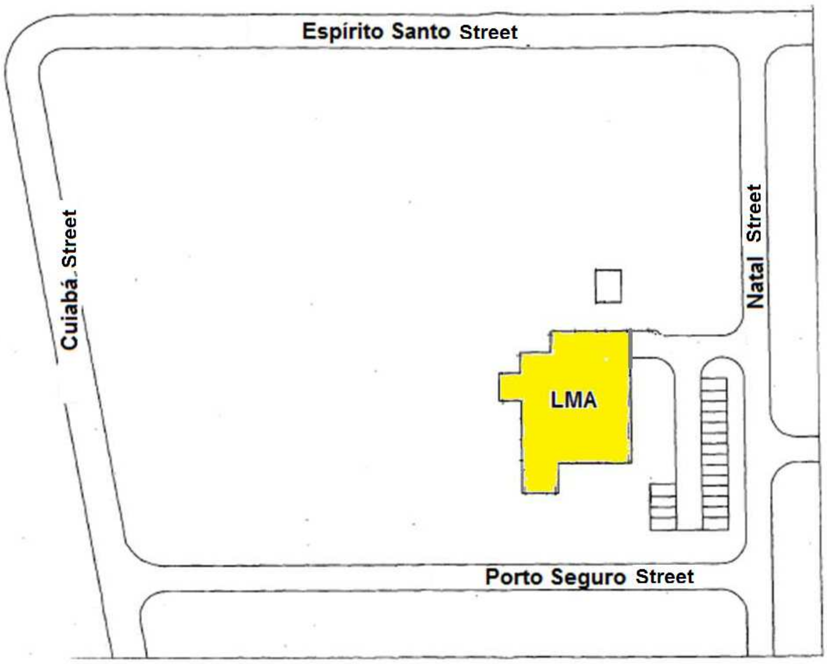


Figure 2.6 - Localization of the Environmental Monitoring Laboratory (LMA) in the Mambucaba village. Source: adapted from [4].

2.3.1 Angra 1 NPP description

Angra 1 NPP is a Westinghouse Pressurized Water Reactor (PWR) generating 657 MW of electricity. It has two core cooling loops, a reactor core with 121 fuel assemblies, and 33 control rods. Water with the addition of boric acid is the reactor's moderator. This fluid also plays the function of the reactor coolant [4]. The expected permanent shutdown date of Angra 1 NPP is December of 2044 considering 20 years of life extension.

Figure 2.7 shows the arrangement of the main buildings of the Angra 1 NPP. The main buildings to be decommissioned are: Reactor Building, North and south Auxiliary Buildings, Fuel Building, Safety Building and Turbine building.

The Reactor Building (Figure 2.8) is a cylindrical structure with an internal diameter of approximately 35.16 m and has a shallow dome on the top. The walls have approximately 0.76 m thick and the dome is 0.61 m thick. Inside this structure there is a cylindrical steel containment having a spherical dome on the top and a spherical/ellipsoidal at the bottom. The inner diameter is approximately 32 m and the height approximately 42 m. The greatest thickness of the containment is 3.82 cm. The space between the two mentioned structures is approximately 1.5 m. This building houses the reactor and other components of the primary circuit such as: pumps, steam generators, pressurizer and piping [4].

The Fuel Building is a reinforced concrete structure located adjacent the Reactor Building in order to allow the spent nuclear fuel to be removed from the reactor and through the Reactor Building. All parts of the structure are isolated. The Fuel Building houses the spent nuclear fuel storage pool and a truck loading/unloading area.

The North and South Auxiliary Buildings are independent constructed with reinforced concrete structures. They are isolated from the adjacent structures and are separated by the Safety Building. These buildings house reactor support systems, offices, electrical switch gear, emergency generators and the control room.

The Safety Building is a reinforced concrete structure and is isolated from other structures. The building is designed to withstand possible internal or external projectiles. This building houses the main steam piping, emergency systems and other safety related support systems.

The Turbine Building is roughly a rectangular building of 36 m x 80 m, height of 42 m and holds 3 floors. This building houses the turbine generator and all power conversion equipment (condenser, pumps and other steam power systems).

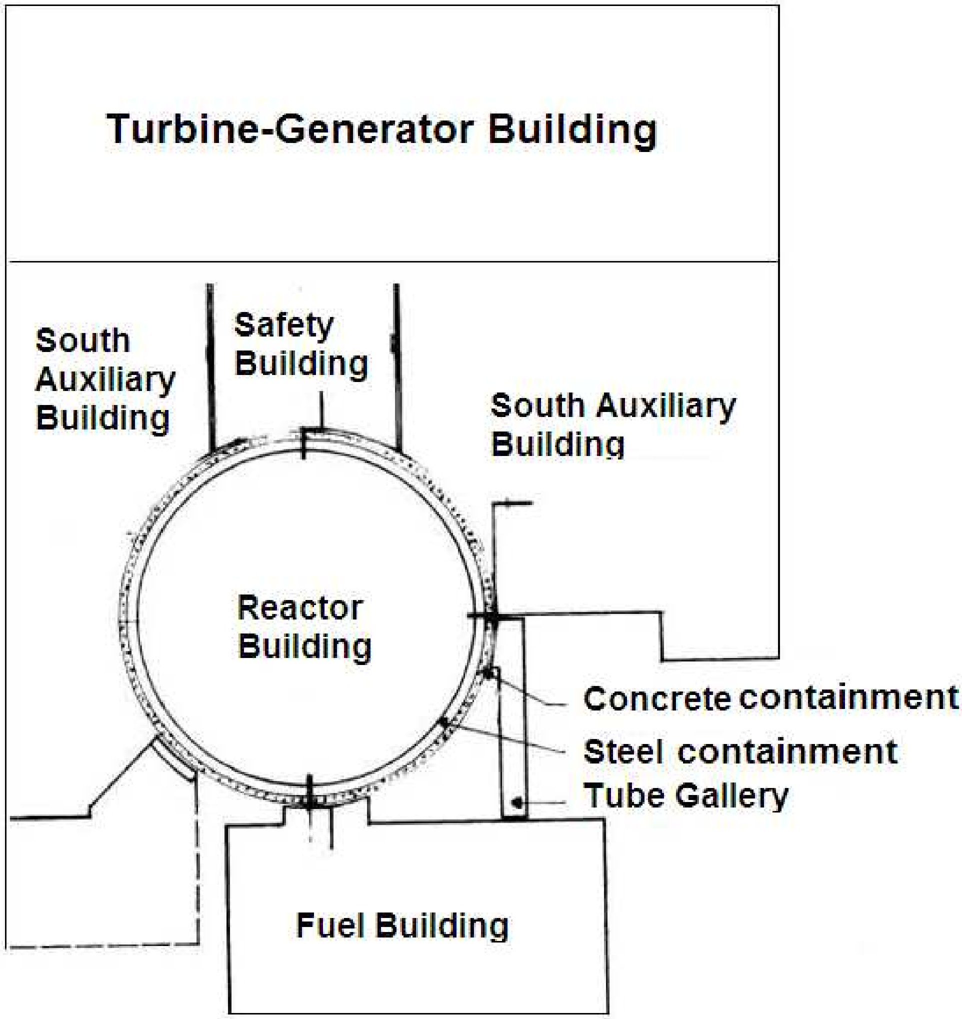


Figure 2.7 - Schematic-drawing of Angra 1. Source: adapted from [4].

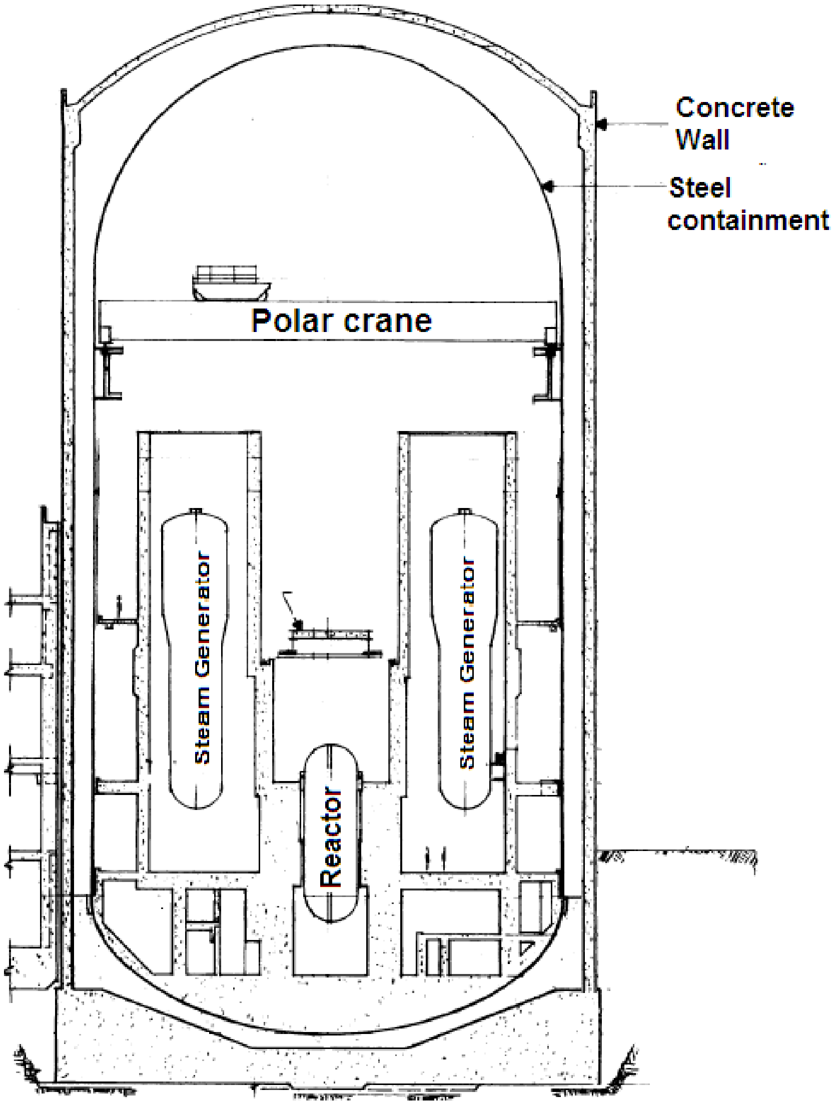


Figure 2.8 - Schematic Drawing of Angra 1 NPP Reactor Building.
Source: adapted from [4].

2.3.2 Angra 2 NPP description

The Angra 2 plant has a Siemens/KWU PWR reactor generating 1356 MW of electricity and is in close proximity to Angra 1. It has four core cooling loops, and a reactor core with 193 fuel elements, and 61 control rods. The reactor's moderator is water with the addition of boric acid. This water also fulfils the function of the reactor coolant [5]. The expected permanent shutdown for Angra 2 is September of 2061, considering a 20 year life extension.

Figure 2.9 shows the Angra 2 main buildings arrangement. The main buildings to be decommissioned are: Reactor Building, Reactor Auxiliary Building, Turbine Building, Main Steam Valves Room and Gas Discharge Chimney.

The Reactor Building (Figure 2.10) has a cylindrical reinforced concrete structure with 60,4 m in diameter, 28.15 m in height and 0.85 m underground. The structure wall is 0.6 m thick. The containment spherical structure rests inside the Reactor Building with its upper half extending above it. The 3 cm thick containment sphere is approximately 56 m in diameter. The Reactor Building partially houses the containment, reactor support systems and piping. Inside the containment are located the reactor and the primary system, and the fuel storage pool [5].

The Reactor Auxiliary Building (Figure 2.11) is located adjacent to the Reactor Building. It houses the auxiliary reactor systems, emergency systems, control room, waste processing systems and HVAC (Heating, ventilation, and air conditioning). The building provides the central access to all controlled areas such as: laboratories, waste facilities and the Reactor Building.

The Gas Discharge Chimney (Figure 2.11) is a 155 m high conical structure of reinforced concrete. It is located in opposite the longitudinal wall of the Reactor Auxiliary Building. The first two levels of the structure are used for bitumen deposit and conventional supplies for the plant. At the intermediate level there is an air sampling system allocated to carry out the monitoring of the radioactive aerosols and gases discharge of the Reactor Auxiliary Building. The last level is the chimney itself.

The Turbine Building is a reinforced concrete structure in an area of approximate 48 x 86 m and 40 m in height. It holds the turbine, condenser, pumps and ancillary steam power system equipment. The building has the whole structure founded on piles, the floors are made of in situ concrete and the roof is a steel structure [5].

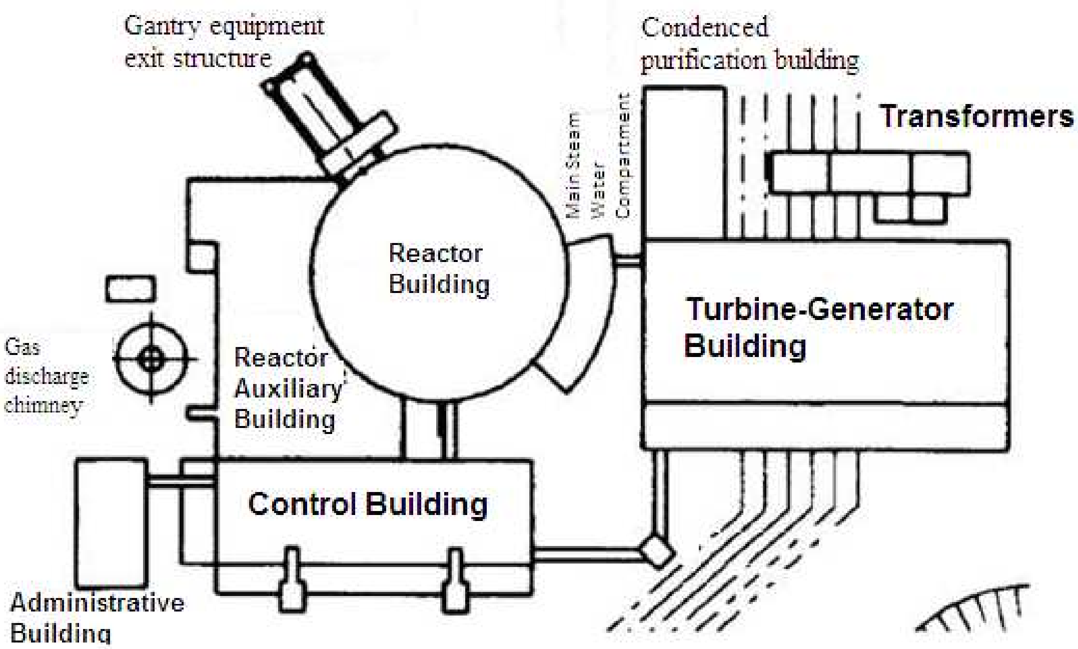


Figure 2.9 - Schematic drawing of the Angra 2 NPP. Source: adapted from [5].

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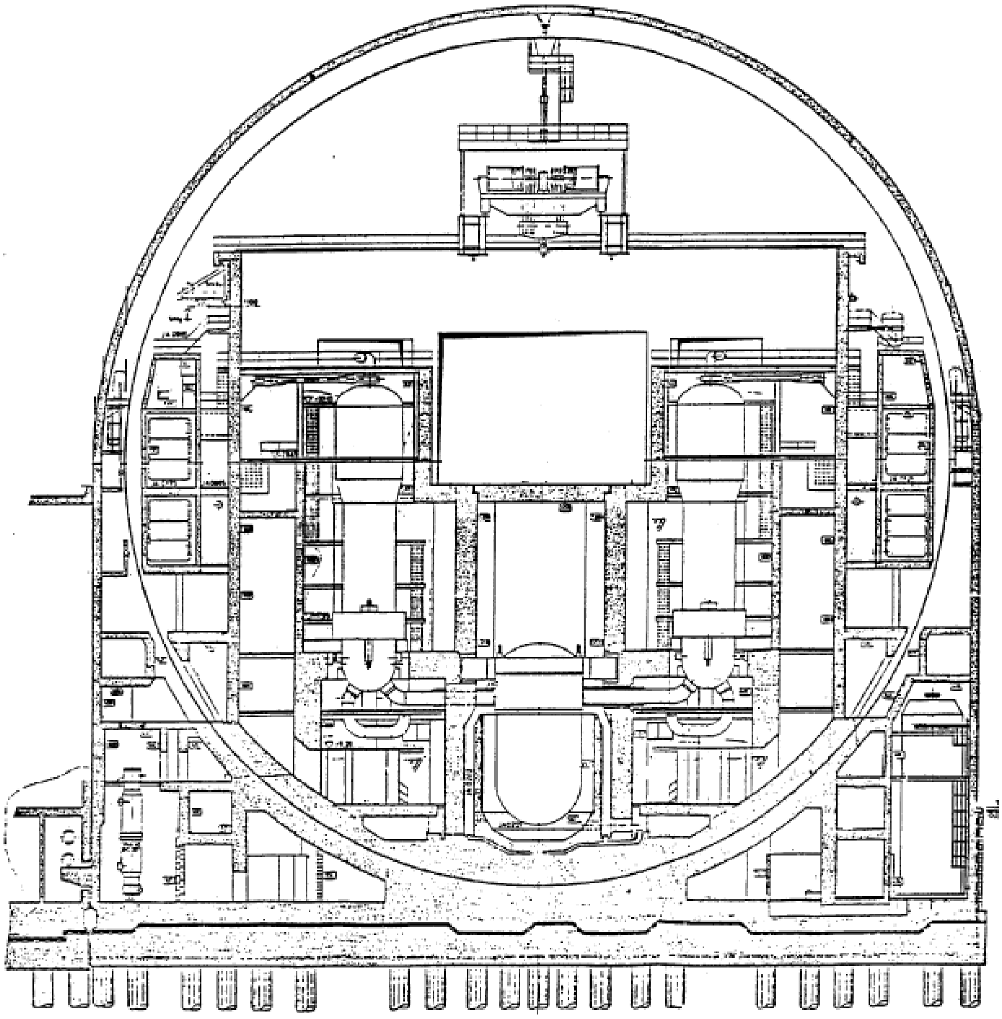

Figure 2.10 - Schematic drawing of Angra 2 NPP Reactor Building.
Source: adapted from [5].

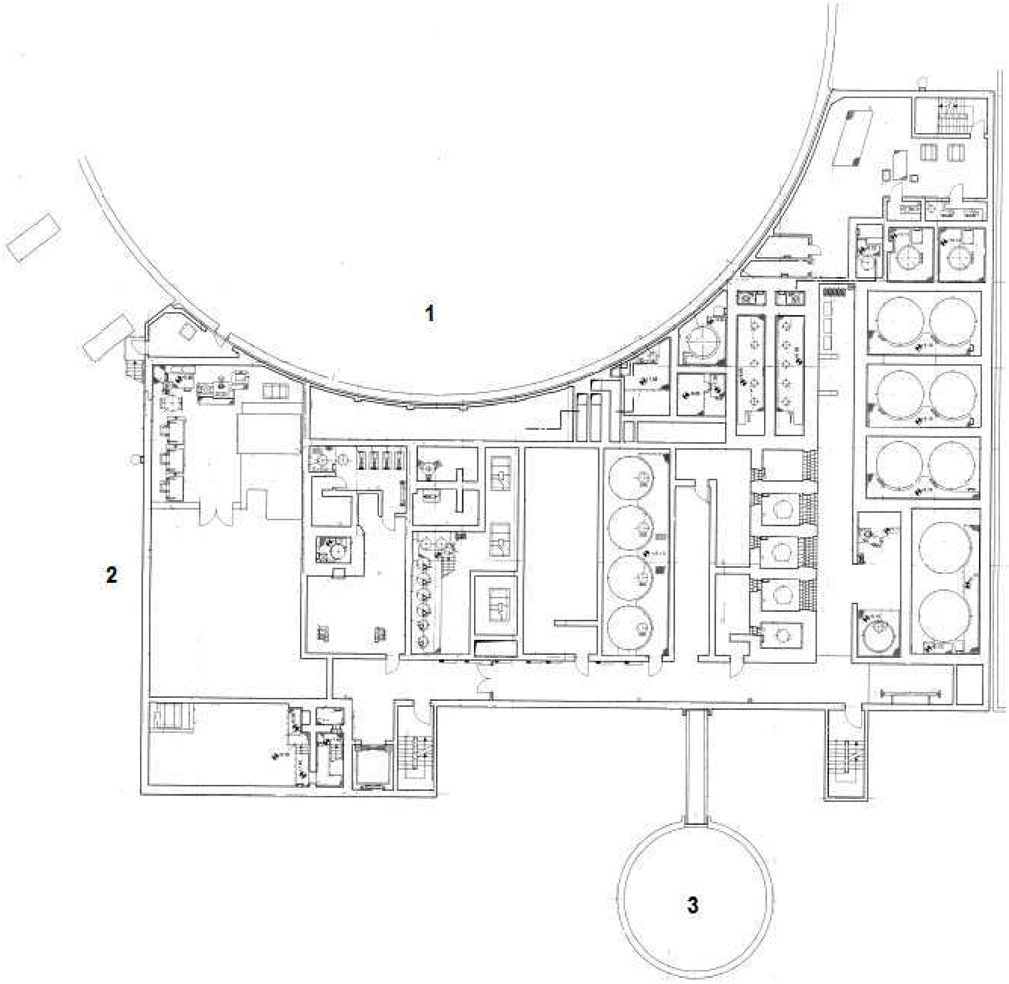

Figure 2.11 - Schematic Drawing of Angra 2. (1) Reactor Building; (2) Auxiliary Building and (3) Gas Discharge Chimney. Source: Adapted from [5].

2.3.3 Angra 3 NPP description

The Angra 3 NPP is under construction and is similar to Angra 2 but with a rated power of 1405 MW [6]. Figure 2.12 shows the arrangement of the Angra 3 main buildings. The main buildings to be decommissioned are the Reactor Building, Reactor Auxiliary Building, Turbine Building, Main Steam Valves Room and Gas Discharge Chimney.

The construction of Angra 3 is expected to be completed in 2022 and the expected lifetime for the plant is 60 years, considering a 20 year life extension. Angra Unit 3 is included in the decommissioning project and it has the same specifications and construction as unit 2, except for the rated power.

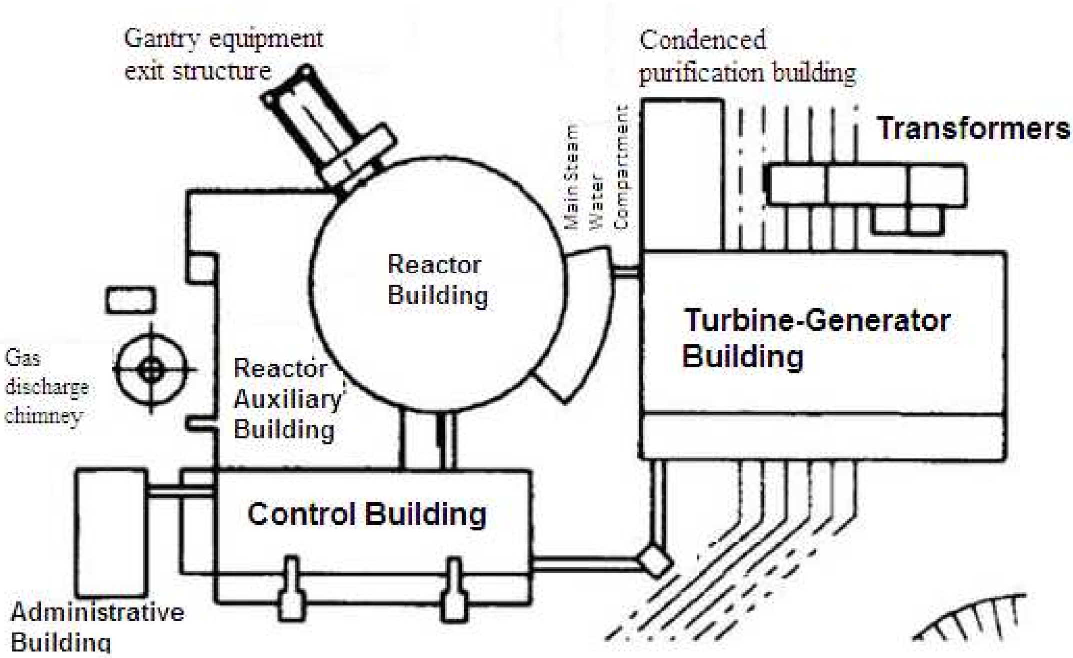

Figure 2.12- Schematic drawing of Angra 3. Source: adapted from [6]

2.3.4 Support buildings

Besides the nuclear power plants, the PDP takes into account the support buildings being the Waste Management Center (CGR), the Complementary Dry Storage Unit (UAS) that is under project implementation and the two laboratories dealing with radioactive materials: the Radiation Monitoring and Calibration Laboratory (LCMR) and the Environmental Monitoring Laboratory (LMA).

2.3.4.1 Waste Management Center (CGR)

The Waste Management Center (CGR) includes the Waste Storage Units 1, 2 and 3, the Waste Monitoring Building (PMR) and the Steam Generator Storage Building (DIGV). Figure 2.13 shows the CGR.

Unit 1 is a reinforced concrete warehouse with metal roof. It has an area of 70 m x 18 m, housing an access area for small operations, a low-level waste (LLW) storage, a medium level waste storage, and an area for storage of damaged barrels and maintenance. It also has a loading/unloading platform.

The Waste Storage Unit 2 has two modules, A and B. The module A is a storage of 37.88m x 17.50 m, consisting of 3 areas: reception area and wastes packaging, drum deposit area and operations area. The module B, constructed later, is a deposit of 32.10 m x 17.50 m and similar to the module A. The two modules are separated and constructed of reinforced concrete with metal roofs. It has a loading/unloading area.

The Waste Storage Unit 3 is a warehouse of 52.90 m x 20.55 m constructed of reinforced concrete with a metal roof. It is divided into two storage areas and a small operations area. It also has a loading/unloading platform.

ELETRONUCLEAR has built a Waste Monitoring Building to perform the radionuclides characterization of radioactive waste generated by the CNAAA operation. It is in compliance with CNEN NN 6.09 standard [10].

The CNAAA Waste Monitoring Building is located in the CGR - Waste Management Center - in the area between the Initial Deposits 1 and 2. It is built of reinforced concrete properly sized and designed to ensure the safety and integrity of radioactive waste from the plants.

The main building purpose is to perform survey and record radioactive isotopes contained in packaged of low and intermediate radioactive waste currently generated by Angra 1 and Angra 2 and in the future by Angra 3. It will also be equipped with equipment to allow the opening of waste containers in order to segregate the material in the containers which may be disposed as industrial waste, and/or re-encapsulated or processed as radioactive waste. This, along with other information, will enable the enough characterization of each waste package.

The Steam Generator Storage Building (DIGV) is a reinforced concrete structure with area of 37.30 m x 24 m x 8 m, wall thickness of 0.9 m, ceiling thickness of 0.5 m, and a flat slab 1 m thickness floor on a sand layer. It is divided into 4 main compartments. The first compartment houses the entry area and a waste container storage area. The second and third compartments house two old steam generators from Angra 1. The forth compartment houses several equipment from Angra 1 (heat exchanger, evaporator and reactor pressure vessel cover). It also contains containers of radioactive waste generated during the equipment removal activities.

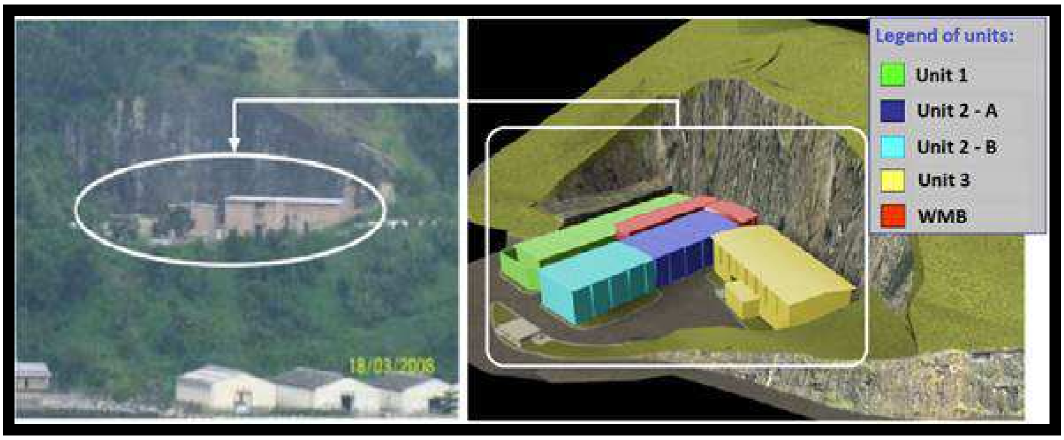

Figure 2.13- Schematic of CGR

2.3.4.2 Complementary Dry Storage Unit (UAS)

Under project implementation ELETRONUCLEAR Complementary Dry Storage Unit (UAS) to storage the spent nuclear fuel (SNF) of Angra 1 and 2 NPPs, under the provisions of 10CFR 72 [11]. This project is based on the USNRC licensed Holtec International HI-STORM FW system, USNRC docket 72-1032 [12], that includes relevant site specific analyses.

The UAS is to be located on a parcel of land presently owned by Electronuclear (ETN) within the property boundaries of the current CNAAA site. The UAS will be built to provide storage of 15 HI-STORM FW casks with the potential to be expanded for 72 HI-STORM FW casks storage.

The total area occupied by the UAS is 4560 sq meters, with a concrete storage pad, of 13.530 sq meters of the total site of CNAAA.

As shown in the layout drawing, the CNAAA UAS consists of the following

SSCs (Structures, Systems and Components) [13]:

a. Concrete storage pad

b. The HI-STORM FW casks (Figure 1.2.1)

c. HI-TRAC VW

d. Variable Elevation Cask Staging Pedestal (VECASP)

e. Transfer Carriage

f. Hydraulic Lifting Gantry (HLG)

g. Ancillary Equipment Warehouse to store the HI-TRAC VW, ancillaries and spare parts (30meters x 23meters).

h. Security Building at the entrance to UAS to house security personnel staff and access control facilities(7.3 meters × 6.2 meters).

i. Safety Fence

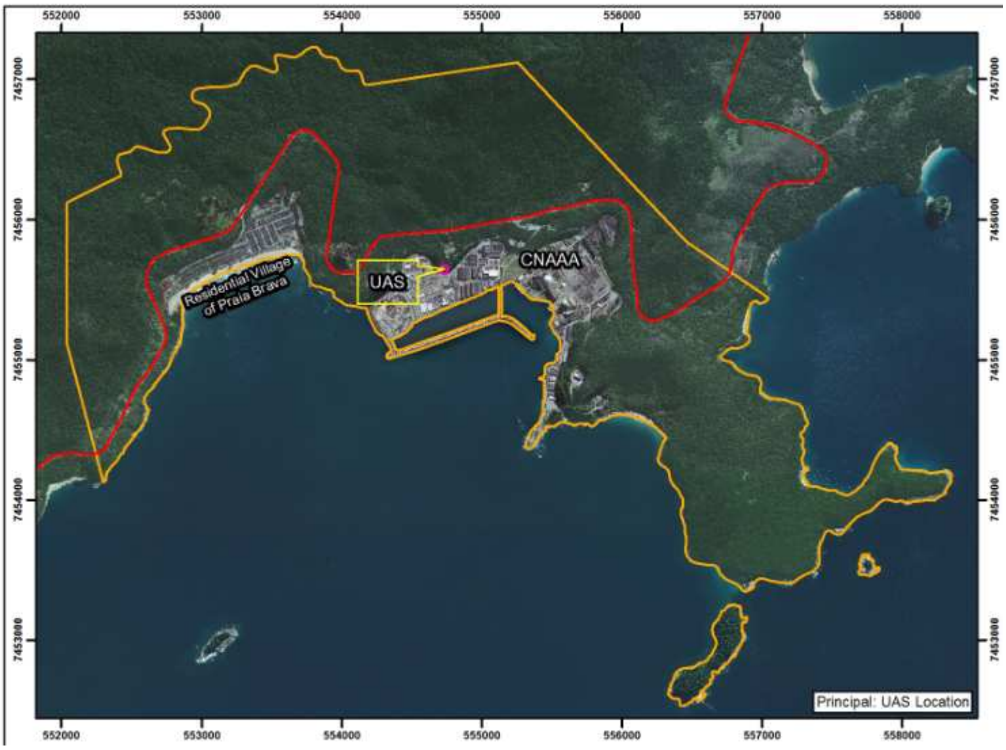

Figure 2.14- Geographical Layout of Proposed CNAAA UAS Site [12]

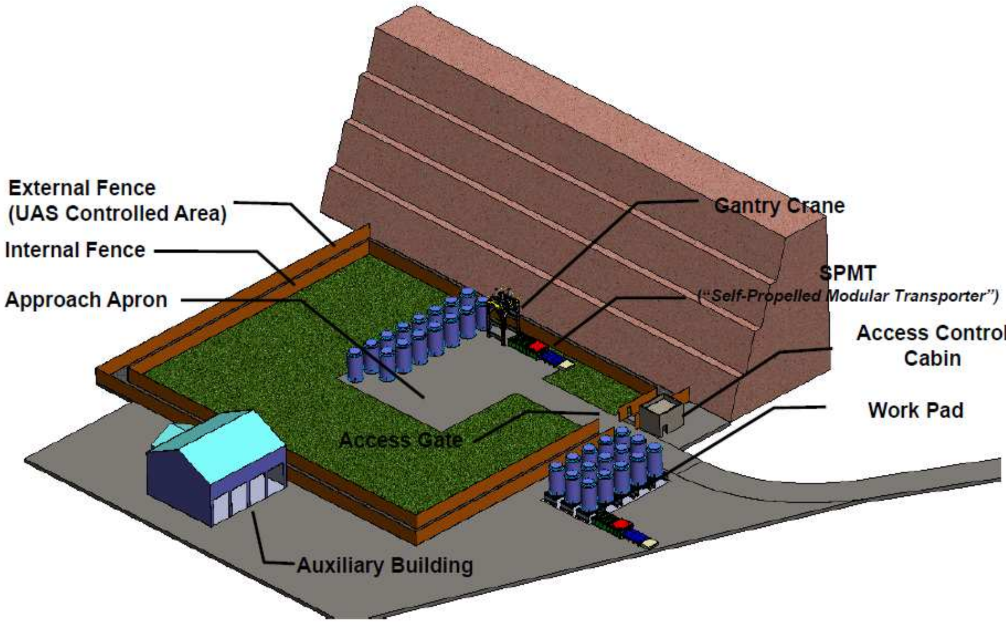

Figure 2.15- UAS concept design (Schematic Drawing)

2.3.4.3 Radiation Monitoring and Calibration Laboratory (LCMR)

The Radiation Monitoring and Calibration Laboratory is a restricted area of 138 m², one story concrete structure with 4 rooms. Part of the building is built with reinforced concrete, another with concrete blocks and roof with concrete. The rooms are the source room, operating room, instrument storage room and exposition room. Its location is shown in south of the Angra 1 NPP and near the Emergency Diesel Building [4] (Figure 2.5). The purpose of the Radiation Monitoring and Calibration Laboratory is to provide calibration services for the radiation monitoring instruments used at the CNAAA.

2.3.4.4 Environmental Monitoring Laboratory (LMA)

The Environmental Monitoring Laboratory is located outside the CNAAA site in the village of Mambucaba 10 km away from the CNAAA (Figure 2.6). The laboratory consists of the laboratory building and an emergency power building. The laboratory building is one story constructed with reinforced concrete, concrete blocks, and ceramic tile roof. The emergency power building is made of reinforced concrete with a tile roof. The laboratory has several corridors with offices and monitoring rooms with radiation, chemistry and biology instrumentation. The radiation laboratories include alfa, beta and gamma radiometry and dosimetry monitors [4].

2.4 Radiological status

The need of radiation protection actions during the decommissioning of the CNAAA derives from contamination and activation of materials during the commercial operation of the nuclear power plants. Part of their structures, systems and equipment are contaminated or activated during commercial operation. Floor and wall surfaces, concrete structures, spent fuel storage racks, and large components such as steam generators, pumps, pressurizers and large pipes will be contaminated. The reactor pressure vessel and its internals, and the biological shield will be activated.

2.4.1 Contaminated structures

The potentially contaminated structures in the CNAAA are those included in the following buildings:

- Angra 1 - Reactor Building (ERE), North Auxiliary Building (EAN), South Auxiliary Building (EAS) and Fuel Building (ECB);
- Angra 2 and 3 - Reactor Building (UJA, UJB & UJF), Reactor Auxiliary Building (UKA);
- Radiation Monitoring and Calibration Laboratory (LCMR);
- Waste Management Center (CGR); and
- Environmental Monitoring Laboratory (LMA)

2.4.2 Contaminated systems and equipment

The potentially contaminated systems and equipment in the CNAAA are the following:

- Primary System;
- Pipes of the Nuclear Steam Supply Systems;
- Fuel pool storage and ancillary systems;
- Air Conditioning and ventilation Systems of contaminated areas;
- Reactor pressure vessel;
- Steam generators;
- Reactor coolant pumps; and
- Pressurizers.

2.4.3 Surface soil contamination

There is no surfaced soil contamination in the CNAAA site.

2.4.4 Subsurface soil contamination

There is no subsurface soil contamination in the CNAAA site.

2.4.5 Surface water contamination

There is no surface water contamination in the CNAAA site.

2.4.6 Groundwater contamination

There is no groundwater contamination in the CNAAA site.

2.5 Operating history of the CNAAA plants

2.5.1 Authorized activities

2.5.1.1 History of Angra 1 NPP

The construction of Angra 1 NPP was completed in 1982 and the expected permanent shutdown date is 12/31/2044 including a life extension of 20 years. Its nominal electric power is 657 MW. The first criticality was established in 13/03/1982 and the commercial operation started in 01/01/1985. The plant's reliability factor is 97% and the average generation in relation to the maximum potential, from the start of commercial operation until 31/03/2013, is 48.51% [14]. Figure 2.16 shows the gross electricity generated by the plant from 1985 to 2016 and shows a good generation history with performance compatible with international best practices during the past 20 years.

Twenty three fuel reloads have occurred in Angra 1 from the operation start until 2018. Angra 1 faced problems regarding some equipment in the first years of its operation, which included: a) 48,000 tubes from the condenser were replaced by others made of titanium; b) some transformers and the static inverters had to be replaced; and c) two new emergency diesel generators had to be installed.

There was a replacement of two steam generators between late January 2009 and early June 2009 that put the plant out of the national electricity system. In March 2013 the reactor vessel cover was changed. The steam generators and the reactor vessel cover that was removed were transferred to the DIGV waste storage facility.

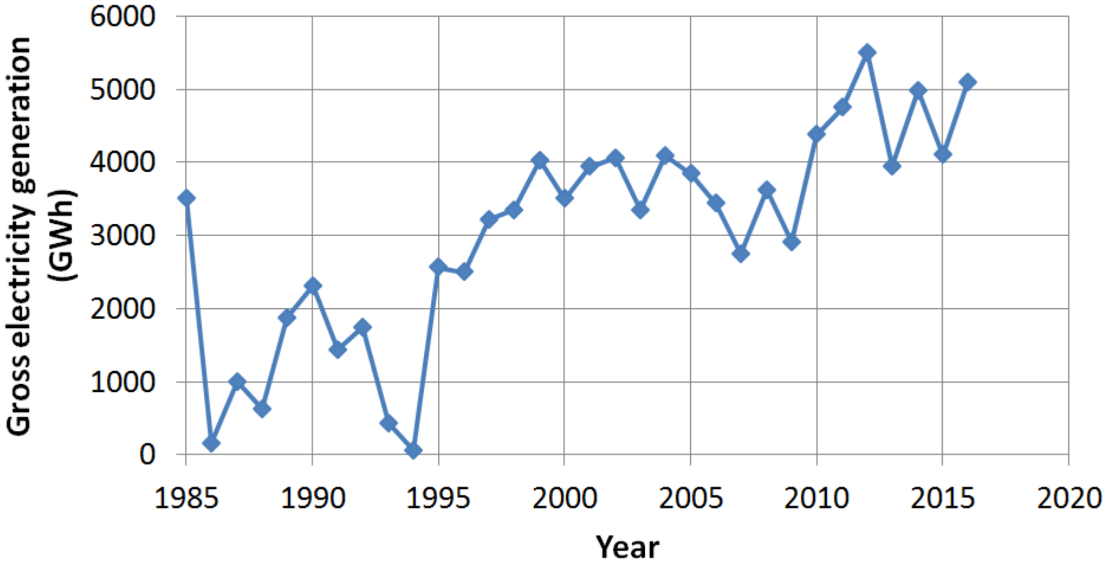

Figure 2.16 - Gross electricity generated by Angra 1 between 1985 and 2016.

2.5.1.2 History of Angra 2 NPP

The construction of the Angra 2 NPP started in 1976. However, between 1983 and 1996 the project had its pace progressively decelerated due to the reduction of the available financial resources. In 1996 the construction activities restarted and the first criticality was established on 14/07/2000. The expected permanent shutdown for Angra 2 is 9/30/2061, that includes a 20 years life extension. The plant nominal power is 1356 MW and the commercial operation in 01/02/2001. The plant's reliability factor is 97%. The average electricity generation relative to the maximum potential generation is 82.87% from the start of commercial operation (01/02/2001 up to 31/03/2013). There were 9 fuels refilling in this period until 2013. Figure 2.17 shows the gross electricity generated by the Angra 2 NPP from 2001 up to 2016.

Angra 2 NPP has a very good historic record and in 2012 presented an outstanding performance. According to Nucleonics Week, an American publication specialized in nuclear power, the plant held in 2012 the 18th place regarding power generation among the 437 plants in operation in the world, with a gross output of 10645 GWh. In 2012 the Availability Factor index was 92.06% for Angra 2. During its operation scheduled maintenances have occurred without major equipment replacements as occurred with Angra 1.

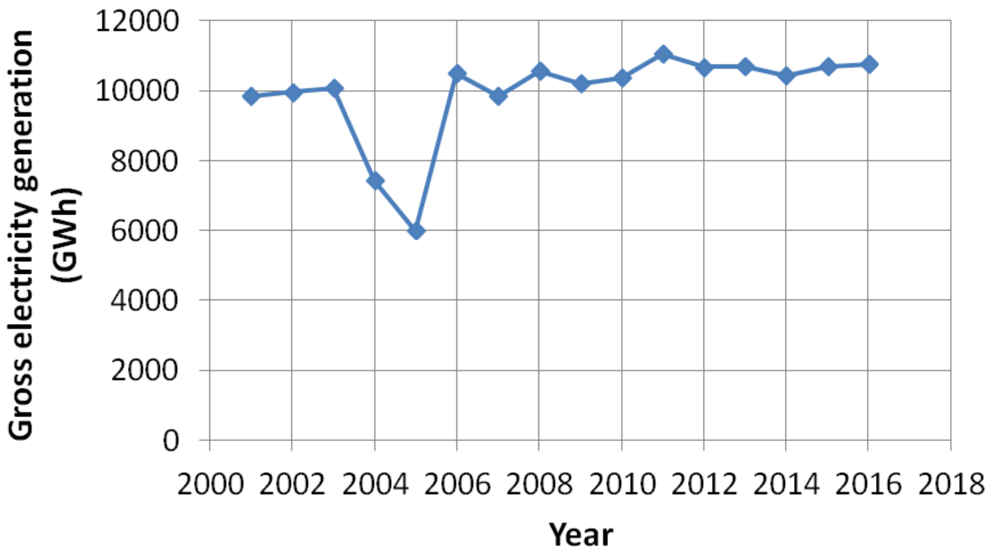

Figure 2.17- Gross electricity generated by Angra 2 between 2001 and 2016.

2.5.1.3 History of Angra 3 NPP

The Angra 3 nuclear power plant is under currently construction. The construction for Angra 3 started in 1984 and was discontinued in 1986. In 2010 Eletronuclear obtained licenses and permits to restart construction, issued by the National Energy Policy Council, the National Commission of Nuclear Energy and the National Institute of Environment and Renewable Resources. Angra 3 will be similar to Angra 2 but with updated design including improvements developed by the nuclear industry. The rated power of Angra 3 will be 1405 MW. The expected commercial operation is 2022 and the expected permanent shutdown is 60 years later (2082) considering a life extension of 20 years.

2.5.2 License or authorization history

The licenses and authorizations issued to the CNAAA are presented in Table 1.1. The history of the process is given in sect. 1.1.

2.5.3 Spills, activated materials and occurrences affecting decommissioning

The contamination of concrete and metal structures come from spills occurred during work procedures and from water contamination. The volumes of contaminated concrete were estimated through the contaminated surfaces times the penetration depth of the contamination, usually 1 to 5 cm. The neutron activated concrete is estimated in a similar manner with activation depth of 10 to 40 cm. The bioshields are considered completely activated and are the biggest source of radioactive waste. Tables 2.3 to 2.6 present the volumes of contaminated concrete for the several buildings from Angra 1. Tables 2.7 to 2.9 present volumes of contaminated concrete and metals for the several buildings from Angra 2. Table 2.10 presents the volume of neutron activated concrete for Angra 1 and Angra 2. About 70 % of the total radioactive material comes from the activated bioshields and inner ring.

The only occurrences have been the removal of two steam generators and the reactor vessel cover of the Angra 1 nuclear power plant. This equipment was transferred to the DIGV waste storage.

Table 2.3 – Contaminated concrete structures in the Auxiliary Building North from Angra 1.

Room/Area	Structure	Volume m3	Information source
525	Walls	1,46	Survey
525	Floor	0,65	Survey
525	Ceiling	0,32	Survey
523,523a,b,c	Walls	1,14	Survey
523,523a,b,c	Walls	1,27	Survey
523,523a,b,c	Floor	1,76	Survey
523,523a,b,c	Ceiling	0,88	Survey
500			Report
Total		7,48	

Table 2.4 – Contaminated concrete structures in the Auxiliary Building South from Angra 1.

Room/Area	Structure	Volume m3	Information source
204	Walls	0,38	Survey
204	Walls	0,15	Survey
204	Floor	0,07	Survey
204	Ceiling	0,04	Survey
206/206a	Walls	1,56	Survey
206/206a	Walls	0,76	Survey
206/206a	Floor	3,60	Survey
206/206a	Ceiling	0,72	Survey
Laundry	Floor		Report
Tool Decon/311	Walls	0,99	Survey
Tool Decon/311	Walls	0,63	Survey
Tool Decon/311	Floor	1,89	Survey
Shop	Walls	0,17	Survey
Shop	Walls	1,22	Survey
Shop	Floor	1,28	Survey
Total		13,45	

Table 2.5 – Contaminated concrete structures in the Safety Building from Angra 1.

Room/Area	Structure	Volume m3	Information source
127	Floor	0,69	Survey
106	Walls	1,10	Survey
106	Floor	0,12	Survey
106	Ceiling	0,06	Survey
110	Walls	1,10	Survey
110	Floor	0,29	Survey
110	Ceiling	0,06	Survey
112	Floor	0,04	Survey
150	Floor	1,13	Survey
151	Floor	1,13	Survey
123	Floor		Report
Total		5,73	

Table 2.6 – Contaminated concrete structures in the Reactor Building from Angra 1.

Room/Area	Structure	Volume (m3)	Information source
VA2B	Floor	0,47	Survey
	Floor	44,72	Survey
pool	Wall	19,50	Survey
pool	Wall	0,89	Survey
pool	Wall	2,07	Survey
pool	Floor	4,60	Survey
414/414A	Floor	3,19	Report
414H	Floor	1,11	Report
Total		76,54	

Table 2.7 – Contaminated concrete structures in the Auxiliary Building from Angra 2.

Room/Area	Structure	Volume (m3)	Information source
213	Floor	0,20	Survey
132	Floor	0,18	Survey
411	Floor	0,32	Survey
411	Wall	0,48	Survey
124			Report
141, 142, 143, 144, 146	Floor	4,58	Report
149	Floor	0,44	Report
150	Floor	0,43	Report
161	Floor	2,59	Report
338	Floor	1,10	Report
514	Floor	2,80	Report
416	Floor	0,49	Report
421	Floor	0,13	Report
Total		13,75	

Table 2.8 – Contaminated concrete structures in the Reactor Building from Angra 2.

Room/Area	Structure	Volume (m3)	Information source	Room/Area	Structure	Volume (m3)	Information source
34	Floor	0,05	Survey	521/522/523	Floor	1,02	Survey
135	Floor	0,59	Survey	521/522/523	Floor	0,06	Survey
741	Floor	0,60	Survey	floor	Floor	5,10	Survey
742	Floor	0,11	Survey	floor	Floor	1,73	Survey
cavity	Wall	7,42	Survey	floor	Floor	2,66	Survey
cavity	Wall	5,32	Survey	760	Floor	0,03	Survey
cavity	Floor	2,01	Survey	761	Floor	0,08	Survey
845	Floor	0,05	Survey	941/951	Floor	6,96	Survey
845	Floor	0,19	Survey	338	Floor	0,30	Report
845	Floor	0,06	Survey	511	Floor	0,32	Report
845	Floor	0,08	Survey	514	Floor	0,13	Report
845	Floor	0,21	Survey	416	Floor	0,32	Report
floor	Floor	5,06	Survey	126/127	Floor	3,14	Report
floor	Floor	1,40	Survey	421			Report
All floor	Floor	48,63	Survey	Inside	Wall	37,38	Report
677/678	Floor	0,39	Survey	Inside	Floor	4,92	Report
Total						**136,32**	

Table 2.9 – Contaminated metal structures of the spent nuclear fuel pool from Angra 2.

Room/Area	Structure	Volume (m3)	Information source
fuel pool	Walls	7,98	drawings
fuel pool	Walls	5,67	drawings
fuel pool	Floor	2,31	drawings
Total		15,96	

Table 2.10 – Neutron activated concrete structures from Angra 1 and Angra 2.

Location		Room/Area	Structure	Volume (m3)	Information source
Angra 1	Reactor Building	Bioshield	containment	208,95	Calculation
		Inner ring	containment	120,70	Calculation
Angra 1		**Total**		**329,65**	
Angra 2	Reactor Building	Bioshield	containment	236,15	Calculation
		Cavity	wall	2,80	Survey
		Cavity	floor	14,84	Survey
		Cavity	walls	73,85	Survey
		Cavity	floor	23,22	Survey
Angra 2		**Total**		**350,86**	

2.5.4 Previous decommissioning activities

In 2014 Eletronuclear submitted to CNEN the Preliminary Decommissioning Plan for the CNAAA with first estimates of total cost for decommissioning the whole site, and alternative strategies for undertaking the decommissioning [3].

2.5.5 Prior on site burial

There have been no previous burials of nuclear waste, contaminated materials or activated materials on the CNAAA site until 2016.

3 CNAAA DECOMMISSIONING STRATEGY

The objective of this Chapter is to present the strategy chosen for the decommissioning of the CNAAA.

3.1 Introduction

Brazilian regulations presented in CNEN Standard No. 9.01 [1] and the IAEA documents [2, 15] define the basic possible strategies for decommissioning nuclear power plants. The definitions presented by the IAEA for these strategies are [15]:

a) Immediate dismantling: The decommissioning actions begin shortly after the permanent shutdown. Equipment and structures, systems and components of a facility containing radioactive material are removed and/or decontaminated to a level that permits the facility to be released from regulatory control for unrestricted use, or released with restrictions on its future use.

b) Deferred dismantling: In this case, after removal of the nuclear fuel from the facility (for nuclear installations), all or part of a facility containing radioactive material is either processed or placed in such a condition that it can be put in safe storage and the facility maintained until it is subsequently decontaminated and/or dismantled. Deferred dismantling may involve early dismantling of some parts of the facility and early processing of some radioactive material and its removal from the facility, as preparatory steps for the safe storage of the remaining parts of the facility.

The immediate dismantling is the preferred strategy [15] since it recovers the site in the shortest time length. If the site presents specific conditions and characteristics after detailed evaluation, other strategies may be considered, i.e., deferred dismantling or a combination of the two strategies. In the case of the CNAAA, a multiple plant site, it is beneficial to consider a combination of the strategies since there will be 3 nuclear power plants in operation. The power plants in the site use several systems related to operations, safety, radiological protection and waste management that are shared among the 3 nuclear power plants This creates interdependencies that must be considered before defining a decommissioning strategy.

Regarding a deferred dismantling, the plant can be kept in a safe condition for a prolonged period to allow the radioactive material to decay in the plant. This action can facilitate the dismantling work and the working teams can act under lower radiation doses at the end of the decay period.

The decommissioning process is carried out through 5 main tasks briefly described below. These tasks are necessary to be undertaken for any adopted strategy, i.e., immediate dismantling, deferred dismantling, or a combination of deferred and immediate dismantling [1, 2, 7, 10, 15-34]. A study regarding the decommissioning of multiple reactor sites, considering their interdependencies and possible influence on human resources, materials, and financial is provided in [27]. These tasks are discussed in detail in chapter 5.

3.1.1 Planning and preparation

Planning and preparation involves the initial engineering, planning and structuring the organization to undertake the coming decommissioning activities. If the decommissioning strategy involves deferred dismantling the main planning activities should be split in two parts: one part is for safe storage planning after the shutdown, and other part for planning to decontamination, dismantling and site restoration activities, after the safe storage period.

3.1.2 Transition period

This period is also referred as transition from operational to decommissioning status [21, 22]. It Involves the removal of the last reactor core and the various plant systems. Furthermore, all of the primary circuit and auxiliary systems are decontaminated and dried. After that, there are performed plant's physical inspection and radiometric survey. The objective of these activities is reducing the inventory of radiological material and removing of hazardous material such as lead, asbestos and chemicals.

All the plant's infrastructure can be re-evaluated and reassigned, involving modifications of buildings and removing of systems no more needed after the end of operation, to make room for dismantling and packaging activities and interim waste storage. It may also involve introduction of temporary structures. The action also involves dismantling and removal of all unnecessary systems and infrastructures to simplify and lower operating costs, reduce surveillance and maintenance requirements. The plant is set in a safe condition until decommissioning starts. This task may take from one to two years.

If the decommissioning strategy involves deferred dismantling, this task includes the preparations for safe store period with additional infrastructure and systems for safety, security and surveillance, taking additional one to two years.

3.1.3 Safe storage period

The objectives of the safe store strategy are to place the nuclear installation into a condition of safe long-term storage and at the same time reduce maintenance needs. The strategy allows time for certain conditions to be met or activities to be performed prior to the final dismantling of the facility. Additionally, longer periods of safe storage allow reducing the radiation dose risk to the workers that will dismantle the plant and possibly the amount of higher level radioactive waste [24].

The activities during this period are surveillance, maintenance of structures and needed systems, and building renovations when necessary. The surveillances aim at preventing structure degradation along time or due to external events or intrusion; maintaining systems to prevent water ingress, protection against groundwater infiltration, and protection against extreme weather; to warrant protection against fire; to monitor radiological conditions and detecting any unexpected release of radioactive effluents. Building renovations include renovate existing structures, make provisions for high integrity waterproof and construction of protecting barriers in different areas.

The surveillance and maintenance include actions that occur in normal and abnormal conditions such as accidents. Examples of surveys to confirm the integrity of the plant or building are radiation level, temperature, humidity, corrosion, atmospheric pollutant level, facility security, drainage, ventilation, concrete and steel structures status, and material coatings status. The frequency of routine inspections and surveys will be once or twice a year but it may change according to the area conditions.

3.1.4 Plant decontamination and dismantling (D&D)

The activities during this period include decontamination and/or dismantling of all contaminated or activated plant systems, equipment and materials, which will be removed, separated, properly packaged and transported to a final storage facility. These activities take around six years and include the most critical and specialized tasks: removal of reactor internals, reactor pressure vessel (RPV), and large components that usually takes two to three years. These activities are the most expensive part of D&D activities and have to be performed by specialized crews.

The D&D activities produces a large amount of radioactive material, such as major components of the primary circuit, piping, valves, tanks, radiological shielding, fuel storage cells, contaminated concrete, etc. All these materials must be carefully packaged and sent to storage in appropriate locations and continuously monitored.

3.1.5 Demolition and Site Restoration

The activities of this period intends to bring the site to the final condition defined in the decommissioning plan. The final state defines how the site should be at the end of the decommissioning, establishes site future uses, the site remediation needs and the future users/population exposure.

This period also involves conventional demolition of uncontaminated and decontaminated buildings, conventional waste removal, radiological characterization of the site, and site remediation. This task takes one to two years, depending on the definition of final condition of the site.

3.2 Factors affecting the CNAAA decommissioning strategies

Several factors can influence the decision-making about the best decommissioning strategy [1, 15-17, 21, 23]. For the CNAAA the main ones are: definition of the end state; availability of radioactive waste storage off site to take in low and intermediate contaminated materials; availability of spent nuclear fuel storage off site to take in the irradiated fuel generated during the operation of Angra 1, Angra 2 and Angra 3; and interdependences among the plants. Below these factors are discussed.

3.2.1 Final state of the site

The end or final state of the site describes the condition of the site at the end of the decommissioning process, establishes a site that can be used in the future for different purposes. The final state of the site has direct influence on the amount of decommissioning amount of effort and cost that must be expended to meet this end state. There are basically two alternatives for the site final status: site with unrestricted release and site a with restricted release. For the latter, the regulatory body (CNEN) may establish different requirements, criteria for decontamination levels and long term institutional controls.

The end state for the CNAAA after the decommissioning, defined for all considered alternatives of decommissioning strategy, is unrestricted release, i.e., the site will be released from CNEN's regulatory control, and consequently will be available for any use by Eletronuclear or members of the public. This choice of final state was made aiming at conducting the decommissioning process with the objective of recovering the CNAAA site with minimum environmental and social impacts to the Brazilian society.

3.2.2 Availability of permanent disposal sites for radioactive waste and spent nuclear fuel

A major component of the decommissioning work scope is the packaging, transporting and disposing of contaminated and activated equipment, piping, components and concrete. It is assumed in all of the decommissioning strategy alternatives that permanent disposal sites for radioactive waste and spent nuclear fuel will be available when necessary.

Brazilian law establishes that the responsibility for the final disposal of radioactive waste shall be of the Federal Government and carried out by the National Commission for Nuclear Energy (CNEN). A site selection process aimed at the construction of a Brazilian Repository for the low and intermediate level radioactive waste is currently being performed. Regions of interest have already been identified and areas are being considered as candidate sites. Once the final candidate sites are chosen, the next step will be the public acceptance program. This involves the identification and discussions with the appropriate stakeholders in the selected areas. CNEN is currently performing geological research in the candidate sites in order to achieve a final decision.

Eletronuclear is building a temporary dry-storage facility in the CNAAA to accommodate spent nuclear fuel beyond the current capacity of Angra 1, 2 and 3 in-plant storage pools and allow the fuel currently in the pools to be removed to dry storage and allow decommissioning. Eventually, the spent nuclear fuel shall be removed to a permanent off site facility to meet the end state criteria established for the CNAAA decommissioning (section 3.2.1).

3.2.3 Plants Interdependence factors

The interdependence factors among Angra 1, Angra 2 and Angra 3 affecting the decommissioning of the CNAAA are discussed in the sections below.

3.2.3.1 Common systems used in the operation of Angra 1, 2 and 3

Although there are three nuclear power plants at the CNAAA they have very few systems in common because each one was and will be built with almost 20 years of difference. There are only 3 systems providing services which are common to Angra 1, Angra 2 and Angra 3 during commercial operation. They are [25]:

- System for Water Demineralization (GC). This system produces demineralized water for Angra 1 and Angra 2 and will produce it for Angra 3 too. It is localized in the Angra 2 power plant. The produced demineralized water is distributed to the other power plants through ducts of the system of demineralized water supply of the CNAAA.

- Auxiliary Steam System and Auxiliary Condensate Collection System (LBG/LCN). These systems provide steam and condensate collection for auxiliary activities during normal operation and stoppages of the nuclear power plants. It is located in the Angra 2 power plant. The steam and condensate are delivered and collected through ducts between the nuclear power plants. Currently these systems provide services for Angra 1 and Angra 2 and when Angra 3 starts operation they will provide services to the 3 nuclear power plants. Then the steam will be produced in Angra 2 and Angra 3 depending on demand and availability of each plant.

- System for Biocide Treatment of Cooling Water (PUS). This system produces and injects sodium hypochlorite in the cooling water of the condensers and other heat transfer equipment to avoid proliferation of microorganisms. This system is located in the Angra 2 power plant. Currently it supplies treated water to Angra 2 and Angra 1 during stoppages through ducts, and in the future to Angra 3 too.

Figure 3.1 presents the interdependencies of the 3 nuclear power plants with regard to these 3 systems. The arrows in Figure show the source in Angra 2 going to 1 and 3 Since they are located in Angra 2 it does not depend on the other plants for normal operation. In the other hand, Angra 1 and Angra 3 require these systems for normal operation, and therefore. Thus when Angra 2 is decommissioned it will be necessary to implement modifications to cope with these interdependences.

The modifications are not complex. When Angra 1 starts its decommissioning, the ducts connecting these systems to Angra 1 will have to be isolated. These systems will then provide services to Angra 2 and Angra 3. When Angra 2 starts decommissioning, these systems must continue to operate to provide services to Angra 3 or else they will have to be transferred to Angra 3. The ducts connecting them to Angra 2 will have to be isolated.

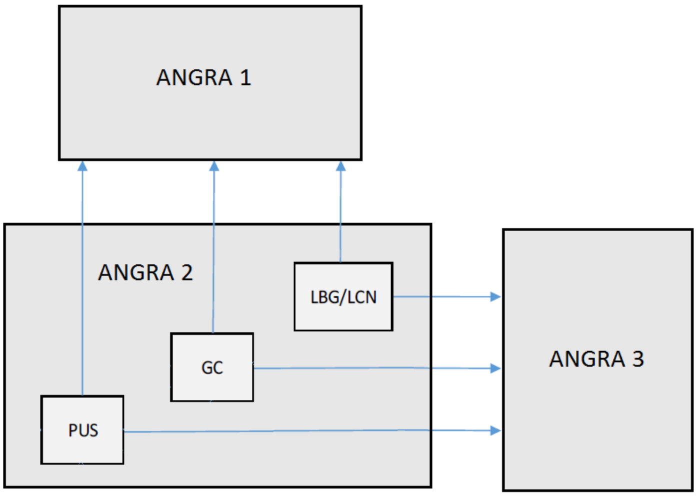

Figure 3.1 - Common systems among Angra 1, Angra 2 and Angra 3. Angra 1 and Angra 3 require systems from Angra 2 to operate. Adapted from Ref. [25].

3.2.3.2 Location and routes

The 3 plants location in the site may interfere with decommissioning activities of a plant and the operation of the others. Angra 1 and Angra 2 plants are close to each other while Angra 3 is distant from these two. The Angra 1 decommissioning can start earlier as long as it does not disturb Angra 2 operation. Starting dismantling of Angra 1 and Angra 2 is not expected to disturb the operation of Angra 3.

During the transition and the D&D periods there may be intense decommissioning activities at Angra 1. As Angra 1 and Angra 2 are close together, the decommissioning activities in Angra 1 could interfere in the Angra 2 operation. To avoid interference it is necessary to define areas of dismantling and decontamination activities and crossing routes of these materials through the plant site.

The site exit routes would be the current Angra 1 and Angra 2 or Angra 3 access roads in the site. The radioactive waste can be removed from the site using the existing roads in the area. When Angra 2 starts decommissioning the interference in Angra 3, still in operation, would be much smaller. The pier located on the right of Angra 2 could be used for maritime transportation. The road transport routes would be similar to those described above for Angra 1.

3.3 Alternatives considered for the decommissioning

Three different alternatives were considered for decommissioning the CNAAA namely immediate dismantling of all plants, combination of deferred and immediate dismantling, and deferred dismantling of all plants – latest date. The immediate dismantling option is the preferred option by several studies and international guides because it reduces radiological risks at an earlier date and allows releasing the site for the public more rapidly. However, if circumstances related to safety, management, cost, and to the factors listed in sect. 3.2 are present another option may be justified and used [15-17, 23].

For all alternatives, it is anticipated that Angra 1, Angra 2 and Angra 3 will shut down in 12/31/2044, 9/30/2061 and 12/31/2082, respectively. The total plant lifetime for each plant is 60 years (40 years of design lifetime plus 20 years of life extension). The alternatives considered are described below.

3.3.1 Alternative 1 – Immediate dismantling of all plants

The first alternative for decommissioning considers the immediate dismantling of all plants. Figure 3.2 shows the schedule for immediate dismantling. The completion of the decommissioning process for Angra 1, Angra 2 and Angra 3 would occur in 2054, 2070, 2091, respectively. The CNAAA site unrestricted release would occur in 2095.

A positive aspect of these alternatives is that the whole process of decommissioning of each nuclear power plant occurs in 16 years. It reduces radiological risks in each plant at an earlier date and allows releasing the site for the public more rapidly. A negative consequence of this strategy is that it requires three mobilizations and demobilizations of resources and personnel to carry out the decommissioning activities of each plant. It presents periods of high and low level of activities which tend to be more expensive. Additionally, no decay time is allowed for any of the plants. This approach also tends to be more expensive to keep good health conditions for the work force.

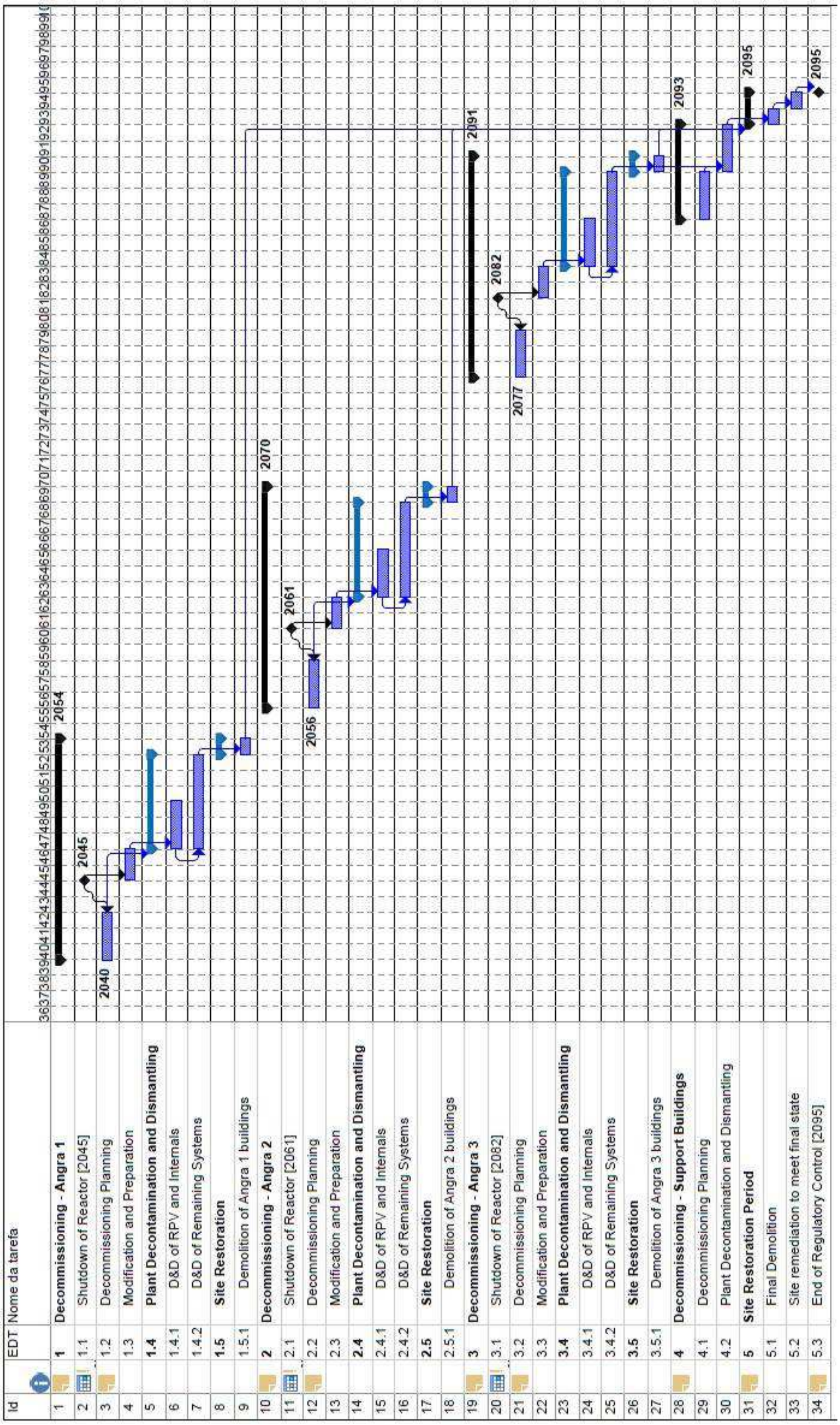

Figure 3.2 – Alternative 1 for the CNAAA site decommissioning – immediate dismantling

3.3.2 Alternative 2 – Combination of deferred and immediate dismantling

In this alternative the basic decommissioning strategy for Angra 1 and 2 will be deferred dismantling, as defined by the International Atomic Energy Agency [15]. This strategy will place the two plants into an extended safe storage configuration. The two facilities will be left relatively intact with structures maintained in a stable condition. Systems that are not required to support the ventilation, safety systems, or site security are drained, de-energized, and secured. Minimal cleaning/removal of loose contamination and/or fixation and sealing of remaining contamination is performed prior to safe storage. The Angra 3 approach will be to implement the IAEA immediate dismantling strategy upon permanent shutdown.

As previously stated, after the permanent shutdown of Angra 1 and 2, each reactor will be placed into a safe storage configuration until Angra 3 is permanently shutdown. Figure 3.3 shows the schedule of this alternative.

The critical path activity for the decommissioning of these three reactors will be the removal of the reactor internals and the reactor vessel. A specialized team with specialized equipment to perform these activities will be required. The dismantling of the reactor internals and vessel of Angra 1 is back calculated based on the shutdown date for Angra 3, doing Angra 2 second and Angra 3 third. The approach is to establish a dedicated team to perform the reactor internal and vessel removal activities from all three reactors in series. By starting with the removal of the reactor internals and vessel of Angra 1, the dose rates will have decayed during the approximate 20-year safe storage period.

Safe storage activities will include maintaining a security/guard force, preventive and corrective maintenance on security systems, area lighting, general building maintenance, ventilation, routine radiological inspections, maintenance of structural integrity, fire protection, and environmental and radiation monitoring.

Prior to starting dismantling operations, site services will be reactivated, a decommissioning management organization will be assembled and planning will be performed. Planning will include engineering; additional facility and site characterization as necessary and the development of work plans, specifications and procedures.

After decontamination and release of the buildings, demolition and site restoration activities will be performed. Affected areas would be backfilled with suitable fill materials.

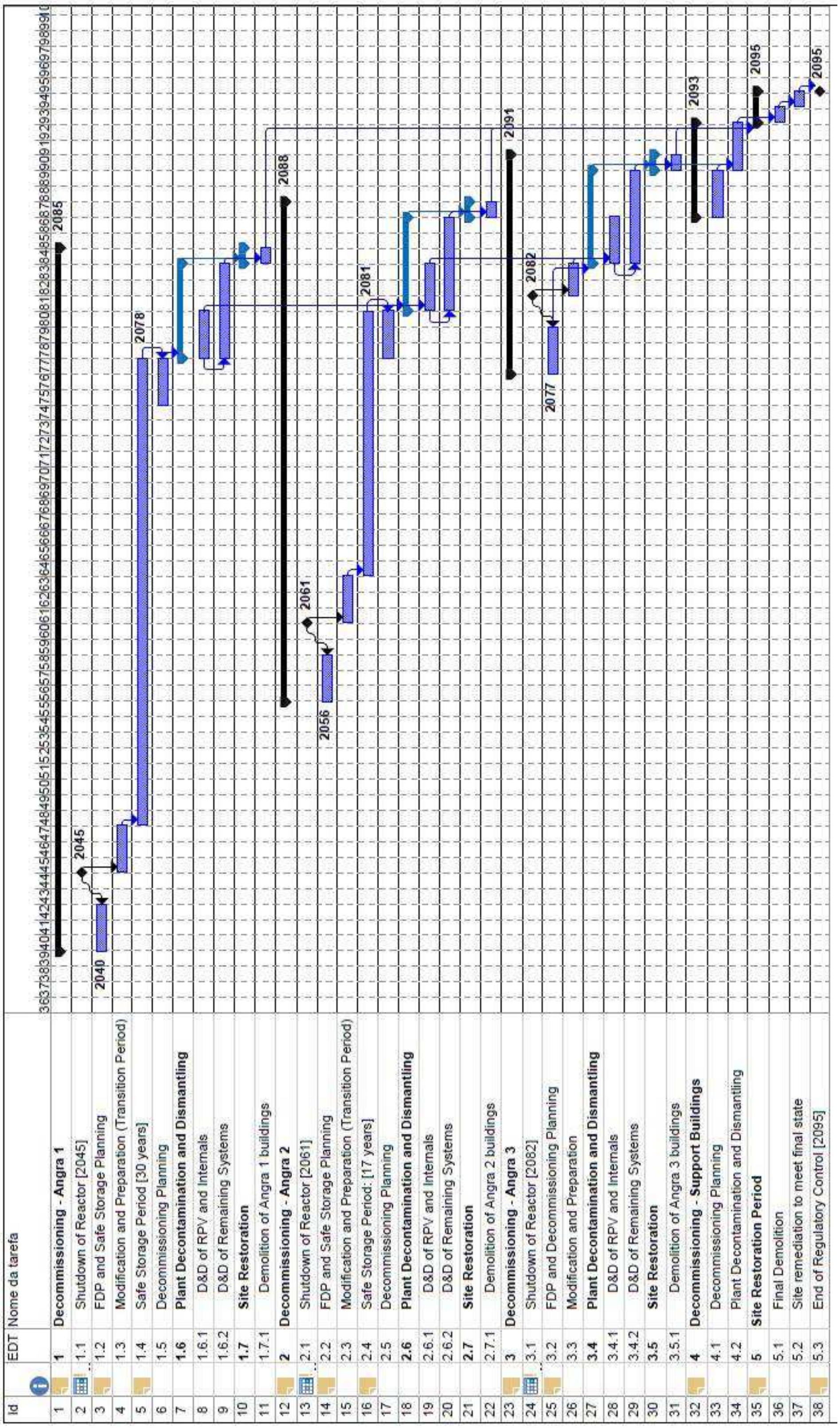

Figure 3.3 – Alternative 2 for the CNAAA site decommissioning – combination of deferred and immediate dismantling.

3.3.3 Alternative 3 – Deferred dismantling of all plants – latest date

In the third alternative the basic decommissioning strategy for Angra 1, 2 and 3 will be deferred dismantling, as defined by the International Atomic Energy [15]. This alternative, shown in Figure 3.4, considers that the plants dismantling would be sequential for the reasons already mentioned, and all three plants would be placed in safe storage. The difference is that the safe storage period for Angra 1 would be completed in 60 years, which is the longest period accepted in Brazilian regulations [1].

The motivation for this alternative is to present the longest possible decommissioning process allowed which present the following advantages: biggest possible reduction of workers to radiation exposition, longest radioactive decay for the Angra 1 power plant, and for allowing the biggest growth of the decommissioning funds through accruing interest. The disadvantages are delaying decommission completion and site release and additional costs of the increase of the safe storage period.

Figure 3.4 shows that the decontamination and dismantling of Angra 1 starts in 2098 and those for Angra 2 and Angra 3 follows in sequence. These activities can be rapidly performed once the necessary resources are available. The site will be cleared for general use after 2115.

For the whole CNAAA, the difference between the shortest decommissioning duration (alternatives 1 and 2) and the longest decommissioning duration (alternative 3) is 20 years. In the first case, the site is released to the public in 2095 and in the second case in 2115.

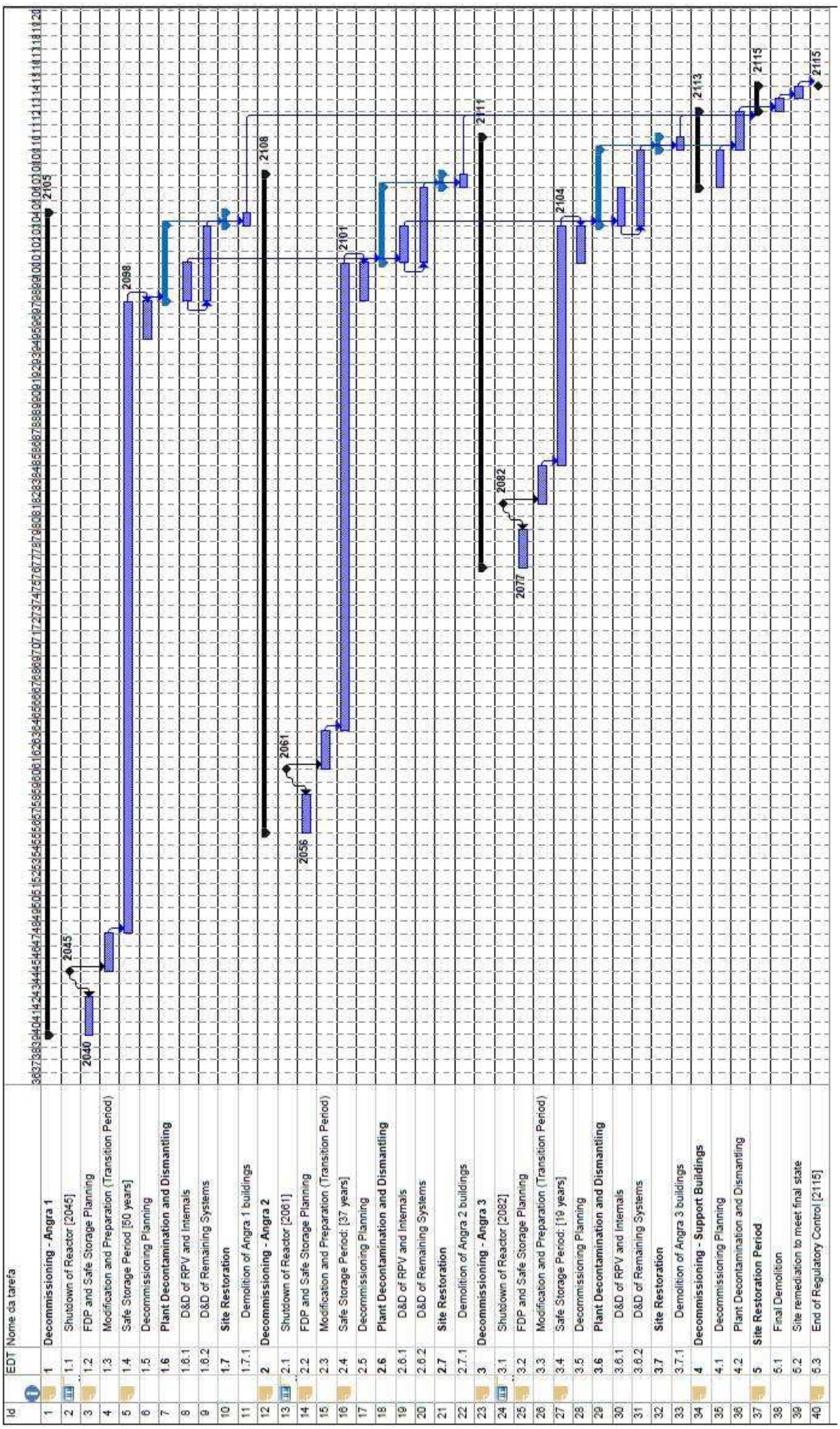

Figure 3.4 – Alternative 3 for the CNAAA site decommissioning –deferred dismantling of all plants – latest date.

3.3.4 Selected alternative for the CNAAA decommissioning

Taking into account the options presented, Eletronuclear selected the second alternative (combination of deferred and immediate dismantling) as the best option. In this strategy Angra 1 and Angra 2 will undertake deferred dismantling until Angra 3 ceases its operation and starts immediate dismantling as shown in Figure 3.3. The rationale for selecting this strategy is given in sect. 3.4.

3.4 Rationale for chosen strategy

Three strategy alternatives for the decommissioning of CNAAA plants were presented. The chosen alternative 2, shown in Figure 3.3, considers the basic decommissioning strategy for Angra 1 and 2 to be deferred dismantling, as defined by the IAEA [15]. This strategy places the two plants into an extended safe storage configuration. The Angra 3 approach is to implement the IAEA immediate dismantling strategy upon permanent shutdown [15].

The chosen strategy reduces radiological risks at an earlier date and allows releasing the site for the public more rapidly. It provides a relatively stable work force for a longer period once decontamination and dismantling (D&D) activities begin, than if the plants went into immediate dismantling as they permanently shut down. By following this approach there will be less impact on the local economy once D&D begins. It allows the continued collection and growth of decommissioning funds, and sufficient time to ensure a final disposal site is available for radioactive waste and spent fuel disposition is available. .

During the D&D part of the decommissioning it also provides a stable workforce and allow the team to gain experience as they move to the less decayed internals and vessels and newer systems. As the reactor, internal and vessel removal activity is completed for one reactor, this specialized team moves to the next reactor and additional personnel can begin the decontamination and dismantling activities for the remaining reactor systems and buildings. If there are times when a crew is not completely utilized, they may be reassigned to perform activities at one of the support facilities.

By using this approach, the onsite workforce will be reduced during the period from the start of the Angra 1 safe storage period until the planning begins for the removal of the Angra 1 reactor vessel internals (approximately 37 years). At that time the work force will increase and become relatively stable until the Angra 3 decommissioning is completed. This approach also allows the decommissioning fund to grow based on the longer operational period of Angra 2 and 3, and the increase of the fund based on interest accrual and other long term financial growth methods.

4 PROJECT MANAGEMENT

4.1 Introduction

The decommissioning project should observe many regulations and standards to plan, manage and implement the decommissioning activities. Some are legal and mandatory regulations and others are recommendations but contain important requirements from acknowledged past experiences.

The main national regulatory documents contain mandatory requirements for the decommissioning project and are listed below:

- Norma CNEN NN 9.01, Descomissionamento de Usinas Nucleoelétricas [1];
- Norma CNEN NN 3.01, Diretrizes básicas de proteção radiológica [7];
- Norma CNEN NN 6.09, Critérios de aceitação para deposição de rejeitos radioativos de baixo e médio níveis de radiação [10].
- Norma CNEN NN 1.16, Garantia da Qualidade para a Segurança de Usinas Nucleoelétricas e Outras Instalações [26].
- Norma CNEN NN 8.01, Gerência de rejeitos radioativos de baixo e médio níveis de radiação [28];

The main international standards for decommissioning were issued by the IAEA and cover the major topics related to decommissioning management, activities and safety. They are:

- Safety Report Series no. 45, Standard format and content for safety related decommissioning documents [2];
- IAEA-TECDOC 1478, Selection of decommissioning strategies: issues and factors [16];
- Technical Report Series No. 420, Transition from operation to decommissioning of nuclear installations [22];
- Safety Standards Series No. WS-G-2.1, Decommissioning of Nuclear Power Plants and Research Reactors [23];
- Safety Reports Series No. 26, Safe Enclosure of Nuclear Facilities during Deferred Dismantling [24];
- Technical Reports Series No. 399, Organization and Management for Decommissioning of Large Nuclear Facilities [29];
- Technical Report Series No. 462, Managing low radioactivity material from the decommissioning of nuclear facilities [30];
- Safety Reports Series No. 36, Safety Considerations in the Transition from Operation to Decommissioning of Nuclear Facilities [31];

- Technical Reports Series No. 389, Radiological Characterization of Shut Down Nuclear Reactors for Decommissioning Purposes [32];

- IAEA Safety Standards Series No. GS-R-1, Legal and Governmental Infrastructure for Nuclear, Radiation, Radioactive Waste and Transport Safety [33];

- Safety Standards Series No. WS-R-3, Remediation of Areas Contaminated by Past Activities and Accidents [34].

The regulations and standards listed in this section should be revised periodically for new editions. New relevant documents can be included as well as obsolete ones be removed. These revisions should be carefully analysed for its changes and impacts on the planned decommissioning activities.

4.2 Project management approach

The decommissioning of the CNAAA will be treated as a program with several projects aiming at the completion of its main activities. These projects are shown in Table 4.1. Each project has its own characteristic activities and requires appropriate management teams, work skills and fund.

For the Project 1 (Preliminary planning and preparation), the main activities are related to planning and keeping information about the plant updated. The main regulatory document for the decommissioning process in Brazil [1] establishes that the Preliminary Decommissioning Plan (PDP) (this document) should be prepared and maintained up to date through periodical revisions during the operational life of the nuclear power plant. The second required document, the Final Decommissioning Plan (FDP), will be elaborated with latest detailed information and should be approved by the Brazilian Nuclear Regulatory Agency (CNEN) before starting the decommission process [1].

The Projects 2, 3 and 4, related to the decommissioning of each NPP, include activities related to removal of radioactive waste from the site, removal of nuclear fuel, safe storage activities, decontamination activities, dismantling activities and site restoration. The main work packages for these projects are in Table 4.2. The main work packages of the Projects 5 and 6 are mostly building demolition and site restoration.

Table 4.1 – Projects of the decommissioning program of the CNAAA.

Projects	Observation
1) Preliminary planning and preparation	During this period, decommissioning activities are detailed in the Preliminary Decommissioning Plan.
2) Decommissioning of Angra 1	Starts in 2040, 5 years before Angra 1 permanent shutdown and ends on 2085. Deferred dismantling strategy. Duration of 46 years.
3) Decommissioning of Angra 2	Starts in 2056 5 years before Angra 2 permanent shutdown and ends on 2088. Deferred dismantling strategy. Duration of 33 years.

4) Decommissioning of Angra 3	Starts in 2077 5 years before Angra 3 permanent shutdown and ends on 2091. Immediate dismantling strategy. Duration of 15 years.
5) Decommissioning of the support buildings	It starts in 2087 about 3 years before all nuclear power plants have been decommissioned. It ends on 2093. Duration of 6 years
6) Site restoration to the agreed end state	It starts in 2093 and ends on 2095. Duration of 2 years.

Table 4.2 – Main work packages for the subprojects dealing with the decommissioning of Angra1, Angra 2 and Angra 3. Note that Angra 3 does not have the work package 1.4 because it will undergo immediate dismantling.

1	**Decommissioning of each CNAAA NPP**
1.1	Shutdown of Reactor
1.2	FDP and Safe Storage Planning
1.3	Modification and Preparation (Transition Period)
1.4	Safe Storage Period
1.5	Decommissioning Planning
1.6	**Plant Decontamination and Dismantling**
1.6.1	D&D of RPV and Internals
1.6.2	D&D of Remaining Systems
1.7	**Site Restoration**
1.7.1	Demolition of plant buildings

The administrative functions, organizational structures, and the resources should be made available on time for all subprojects. The Engineering Support Superintendent (DO) will provide manpower and funds for the subproject planning and preparation. It will constitute a group with expertise in decommissioning that should be responsible for this subproject. This group will grow throughout the process to provide the manpower necessary to implement the other subprojects in the due time. The decommissioning fund will provide the necessary financial resources for all other subprojects.

The review and monitoring of the decommissioning project of the CNAAA will follow the Eletrobrás / Eletronuclear project management system which is based on internal documents [35-37]. These and other internal documents, mostly work instructions, were elaborated based in the Project Management Body of Knowledge - PMBOK and in some of national and international standards [38-40]. The systems for tracking schedule and cost, for keeping records, and for quality assurance will also follow the current Eletrobrás / Eletronuclear systems [26, 35-40].

4.3 Project management organization and responsibilities

Figure 4.1 presents Eletronuclear's organizational chart with the selected units that could participate in the decommissioning process. The decommissioning team is shown in yellow.

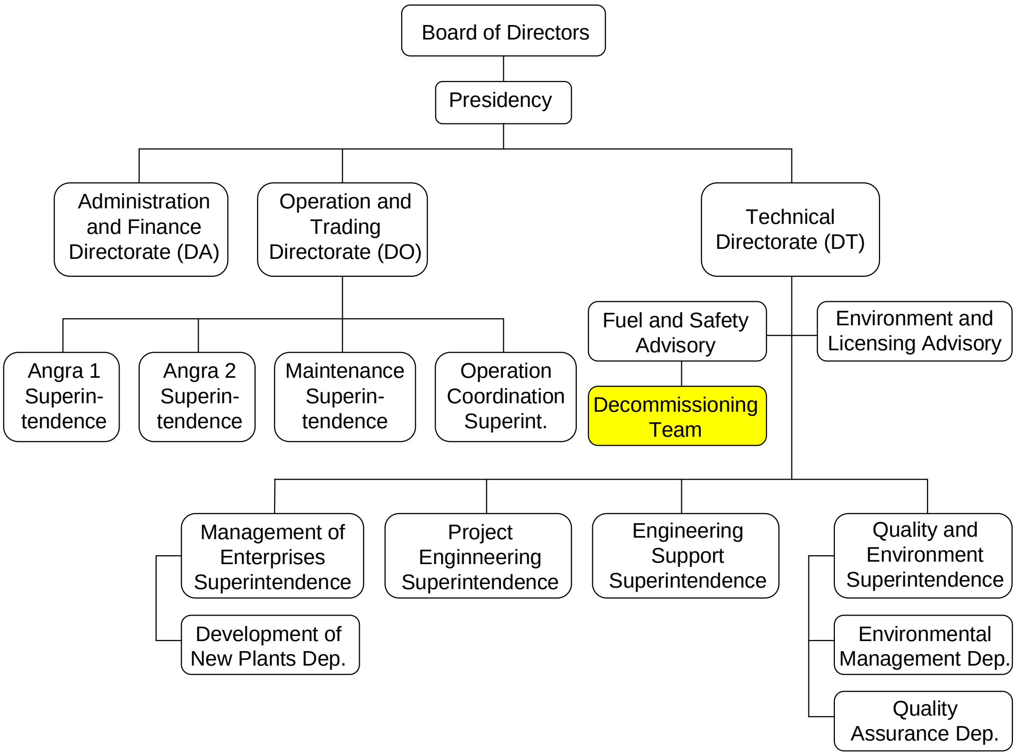

Figure 4.1 – Eletronuclear's simplified organizational chart showing the Decommissioning Team.

The Decommissioning Team will be responsible for the planning and preparation of Decommissioning Program and reviewing and updating the PPD. It will constitute a management group with expertise in decommissioning that will interact with other engineering operations groups of Eletronuclear in other directorates. The team should have about 10 individuals with specific knowledge on decommissioning nuclear power plants. The team reports to the senior management, who is not responsible for day to day operations of the plant [29].

The expertise required during Project 1 (Planning and preparation) includes aspects such as decommissioning, waste management, cost estimation and licensing. The main expertise of the Decommissioning Team is shown in Figure 4.2. Assistance will be needed from personnel with detailed knowledge of the plant, technical experts and planning system specialists and from external contractors [29].

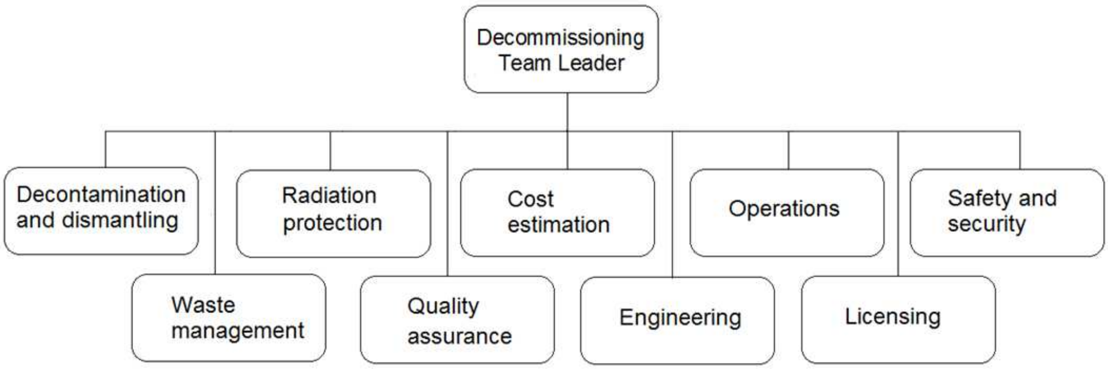

Figure 4.2 – Expertise required from the Decommissioning Team [29].

These other groups will provide engineering support, development, and evaluation of technical solutions for the plant under decommissioning. Their responsibilities include providing engineering solutions for decontamination as well as initial and final dismantling plans, costs follow-ups, safety, and general planning activities.

As the permanent shutdown of Angra 1 approaches, the Decommissioning Team should become the Management of the Decommissioning Program (MDP) of the CNAAA, preferably before operation ceases. The MDP, in consultation with management of the operating organization, should develop and get approved the Final Decommissioning Plan (FDP). As decommissioning proceeds, the MDP will expand to include people with necessary and adequate qualification and experience [29]. In the following sections we describe the current structure of Eletronuclear and how it will interact with the Decommissioning Team and or MDP.

4.3.1 Interaction of the several directorates with the Decommissioning Team

The Technical Directorate (DT) with its many departments (Superintendence and Advisories) will constitute the main organizational group responsible for all the decommissioning process providing expertise and staff for the all 6 projects of the Decommissioning Program. The Technical Directorate (DT) shall have the support of other units to perform the activities of the Decommissioning Program.

The Quality Assurance Superintendence will be responsible to establish a Quality Assurance system in the Decommissioning Program, and will be active since the start of the project.

The Operations and Trading Directorate has the comprehensive responsibility for carrying out the operation and maintenance of the plant under decommissioning. This responsibility is carried out from the shutdown of the reactor and transition period, during all the safe storage period, until the final plant decontamination and dismantling.

In the Operation and Trading Directorate (DO), during its operational life each of the Angra's plant have its own Superintendence. The suggestion is that after its operational life each of the Angra's Superintendence will become the respective Superintendence of the Plant under Decommissioning, which is responsible for the transition and safe storage of the plant. This will assure a smooth transition from operation to safe storage using the same operational team and personnel, and to keeping and using the knowledge of the plant obtained during the operational life of the reactor. This will also help to soften the unemployment stress caused by the permanent shutdown of an active reactor.

The responsibilities of this superintendence includes the preparation of working plans, execution and control of plant modification; elaboration of the items to prepare the decommissioning activities; definition of plant deactivation activities; activities and control definition for the disabled plant safe operation; definition of the plant activities and decommissioning planning; and definition of activities and requirements for site recovery and safety.

The tasks may be performed by own or contractors teams according to the most appropriate conditions at the time, since the decommissioning may last 60 years depending on the adopted strategy.

For the shutdown of a reactor it is estimated that is necessary to have a team of around 100 workers. For the operation of a deactivated plant it is necessary much less personnel. It is estimated around 30 workers due to the concomitant use of personnel involved in the operation of the plants still in operation. For the decontamination and dismantling, the need for staff increases again to around 100 individuals per plant under decommissioning. As the plants are being decommissioned in sequence, according to the chosen strategy, the staff number should remain approximately constant because the specialized personnel will migrate from one plant to another.

The Maintenance Superintendence is shared with all three Angra's plants. The maintenance of the plant during its safe storage period could be shared with the maintenance of the still operational plants reducing the overall cost of the safe storage period.

The Administration and Finance Directorate (DA) will be responsible for the Decommissioning Program funds, from its periodic collection, investment and report to CNEN, assuring a transparent process to accumulate the necessary funds for the execution of the decommissioning process.

4.4 Task management organization and responsibilities

The several projects under the Decommissioning Program will be developed through subprojects which are divided in tasks and work packages. Figure 4.3 presents the basic structure for handling all activities of the project. The control of tasks and work packages the projects will follow the current procedures of Eletronuclear [29, 35-37, 40].

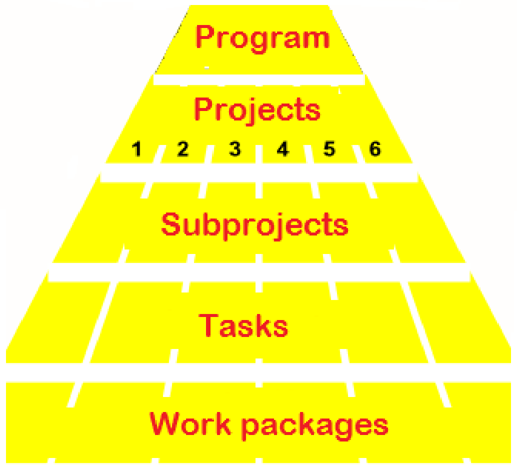

Figure 4.3 – Structure for handling the program [29, 40].

4.5 Safety culture

The Decommissioning Program for the CNAAA will follow all work, project and safety norms of Electronuclear and CNEN. The safety culture is based on the assertion that safety comes first. All Eletronuclear employees, from the president and directors to engineers, technicians and personnel performing basic activities must pay attention to safety and consider it above all other issues.

The Decommissioning Directorate will establish proper training to all employees (from Eletronuclear and DGCs) to call attention to the necessity that high levels of safety must be maintained during this new phase of the plant life cycle. To monitor the safety culture of the decommissioning crew the management will utilize the following indicators: the number of work accidents (industrial or radiological), number of contamination incidents, and the radiation dose absorbed by workers. Any increase in these indicators will signal a deterioration of safety culture among the employees and will require proper correction actions.

The DCG organizations and external collaborators will be also required to have and maintain high levels of safety culture. The safety culture indicators will be monitored for all DCG employees too.

4.6 Training

The Decommissioning Directorate will enforce proper training for all employees to avoid radiological and industrial risks. Since the decommissioning activities differ from the operation of nuclear power plant, all CNAAA employees undertaking decommissioning activities will have to obtain proper training. The Eletronuclear training department will prepare and deliver specific courses covering technical and management problems related to decommissioning.

All external collaborators from the DCGs will undertake decommissioning training from the Eletronuclear training department before entering in any work activities.

4.7 Contractor support

Eletronuclear will take use a decommissioning general contractor (DGC) for performing decommissioning activities and specialty contractors will perform specialized tasks during the decommissioning activities. These contractors will have to adhere to all norms and procedures of Eletronuclear which will conduct the necessary supervision and verifications. The project managers of the CNAAA decommissioning program, under the Decommissioning Directorate (DD), will contract the DGCs organizations. These DGCs will perform tasks such as decontamination of systems and structures, dismantling, packaging of radioactive wastes, plant and environmental surveys, etc.

Projects 2 to 6 shown in Table 4.1 will be undertaken by DGCs. ETN will provide oversight and retain overall responsibility for ensuring that all regulatory requirements are met. The DGCs will provide a project manager and engineering and support staff for each of the projects. ETN will provide the labor force to implement the activities during each project.

4.8 Schedule control

The schedule control will follow the procedures from Eletronuclear [35-37]. It is based on the work breakdown structure (WBS) of the main activities which is developed during the cost estimate process of the decommissioning and reviewed periodically. The developed WBS will define activities down to the level of work package shown in Figure 4.3. They specify the lowest level of activity requiring actions and controls from the decommissioning management. After sequencing the activities, defining their durations, assessing uncertainties and contingencies, the projects will be ready to be executed. The project management controls to ensure their adherence to the established schedule will follow the Eletronuclear procedures of project management [35-37].

5 DECOMMISSIONING ACTIVITIES

5.1 Introduction

This Chapter presents the main activities and respective sequence to carry out the decommissioning process of the CNAAA [1, 2, 7]. In the strategy considered for decommissioning the CNAAA and described in sect. 3.3.2, Angra 1 and Angra 2 will undertake deferred dismantling and Angra 3 will undertake immediate dismantling. The end state of the CNAAA site is unrestricted use by the public. This decommissioning strategy divided the decontamination and dismantling (D&D) period for the CNAAA into 2 large groups of activities: a) the removal of the reactor internals, vessel and large components, and b) decontamination, dismantling and removal of contaminated systems and structures. The activities of item (a) will be carried out in sequence for the three units. The support buildings of the CNAAA (Waste Management Center, Complementary Dry Storage Unit, Radiation Monitoring and Calibration Laboratory and Environmental Monitoring Laboratory) will be decommissioned concurrently during the D&D phase for the three plants.

Section 5.2 presents the decommissioning activities for each nuclear power plant of the CNAAA. Sections 5.3 to 5.6 presents the decommissioning activities for the support buildings and the remaining site. The decommissioning activities will be in accordance with requirements established by CNEN [1, 7] and international standards and guides.

5.2 Decommissioning activities for the CNAAA

This section presents the major decommissioning activities for each nuclear power plants and support facilities in the CNAAA. The activities follow the chosen strategy for decommissioning of the CNAAA presented in Chapter 3 [41]. The main phases of the decommissioning activities for each unit of the CNAAA are:

a) Plant Shutdown – at the end of operations, the nuclear power plant is permanently shutdown.
b) Transition period - including the final portion of the commercial operation of the nuclear power plants, the safe storage planning and placing the three plants into safe storage;
c) Safe storage period – only for Angra 1 and Angra 2 which undertake deferred dismantling;
d) Decommissioning planning - planning the details for decontamination and dismantling of each unit near the end of the safe storage period;
e) Decontamination and dismantling period – removing the radioactive material to meet the unrestricted release criteria; and
f) Demolition and site restoration – demolition of uncontaminated buildings and site restoration.

Figure 5.1 presents the overall schedule for the decommissioning activities planned for the CNAAA. In the following sections we describe each of these phases for Angra 1, 2 and 3.

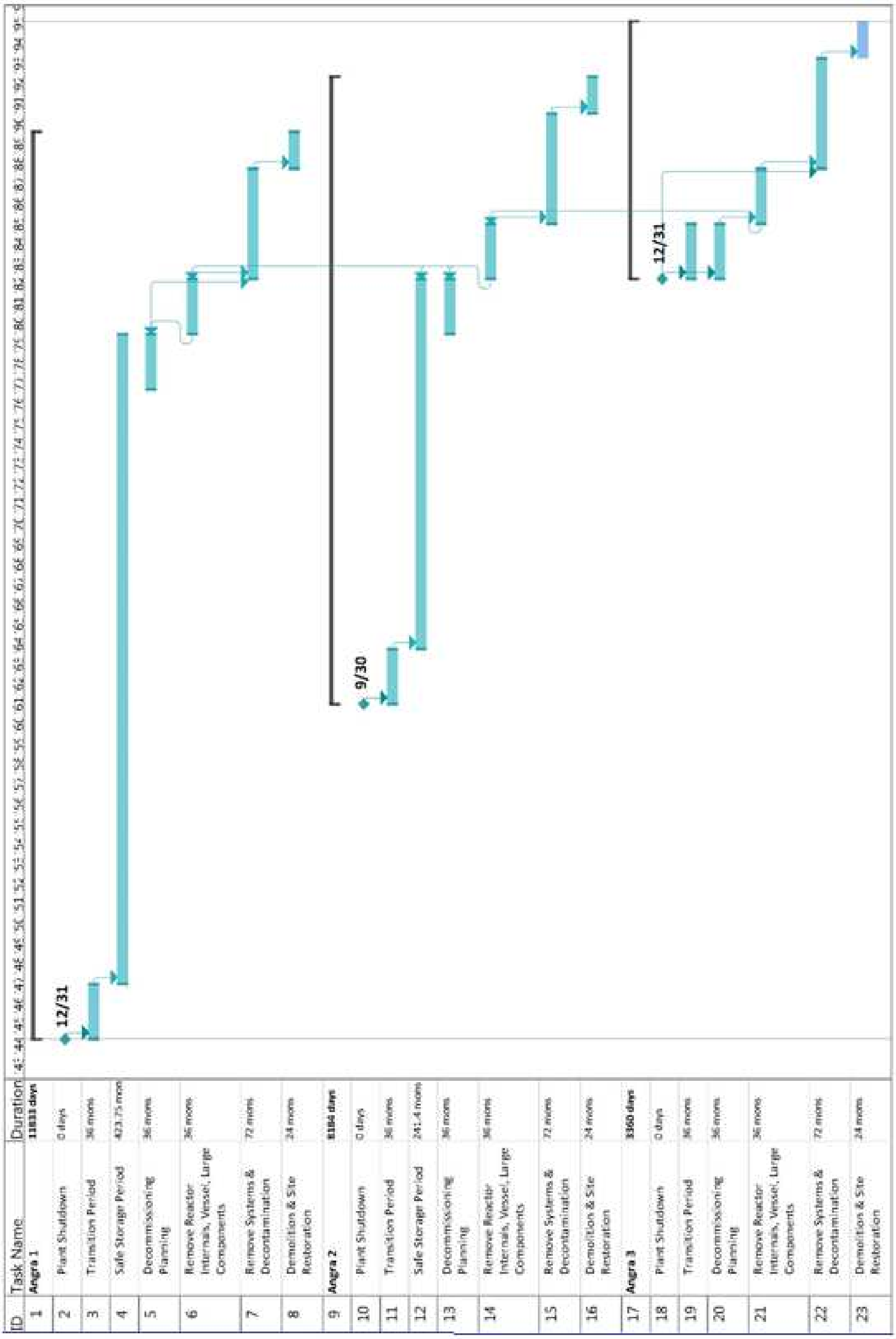

Figure 5.1 – Schedule for decommissioning the CNAAA site [41].

5.2.1 Decommissioning activities for Angra 1

In this section, we present the 6 main activities to be performed to carry out the decommissioning process of Angra 1. The Angra 1 buildings under decommissioning are the Reactor Building, Safety Building, North Auxiliary Building, South Auxiliary Building, Turbine Generator Building and the Fuel Handling Building.

5.2.1.1 Plant Shutdown

At the end of operations the nuclear power plant is permanently shutdown and starts the activities aiming at achieving the end state defined in the decommissioning program.

5.2.1.2 Transition period for Angra 1

The transition period from commercial operation to the decommissioning of Angra 1 will last three years. At the end of this period, Eletronuclear will have an approved Final Decommissioning Plan (FDP) [1]. Transition activities occur between operation and the placement of Angra 1 in a safe and stable condition before undergoing safe storage. During this period numerous plans are prepared and plant modifications are implemented to adapt Angra 1 to new objectives and requirements [22, 31]. The activities carried out during the transition phase are divided into two groups: the safe shutdown activities and the decommissioning planning and safe storage preparation activities.

The safe shutdown activities will include draining systems, decontaminating some areas, treatment of operational waste, removal of the spent fuel and disposal of operational waste, removing sources, removing hazardous material, etc. The decommissioning preparation activities will include detailed decommissioning planning, decontaminating some areas, retiring minor equipment and systems, conducting radiological and waste characterizations, etc. The removal and dismantling of major components of Angra 1 are left to the decontamination and dismantling period. Table 5.1 presents the main activities necessary to meet the goals of this phase.

Table 5.1 – Safe shutdown activities performed in the transition phase [31].

Activities
• Removal of spent fuel.
• System cleanout operation – this includes primary circuit drainage, chemical decontamination, removal of water and other operating fluids, drainage and de-energizing of contaminated system.
• Treatment, conditioning and disposal of operational waste.
• Decontamination or fixing of contamination – decontamination to reduce

occupational exposure during future decommissioning activities, reduce potential contamination risks, system decontamination to reduce general radiation level in work areas.
• Removal of hazardous material such as asbestos, lead, PCB, chemicals, mercury.
• Identification of systems that will support decommissioning activities.
• Preparation of rooms and buildings during transition – define which rooms and buildings may have routine, periodic or no access.
• Protection from external and internal events – physical protection, fire prevention, flood prevention, sealing protection.
• Removal of minor components.

The spent nuclear fuel coming out of the reactor will be stored for at least three years in the spent fuel pool of the Fuel Building of Angra 1 until sufficient decay heat occurs. After that, the spent fuel will be removed to a dry storage facility.

The turbine building may be emptied in order to provide space for future decommissioning activities [31]. To perform these activities, it will be necessary to verify the interdependencies listed in Chapter 3 to avoid affecting the normal operation of both Angra 2 and Angra 3 power plants.

To perform the operational work of this phase, Eletronuclear will use professionals remaining from the Angra 1 operational staf, and from specialized contractors to carry out specific decontamination and dismantling activities, environmental surveys, etc. Table 5.2 shows the work tasks planned to be performed by the Angra 1 crew and by external contractors for the transition phase to support the decommissioning activities.

At the end of the transition phase, Angra 1 transition will enter the safe storage period.

Table 5.2 – Decommissioning activities performed during the transition phase

Activities
• Facility and site characterization.
• Preparation of the final decommissioning plan and supporting documents.

• Reorganization of staff to support decommissioning.
• Preparation of supporting engineering and work documents.
• Characterization and inventory of radioactive material – radiological and environmental surveys.
• Procurement of long lead items and equipment.
• Waste management planning.
• Preparation for safe storage.
• Upgrade or modify infrastructure to support decommissioning.

5.2.1.3 Safe storage period for Angra 1

The safe storage period of Angra 1 is very long and will last 34 years. The goals of this phase are placing Angra 1 into a condition for safe long-term storage, reduce maintenance needs during this period, and prepare the plant for the next decommissioning phase of decontamination and dismantling of systems, components and structures [24]. The main activities to be performed during this period are conducting maintenance and surveillance activities in the buildings, rooms and systems, monitoring the radiation and environment conditions of the plant, maintaining it in a safe condition, and providing physical security during this long period [23, 24].

The long safe storage period allows for the radioactive decay of the reactor pressure vessel and its internals, which are the most radioactive items in the decommissioning process. Near the end of the safe storage period the planning for the D&D phase will be started. This effort will be facilitated by the radioactive decay of systems and structures [24].

Due to the long safety storage period of Angra 1 care will be taken to ensure that knowledge about the plant is not lost. A system of knowledge management will be implemented to collect information from the operation staff and store it for utilization during the D&D planning phase [24].

The significant safety issues during the safe storage period are: maintaining access control to prevent unauthorized people from entering the safe storage areas; potential failure of barriers used to confine radioactive materials, possible changes in localized contamination level;, deterioration of buildings, structures, systems and equipment with impact on worker access, the environment, or on final D&D activities; maintaining physical structure of the buildings, and spread of contamination during maintenance and surveys.

As time allows other activities will occur during this period such as removal of non-essential systems for the safe storage period or for the D&D activities, reduction of the radiological footprint, decontamination of areas, additional radiological surveys, removal of non-radiological hazards, and demolition of released portions of the facility [24].

5.2.1.4 Decommissioning planning for Angra 1

The planning phase for the decontamination and dismantling period will start 3 years before the end of the safe storage period of Angra 1. This planning must be coordinated with the decommissioning activities for Angra 2 and 3.

The planning phase includes management and technical or operation activities. The management activities include administrative activities, preparing licensing and permitting documentation, definition of the main activities sequence, analysis of the companies that will participate in the process, contracting consulting and services firms, contracting the DGC, purchasing equipment and tools, studying legal aspects of decommissioning (taxes, insurance, etc), and defining radioactive disposal sites and waste acceptance conditions.

The technical and operation activities include preparing the site for the D&D phase. For Angra 1 an important activity of this period will be defining and detailing the technology to perform the upcoming D&D activities. The technology for decommissioning is evolving as many nuclear power plants undergo decommissioning today and it will be different in 2079 when it is foreseen the beginning of the decontamination and dismantling activities for Angra 1 [42]. Since these D&D activities will be performed in series for all 3 nuclear power plants of the CNAAA, as defined in Chapter 3, the technologies to be utilized to perform D&D for the 3 nuclear power plants will be defined and detailed during this decommissioning planning period.

Other important activities that will be performed in this period will be evaluating and estimating the D&D waste inventory, preparing the required infrastructure at the site to support decontamination and dismantling activities, and conducting various surveys of the plant. The Table 5.3 presents the infrastructure and plant systems that may require modifications to support the upcoming D&D activities [24].

The Eletronuclear personnel will conduct the activities related to management oversight of contracted companies which will undertake the operational and technical activities.

Table 5.3 Infrastructure and plant system modifications that may be required to support the D&D activities [24].

• Ventilation systems
• Personal monitoring facilities

• Protective clothing change rooms to accommodate a large number of workers
• Waste handling facilities
• Lay down areas to allow temporary storage of waste boxes and large components
• Machine shop to support the needs of the dismantling crew
• Laundry facilities to process protective clothing and cleaning respirators
• Radiological analytical capability to analyze samples taken during dismantling and the final survey
• Security, access control to decommissioning areas, and shipment and reception facilities to control the flow of equipment, materials in the decommissioning areas
• Drainage systems or facilities to accumulate and treat liquid waste streams
• Lighting systems, fire protection systems, alarm systems, power supply systems for decommissioning activities, lifting equipment, and support infrastructure for D&D activities (compressed air, water, etc)

5.2.1.5 Decontamination and dismantling period for Angra 1

After the safe storage period and D&D planning phases, the decontamination and dismantling activities will start. The objective is to reduce the radiation exposure to acceptable levels aiming at the unrestricted use of the CNAAA site in accordance with the approved FDP [1, 2]. The contaminated systems, components and structures will be decontaminated or removed through dismantling, packaging, and shipping of waste to an offsite disposal facility [23, 42, 43]. During these activities, radiation monitoring is carried out to ensure the safety of the worker, general public and environment; and to characterize the generated waste. Following these activities, a comprehensive final radiological survey will be conducted to verify that the criteria established for the CNAAA end state has been met. This period has 4 principal groups of activities: health and safety monitoring and surveying; decontamination activities; dismantling activities; and waste processing including classification, packaging and transportation to offsite disposal facilities [23, 42].

For the implementation of this phase in the CNAAA, the activities are divided into two major sets and will take approximately 9 years. These two sets are: a) removal of reactor internals, reactor vessel and other large components taking about 3 years; and b) decontamination, dismantling, and removal of remaining contaminated systems and structures, taking about 6 years. This approach was chosen because the first item is the most complex and difficult set of decommissioning activities in a nuclear power plant [23, 42, 43] requiring specialized experience and equipment. As described in Chapter 3 of this document, this activity will be performed in series for the three nuclear power plants.

Although these activities will take place in 2079, we present here a rapid overview of the current (2017) practice to show the management their complexity. In 2017 plant characterization is performed through sampling equipment, spectrometers and radiological measuring equipment, and physical and chemical analysis and separation equipment [42]. For dismantling systems and equipment there are in 2017 several cutting techniques: mechanical techniques, thermal techniques and hydraulic techniques [42]. The current (2017) techniques to perform decontamination are sweeping or vacuuming, application of cleaning solutions such as detergents, solvents, hydrolases (very high pressure water jets), etc., use of high pressure liquid jets, use of strippable plastic membranes, blasting with wet or dry high velocity particles, mechanical removal techniques, shaving, use of frozen CO2 and erosion cavitation processes [42]. Eletronuclear will contract specialized companies to conduct these activities.

In the next two subsections we describe these sets of activities planned for Angra 1.

5.2.1.5.1 Removal of reactor internals, reactor vessel and other large components for Angra 1

The first set of activities will be the decontamination, dismantling and removal of large equipment from Angra 1, namely the internals of the pressure vessel, the pressure vessel, steam generators, pressurizers, reactor coolant pumps, large pipes, and spent fuel racks. This is the critical path activity for the decommissioning of the three nuclear power plants in the CNAAA strategy. A contractor with specialized experience and equipment will perform these activities.

The D&D activities planned for each system or major piece of equipment are decontamination (if beneficial), dismantling, packaging and removal from the site. The first equipment to be removed will be the reactor internals and vessel because of their high dose rates and radioactivity. There are several technologies that can be used to perform this activity [42], but the selection of this technology is left to be defined during the decommissioning planning activity, as was explained in section 5.2.1.4. In sequence, the other large components will be decontaminated, segmented, packaged, and removed. Temporary radiation protection methods will be used where practical and necessary for ALARA purposes during these activities. Other necessary safety actions are described in section 5.2.1.5.2.

Table 5.4 presents specific activities for decontamination, dismantling, packaging and removal of systems and large components. Table 5.5 identifies the large components for the three power plants located at the CNAAA.

5.2.1.5.2 Removal of other contaminated systems at Angra 1

The next set of activities will be the decontamination, dismantling and removal of other contaminated systems. These activities will generate large amounts of waste in the form of metallic pieces, airborne radioactive particulates and liquid streams. All this waste will be treated, packaged and transported to the appropriate offsite waste disposal facility.

Table 5.4 – Typical activities for decontamination, dismantling, packaging and removal of systems and large components.

• Cutting reactor internals and reactor pressure vessels.
• Packaging internals and reactor pressure vessels.
• Removal and segmentation of the steam generators and pressurizers.
• Packaging the steam generator and pressurizer waste.
• Cutting and segmenting of other major components.
• Packaging of the major components for offsite disposal.
• Packaging of miscellaneous parts of equipment, cables, pipes, etc. associated with the above activities.
• Cleanup and decontamination of areas.

Table 5.5 – Removal of large contaminated and activated components from Angra 1, Angra 2, Angra 3, and supporting buildings [41].

Large components	Activitities
Large components for Angra 1, 2 and 3: • Reactor Internals; • Reactor pressure vessel; • Steam generators; • Pressurizers; • Reactor coolant pumps; • Large pipes; • Spent fuel racks.	Decontamination, dismantling, packaging and removal.
Supporting buildings: • Reactor pressure vessel; head (DIGV); • Steam generators (DIGV).	Decontamination, dismantling, packaging and removal.

5.2.1.5.3 Contaminated structures

The general strategy will be undertaking structure decontamination procedures followed by radiation surveys to minimize unnecessary decontamination work and generation of radioactive waste. Once a structure is considered released from radiological controls, it will be assigned as an uncontaminated structure for future conventional demolition.

Table 5.6 presents the main D&D activities that will be performed on the structures of Angra 1. The main D&D procedures will be considering highly activated or contaminated structures as radioactive waste. Thus these structures will be dismantled, packaged, and removed as radioactive waste. For large contaminated structures and surfaces it may be used explosive demolition, concrete wall and floor shaving, hydrolase, or wire saw.

Table 5.6 - Main D&D activities on the Angra 1 structures [41].

Removal of contaminated steel liner concrete, contaminated reinforced concrete
Explosive demolition of contaminated concrete
Remove contaminated block wall
Shave Concrete Walls
Shave Concrete Floors

Hydrolase large contaminated surfaces
Wire Saw Contaminated Concrete

These activities require radiation protection measures such as protective clothing, step-off pads and exit monitoring, and the necessary infrastructure presented in Table 5.2. The working areas will require control procedures such as local particulate airborne control, ventilation systems, superfine water misting and portable containments. More details are found in Chapter 11.

Table 5.7 presents the structures in the Angra 1 power plant which will undergo decontamination. It presents the total area of each building that will be decontaminated and the procedure defined to be used. For walls and floor, the decontamination procedure will be shaving the concrete up to 0.5 cm depth. The activated concrete bioshield will not undertake decontamination. It will be cut into pieces through wire saw and removed as radioactive waste.

Typical decontamination techniques for the decontamination of floors and walls are to use a concrete scabbler or shaver. For activated material, it can be removed using diamond wire cutting or conventional concrete demolition techniques (jack hammer). The main D&D activities on the Angra 1 structures are removal of contaminated or activated steel liners and reinforced concrete, shaving or scabblling of contaminated concrete walls and floors and wire saw cut or jackhammer activated concrete [41].

Table 5.7 – Decontamination of structures of Angra 1 and activity description [41].

Structure	Name	Material description	Quantity	Units	Activity description
ERE	Reactor Building	Concrete Wall Contamination	1.233	m2	Shave Concrete Walls
ERE	Reactor Building	Concrete Floor Contamination	1.272	m2	Shave Concrete Floors
EAN	North Auxiliary Building	Concrete Wall Contamination	555	m2	Shave Concrete Walls
EAN	North Auxiliary Building	Concrete Floor Contamination	482	m2	Shave Concrete Floors
EAS	South Auxiliary Building	Concrete Wall Contamination	754	m2	Shave Concrete Walls
EAS	South Auxiliary Building	Concrete Floor Contamination	1.233	m2	Shave Concrete Floors
ESE	Safety Building	Concrete Wall Contamination	133	m2	Shave Concrete Walls

ESE	Safety Building	Concrete Floor Contamination	630	m2	Shave Concrete Floors
ECB	Fuel Handling Building	Concrete Wall Contamination	1.000	m2	Shave Concrete Walls
ECB	Fuel Handling Building	Concrete Floor Contamination	1.000	m2	Shave Concrete Floors
ERE	Reactor Building	Bioshield Activated Concrete	800	m2	Wire Saw Concrete

5.2.1.5.4 Contaminated systems

Table 5.8 identifies the internally contaminated systems which will be removed from the Angra 1 nuclear power plant. The table provides a system identification and the type of items to be removed. There may be portions of systems that pass through contaminated areas and are externally contaminated. These systems are not included in this table.

The general strategy for D&D activities for systems and equipment will be removal and disposal at appropriate facilities outside of the CNAAA site. This strategy will minimize decontamination and rely on the use of radiological controls during the removal of systems and equipment.

These activities require radiation protection measures such as personnel protective equipment, standard radiation protection procedures and exit monitoring. The working areas will require additional control procedures such as local particulate airborne control, ventilation systems, superfine water misting and local contamination controls at disassembly points. More details are found in Chapter 11.

5.2.1.6 Demolition and site restoration for Angra 1

The demolition and site restoration for Angra 1 will start after finishing the D&D activities in the nuclear power plant, and will last approximately two years. The details of these activities are given in section 5.5.

Table 5.8 – Contaminated systems to remove from Angra 1 nuclear power plant and corresponding removal activities [41].

System identification	System Name	Activity
AAC	Aux Bldg Controlled Access Ventilation	Remove contaminated HVAC ducts
ASC	Control Room, Fuel Handling, Service Water Intake, Chlorination Ventilation	Remove contaminated HVAC ducts
CQV	Chemical & Volume Control System	Remove contaminated pipe, valves, pumps, heat exchangers, etc.
DEP	Equipment Drains Primary Plant	Remove contaminated pipe, valves, pumps, heat exchangers, etc
DES	Equipment Drains Secondary Plant	Remove contaminated pipe, valves, pumps, heat exchangers, etc
ED	Electrical Distribution	Remove contaminated electrical cable tray
PCU	Spent Fuel Pool Cooling	Remove contaminated pipe, valves, pumps and heat exchangers
PGV	Steam Generator Blowdown	Remove contaminated pipe, valves, pumps, tanks and heat exchangers.
RCR	Residual Heat Removal	Remove contaminated pipe, valves, pumps and heat exchangers.
SAP	Primary Sampling	Remove contaminated valves, pipes and tanks.
SEC	Containment Spray	Remove contaminated pipe, valves, pumps and tanks.
SEV	Extraction Steam	Remove contaminated pipe, valves, moisture separatores, reheaters and feedwater heaters.
SRB	Boron Recycle	Remove contaminated pipe, valves, pumps, tanks and miscellaneous equipment.
SRC	Component Cooling	Remove contaminated pipe, valves, pumps, tanks, heat exchangers and miscellaneous equipment.
SRR	Reactor Cooling System	Remove contaminated pipe, valves, pumps and tanks.
SVP	Main Steam	Remove contaminated pipes, valves and pumps.
TRG	Gaseous Waste Treatment	Remove contaminated pipes, valves and tanks.
TRL	Liquid Waste Treatment	Remove contaminated pipes, valves and tanks.

5.2.2 Decommissioning activities for Angra 2

In this section we present the 6 main activities to be performed to carry out the decommissioning process of Angra 2. This unit will also undergo deferred dismantling, similar to Angra 1. Since its decommissioning activities are similar to those presented in section 5.2.1 for Angra 1, they will not be detailed in this section. The buildings undergoing decommissioning in Angra 2 are the Reactor Building, Reactor Building Annulus, Main Steam and Feedwater Compartment, Equipment Lock, Auxiliary Building, Gas Discharge Chimney, and Turbine Generator Building.

5.2.2.1 Plant Shutdown

At the end of Angra 2 operation it will be permanently shutdown and begins the activities aiming at achieving the end state of unrestricted release.

5.2.2.2 Transition period for Angra 2

The transition period from commercial operation to the decommissioning of Angra 2 will last 3 years. The activities carried out during the transition phase are also divided into two groups: the safe shutdown activities and the decommissioning preparation activities. Details of these activities are given in section 5.2.1.2.

The spent nuclear fuel coming out of the reactor will be stored for at least three years in the spent fuel pool of Angra 2 until sufficient decay heat occurs. After that, the spent fuel will be removed to a dry storage facility.

To perform the operational work of this phase, Eletronuclear will use professionals remaining from the Angra 2 operational crew, and from specialized contractors to carry out specific decontamination and dismantling activities, environmental surveys, etc. Table 5.1 shows the activities that will be performed during the transition period in Angra 2. Table 5.2 shows the work tasks planned to be performed by the Angra 2 crew and by external contractors for the transition phase to support the decommissioning activities.

At the end of the transition phase, Angra 2 will enter the safe storage period.

5.2.2.3 Safe storage period for Angra 2

The safe storage period of Angra 2 will last 20 years. The goals of this phase are placing Angra 2 into a condition for safe long-term storage, reduce maintenance needs during this period, and prepare the plant for the next decommissioning phase of decontamination and dismantling of systems, components and structures [24]. The main activities to be performed during this period are similar to those described in section 5.2.1.3 for Angra 1. They include conducting maintenance and surveillance activities in the buildings, rooms and systems; monitoring the radiation and environment conditions of the plant; maintaining it in a safe condition, and providing physical security during this long period [24].

5.2.2.4 Decommissioning planning for Angra 2

The planning phase for the decontamination and dismantling period for Angra 2 will start three years before the end of the safe storage period of Angra 2. The objective of this phase is to plan the D&D activities for Angra 2. The activities of this period for Angra 2 is similar to those described in section 5.2.1.4 for Angra 1. Table 5.3 presents the required infrastructure and plant modifications to support the upcoming D&D activities for Angra 2 [24].

The Eletronuclear personnel will conduct the activities related to management oversight of contracted companies which will undertake the operational and technical activities.

5.2.2.5 Decontamination and dismantling period for Angra 2

After the safe storage period and D&D planning phases, the decontamination and dismantling activities will start in Angra 2. Its objective is similar to that for Angra 1 described in section 5.2.1.5, i.e., to reduce the radiation exposure to acceptable levels aiming at the unrestricted use of the CNAAA site in accordance with the approved FDP. The contaminated systems, components and structures will be decontaminated or removed through dismantling, packaging, and shipping of waste to an offsite disposal facility [23, 42, 43]. During these activities radiation monitoring is carried out to ensure the safety of the workers, general public and environment; and to characterize the generated waste. Following these activities, a comprehensive final radiological survey will be conducted to verify that the criteria established for the CNAAA end state has been met.

In the next section we describe the two major sets of activities related to D&D planned for Angra 2 as shown in Figure 5.1.

5.2.2.5.1 Removal of reactor internals, reactor vessel and other large components for Angra 2

The first set of activities will be the decontamination, dismantling and removal of large equipment from Angra 2, namely the internals of the pressure vessel, the pressure vessel, steam generators, pressurizers, reactor coolant pumps, large pipes, and spent fuel racks. This activity will start in 2082 and will last three years. It is the critical path activity for the decommissioning of the three nuclear power plants in the CNAAA strategy. A contractor with specialized equipment will perform these activities.

The D&D activities planned for each system or major piece of equipment are decontamination (if beneficial), dismantling, packaging and removal from the site. The first equipment to be removed will be the reactor internals and vessel because of their high dose rates and radioactivity. Table 5.4 presents specific activities for decontamination, dismantling, packaging and removal of systems and large components, and Table 5.5 identifies the large components for the three power plants located at of the CNAAA.

5.2.2.5.2 Removal of other contaminated systems for Angra 2

The next set of activities will be the decontamination, dismantling and removal of other contaminated systems. These activities will generate large amounts of waste in the form of metallic pieces, airborne radioactive particulates and liquid streams. All this waste will be treated, packaged and transported to the appropriate offsite waste disposal facilities.

5.2.2.5.3 Contaminated systems

Table 5.9 identifies the internally contaminated systems which will be removed from the Angra 2 and 3 nuclear power plants. The table provides the system identification and the type of items to be removed. There may be portions of systems that pass through contaminated areas and are externally contaminated. These systems are not included in this table.

The general strategy for D&D activities of systems and equipment will be the removal and disposal in appropriate deposits outside of the CNAAA site. The strategy will minimize decontamination, and use of radiological controls during removal of systems and equipment.

These activities require radiation protection measures such as personnel protective equipment, step-off pads and exit monitoring. The working areas will require control procedures such as local particulate airborne control, ventilation systems, superfine water misting and contamination control enclosures. More details are found in Chapter 11.

Table 5.9 – Contaminated systems to remove from Angra 2 and Angra 3 and corresponding removal activities [41].

System Identification	System name	Activity
B	Power Transmission and Unit Auxiliary Power Supply	Remove contaminated electric cable tray
FA	Storage of Fuel Assemblies	Remove contaminated pumps
FB	Handling of Fuel Assembly & other Reactor Core Internals	Remove contaminated pumps, tanks and crane
G	Water Supply and Discharge	Remove contaminated pumps and tanks
JD	Control and Shutdown Elements	Remove control rods, borating system (pumps and tanks)
JE	Reactor Coolant System	Remove pumps, tanks, pipes and miscellaneous equipment
JM	Containment and Internals	Remove contaminated pumps, pipes and tanks
JN	Residual Heat Removal System	Remove contaminated pumps, tanks and pipes
KA	Component Cooling System	Remove contaminated pumps, tanks and heat exchangers
KB	Coolant Treatment	Remove contaminated pumps, tanks and heat exchangers
KJ	Refrigerant System	Remove contaminated tanks
KP	Radioactive Waste Processing	Remove contaminated pumps, tanks and miscellaneous equipment
KT	Nuclear Collecting & Drain System	Remove contaminated pumps, tanks and miscellaneous equipment
KU	Nuclear Sampling System	Remove contaminated tanks
PE	Service Cooling Water System Secured Plant	Remove contaminated pumps
QK	Chilled Water System	Remove contaminated pumps and tanks
SR	Workshop, Stores, in Controlled Area	Remove contaminated pumps / tanks

5.2.2.5.4 Contaminated structures

The general strategy for contaminated structures will be to decontaminate the contaminated areas followed by radiological surveys to verify the areas meet the unrestricted release criteria. Table 5.7 presents the main D&D activities that will be performed on the contaminated and activated structures of Angra 2.

Table 5.10 presents the structures in the Angra 2 which will require decontamination or removal. It provides the total area of each building that will be decontaminated and the procedure defined to be used.

Table 5.10 – Decontamination of structures of Angra 2 and 3 and activity description [41].

Structure	Name	Description	Quantity	Units	Activity description
UJA	Reactor Building	Concrete Wall Contamination	1.625	m^2	Shave Concrete Walls
UJA	Reactor Building	Concrete Floor Contamination	12.860	m^2	Shave Concrete Floors
UKA	Aux Building	Concrete Wall Contamination	96	m^2	Shave Concrete Walls
UKA	Aux Building	Concrete Floor Contamination	2.403	m^2	Shave Concrete Floors
UMA	Turbine Building	Concrete Wall Contamination	-	m^2	Shave Concrete Walls
UMA	Turbine Building	Concrete Floor Contamination	-	m^2	Shave Concrete Floors
UKH	Chimney	Concrete Wall Contamination	7.486	m^2	Shave Concrete Walls
UKH	Chimney	Concrete Floor Contamination	886	m^2	Shave Concrete Floors
UJA	Reactor Building	Bioshield	1.256	m^3	Wire Saw Concrete

5.2.2.6 Demolition and site restoration for Angra 2

The demolition and site restoration for Angra 2 will start in 2091 after finishing the D&D activities in the nuclear power plants, and will last approximately 2 years. The details of these activities are given in section 5.5.

5.2.3 Decommissioning activities for Angra 3

The decommissioning activities for the Angra 3 power plant are similar to those detailed in section 5.2.3 for the Angra 2 power plant, except for the non-existence of the safe storage period. Thus Angra 3 will undergo an immediate decontamination and dismantling.

The main activities for Angra 3 will be the transition phase, D&D planning which starts together with the transition phase, the D&D phase, and the final phases of building demolition and site restoration. The management approach for carrying out the decommissioning process of Angra 3 will be similar to those used previously for Angra 1 and Angra 2. The Eletronuclear personnel will be responsible for the management and planning activities with contractors being responsible for D&D activities and technical surveys.

5.2.4 Decommissioning activities for the support facilities

The remaining areas to undergo decommissioning are the support facilities namely the Waste Management Center, the Complementary Dry Storage Unit, the Radiation Monitoring and Calibration Laboratory and the Environmental Monitoring Laboratory. Throughout the decommissioning process, these buildings will be used to support the commercial operation of Angra 2 and Angra 3 nuclear power plants, and some decommissioning activities. Some of these buildings will be decommissioned concurrently during the decommissioning of the three nuclear power plants when personnel become available.

The general decommissioning approach for these support buildings will be to decontaminate any contaminated structures and remove any contaminated systems, equipment or material.

The two steam generators and reactor pressure vessel cover from Angra 1 will be size reduced, packaged and removed to an offsite radioactive disposal site.

The Eletronuclear personnel will be responsible for the management and planning activities with contractors being responsible for D&D activities, technical surveys, and waste transportation.

5.3 Activities related to soil contamination

There is no surface and subsurface soil contamination at the CNAAA site. If contaminated soil is encountered later, the activities to remove this material will be discussed in later versions of this document.

5.4 Activities related to surface water and groundwater

There is no surface water and ground water contamination at the CNAAA site based on current surveys. If contaminated surface water or ground water is encountered later, the activities to remediate this situation will be discussed in later versions of this document.

5.5 Demolition of buildings and site restoration period

The goals of this phase are to provide a site that can be reused for other activities without any need for radiological controls. The main activities are conventional dismantling and demolition of the buildings after being released from regulatory control, preparation of the site for another particular use, and final approval of completion of decommissioning by the regulatory agencies.

The first activity will be the demolition of all remaining buildings of the CNAAA. This is a conventional demolition since these buildings meet the unrestricted release criteria. The waste generated in this process will be sent to conventional waste disposal sites. To reduce the total volume of refuse generated in the conventional demolition, the material will be sorted out for possible recycling.

Since the three nuclear power plants will have very different dates for the end of commercial operation, the conventional demolition will be initiated at different times. Some activities of conventional building demolition will occur in parallel with nuclear D&D activities occurring at the Angra 3 power plant and the support facilities.

The chosen decommissioning strategy defined that such activities will start only after completion of the D&D phases of each nuclear power plant, see Chapter 3. Thus Angra 1 and Angra 2 nuclear power plants will start their conventional demolition and some activities will occur in parallel with ongoing nuclear D&D activities on Angra 3. Table 5.11 presents the quantities of clean (conventional) structures that will be removed from the Angra 1 power plant, and Table 5.12 presents similar data for the Angra 2 and Angra 3 power plants. Table 5.13 presents the large components from these power plants which will be removed such as turbine generator, condensers, transformers, diesel generators, etc.

The final set of activities will be conducting radiation and environmental surveys of the site to verify its compliance with the status of unrestricted release of the site to the public.

The Eletronuclear personnel will be responsible for the management and planning activities with specialized firms being responsible for D&D activities, technical surveys, conventional demolition, and waste transportation.

5.6 Decommissioning schedules

Figure 5.1 shows the schedule for the decommissioning of the CNAAA site [22]. The main set of activities or tasks are the transition period (three years), safe storage period (from zero to thirty-four years), D&D planning (three years), removal of reactor internals, vessel, and large components (three years), removal of systems and decontamination (six years), and demolition and site restoration (two years).

Table 5.11 – Removal of clean (conventional) structures from Angra 1.

Structure	Name	Material description	Quantity	Units	Activity description
ERE	Reactor Building	Concrete	791,7	m³	Bulk removal clean standard (< 0.6m thick) reinforced concrete
ERE	Reactor Building	Concrete	18.288,50	m³	Remove clean monolithic (>0.6m thick) reinforced concrete
ERE	Reactor Building	Steel	6.839,00	m²	Remove clean free standing steel liner
ERE	Reactor Building	Grating	1.972,00	m²	Remove clean grating

EAN	North Auxiliary Building	Concrete	2.537,50	m³	Bulk removal clean standard (< 0.6 m thick) reinforced concrete
EAN	North Auxiliary Building	Concrete	7.215,90	m³	Remove clean monolithic (>0.6 m thick) reinforced concrete
EAS	South Auxiliary Building	Concrete	6.985,90	m³	Bulk removal clean standard (< 0.6m thick) reinforced concrete
EAS	South Auxiliary Building	Concrete	4.393,30	m³	Remove clean monolithic (>0.6 m thick) reinforced concrete
ESE	Safety Building	Concrete	3.682,60	m³	Bulk removal clean standard (< 0.6 m thick) reinforced concrete
ESE	Safety Building	Concrete	2.566,00	m³	Remove clean monolithic (>0.6m thick) reinforced concrete
ECB	Fuel Handling Building	Concrete	2.373,60	m³	Bulk removal clean standard (< 0.6 m thick) reinforced concrete
ECB	Fuel Handling Building	Concrete	3.585,00	m³	Remove clean monolithic (>0.6 m thick) reinforced concrete
ECB	Fuel Handling Building	Structural Steel	8,7	m	Remove structural steel
ETG	Turbine Building	Concrete	5.713,50	m³	Bulk removal clean standard (< 0.6m thick) reinforced concrete
ETG	Turbine Building	Concrete	22.504,10	m³	Remove clean monolithic (>0.6 m thick) reinforced concrete
ETG	Turbine Building	Structural Steel	78,9	m	Remove structural steel

Table 5.12 – Removal of clean (conventional) structures from Angra 2 and 3.

Structure	Name	Description	Quantity	Units	Activity description
UJA	Reactor Building	Concrete	10.178,50	m³	Bulk removal clean standard (< 0.6 m thick) reinforced concrete.
UJA	Reactor Building	Concrete	46.620,60	m³	Remove clean monolithic (>0.6m thick) reinforced concrete.

UJA	Reactor Building	Steel	146,3	m	Remove structural steel
UKA	Aux Building	Concrete	12.194,20	m³	Bulk removal clean standard (< 0.6 m thick) reinforced concrete.
UKA	Aux Building	Concrete	7.152,60	m³	Remove clean monolithic (>0.6m thick) reinforced concrete.
UMA	Turbine Building	Concrete	11.137,90	m³	Bulk removal clean standard (< 0.6m thick) reinforced concrete.
UMA	Turbine Building	Concrete	21.738,80	m³	Remove clean monolithic (>0.6 m thick) reinforced concrete.
UKH	Chimney	Concrete	1.757,70	m³	Bulk removal clean standard (<0.6 m thick) reinforced concrete.
UKH	Chimney	Concrete	678,8	m³	Remove clean monolithic (>0.6 m thick) reinforced concrete.
UKA	Aux Building	Fuel Pool Liner	638,3	m³	Remove contaminated concrete anchored steel liner

Table 5.13 – Removal of clean (conventional) large components from Angra 1, 2 and 3 power plants.

Turbine Generator
Main Condensers
Overhead Cranes > 45 MT
Overhead Cranes/ Monorails > 9 MT
Electrical Transformers > 27 MT
Standby Diesel Generator

6 SURVEILLANCE AND MAINTENANCE

6.1 Introduction

The decommissioning surveillance and maintenance (S&M) program will encompass all its phases for each nuclear power plant and for the whole site, i.e., transition, safe storage, decontamination and dismantling, dismantling of buildings and site restoration. The general goals of the S&M program are ensuring that safe conditions are maintained at the CNAAA site throughout the whole decommissioning process, ensuring protection of the environment, and ensuring adequate conditions for the workers to carry out all decommissioning activities planned for the CNAAA [2, 44-49].

The first plant to enter the decommissioning process is Angra 1 while the other plants will continue under commercial operation. At this moment, only the S&M program of Angra 1 is changed to accommodate the new power plant conditions. As new facilities of the site enter decommissioning their S&M programs will be changed accordingly. The surveillance and maintenance program to be conducted will comply with technical, radiological, environmental and licensing requirements.

This chapter presents initial information of the S&M program for the CNAAA facilities under decommissioning. This program will be detailed in future revisions of the PDP. All this Chapter`s content is based on Ref. [2].

6.2 Building, equipment and systems requiring surveillance and maintenance

The following buildings from the Angra 1, 2 and 3 while in decommissioning will require decommissioning S&M programs:

- Angra 1 including the Reactor Building (ERE), North Auxiliary Building (EAN), South Auxiliary Building (EAS), Fuel Building (ECB), Safety Building (ESE) and Turbine Building (ETG).
- Angra 2 including Reactor Building (UJA, UJB & UJF), Auxiliary Building (UKA), Gas Discharge Chimney (UKH), Main Steam Valves Room (UJE) and Turbine Building (UMA);
- Angra 3 including Reactor Building (UJA, UJB & UJF), Auxiliary Building (UKA), Gas Discharge Chimney (UKH), Main Steam Valves Room (UJE) and Turbine Building (UMA).

After all nuclear power plants have finished their D&D process, the following support buildings will require decommissioning S&M programs:

- Waste Management Center (CGR);
- Complementary Dry Storage Unit (UAS);
- Radiation Monitoring and Calibration Laboratory (LCMR);

- Environmental Monitoring Laboratory (LMA)

Simultaneously, the remainder of the CNAAA site will undergo building demolishment and site recovery and require decommissioning S&M programs.

The supporting buildings are simpler structures, they will enter in the decommissioning process after 2080, and then will undergo immediate dismantling. Thus the important buildings and structures for S&M under the point of view of decommissioning are those necessary for the future D&D of the nuclear power plants. These buildings will be maintained during the whole safe storage periods of Angra 1 and Angra 2 which will last two to three decades. The surveillance and maintenance program will ensure that they are in good operation conditions for the upcoming D&D phases. The turbine building is an example of an uncontaminated building that will be maintained to help the D&D activities of each power plant.

Most of the S&M activities are related to the decommissioning process itself. The activities on systems and equipment during the decontamination and dismantling phases will occur inside the buildings. These activities produce large volumes of dust, airborne particulates and liquid waste which will eventually be properly discharged as gaseous and liquid effluents. Dust and airborne will be discharged through vents and stacks in controlled conditions meeting allowable discharge limits. Similarly, liquid waste will be monitored, treated and eventually discharged.

The S&M program will include radiation protection, particulate monitors, contamination surveys, and environmental dosimeters with alarms, etc. Inside the buildings will be installed continuous particulate air samplers near doorways and other building openings. The ventilation system will be monitored to ensure a negative pressure inside the building to avoid spread of contamination to the outer environment.

The S&M activities for these buildings and structures aim at ensuring structural stability, fire and flooding protection, adequate ventilation, and adequate radiological controls of effluent discharge routes to the environment. Table 6.1 presents an initial list of surveillance items applicable for buildings and structures. More details about limits, technical specifications and necessary maintenances will be defined in future revisions of this PDP.

Table 6.1. Surveillance and maintenance planned for the buildings and structures, systems and equipment of the CNAAA.

Surveillance and maintenance item
Verification of structural condition of the buildings
Verification of fire protection system
Flooding protection

Verification of ventilation systems
Radiological and chemical control of effluents (gaseous and liquids)
Verification of walls and roofs condition to eliminate apertures and breaching
Verification of adequate conditions of different building accesses (windows, doors, etc)
Verification of security

6.3 Systems and equipment requiring surveillance and maintenance

Each decommissioning phase requires specific measures of surveillance and maintenance on systems and equipment because different activities will be performed in each one. For instance, during the decontamination and dismantling phases, many intense and different activities take place in short periods of time while, during the safe storage phases, which will take two or three decades, the main objective is to maintain systems and equipment in adequate conditions for upcoming D&D activities. Below follow initial definitions of S&M programs for systems and equipment in the transition, safe storage and D&D phases.

6.3.1 Systems and equipment during the transition phases requiring S&M

During the transition periods of the three nuclear power plants of the CNAAA many routine and non-routine operations will take place and may require special procedures, preparations and S&M activities. Regarding ending the operation of the nuclear power plants, S&M activities will be necessary to ensure isolation of each plant water, electric and security systems, adequate systems draining, increased effluent discharges, nuclear material removal, operational waste removal, clean-up of the work areas, structural stability, fire and flooding protection, adequate ventilation systems, and adequate radiological control of contaminated areas.

Regarding decommissioning, S&M activities will be necessary to ensure adequate shipment of non-contaminated large components such as turbine generators, condensers, pumps, and pipes, identify and eliminate those systems which will not be necessary for eventual decommissioning, dismantlement of non-contaminated mechanical parts, miscellaneous electrical systems and cables, general decontamination, adequate ventilation systems, adequate radiological control, and adequate handling of large volumes of liquids generated from the general decontamination activities.

Table 6.2 presents an initial list of surveillance items applicable for systems and equipment during the transition phases. More details about limits, technical specifications and necessary maintenances will be defined in future revisions of this PDP.

Table 6.2. Surveillance and maintenance planned for systems and equipment during the transition phases.

Surveillance and maintenance item
Verification of isolation of water systems (sewage, effluents, etc)
Verification of isolation of electric systems
Verification of adequate systems draining
Verification of adequate effluent discharges
Flood control
Verification of structures of systems and equipment
Identify equipment and systems required to support decommissioning
Verification of adequate transport of large uncontaminated equipment (turbine generators, condensers, etc)
Verification of adequate removal and transport of miscellaneous systems
Verification of adequate dismantlement of uncontaminated electrical and mechanical systems
Verification of adequate ventilation systems for conventional work
Radiation protection monitoring - the types of monitors include alpha monitor, direct beta monitor, collimated gamma radiations scanning (NaI), gamma spectroscopy for background issues. Different radiological protection meters such as dosimeters, area monitors, personal dosimeters, alarming dosimeters, hand and foot monitors, manual monitors, particulate air samplers, and liquid samplers.
Verification of adequate disposal of large volumes of contaminated liquids
Verification of adequate decontamination and dismantling of radioactive structures and systems
Verification of adequate radioactive waste packaging
Verification of adequate ventilation systems for radiological work
General clean-ups and housekeeping of work areas

6.3.2 Systems and equipment during the safe storage phases requiring S&M

During the safe store phases of Angra 1 and Angra 2, the main S&M are conducted on those equipment and systems necessary to support the upcoming decontamination and dismantling activities. A major source of concern is the possible deterioration of systems and equipment during the 20 or 30 years of safe storage expected for Angra 1 and Angra 2. Various controls will be implemented to limit the spread of contamination including proofing against birds and animals from entering the buildings to eliminate the possibility of contamination spread. The main S&M activities are related to stability of structures, fire and flooding protection systems, apertures or breaches in walls and roofs, ventilation systems, and radiological control of contaminated areas.

Table 6.3 presents an initial list of surveillance items applicable for systems and equipment during the safe storage phases. More details about limits, technical specifications and necessary maintenances will be defined in future revisions of this PDP.

Table 6.3. Surveillance and maintenance planned for systems and equipment during the safe storage phases

Verification of apertures and breaching of wall and roofs against birds and animals
Stability of internal structures of systems and equipment
Verification of fire protection system
Verification of flooding protection
Verification of ventilation systems
Radiological control of contaminated areas

6.3.3 Systems and equipment during the decontamination and dismantling phases requiring S&M

The activities of the decontamination and dismantling phases are the most intense regarding dealing with contaminated materials. During the transition phases, the dismantling is minimize and only general decontamination is performed to facilitate access to the facility and reduce spread of contamination. In the D&D phases of each nuclear power plant of the CNAAA all contaminated systems are decontaminated and dismantled generating large volumes of decommissioning wastes. These wastes will be packed and shipped off site to appropriate deposits of radioactive waste. Various controls will be implemented to avoid possible hazard, radiological contamination and radiation exposure to the workers.

Several systems will be installed to facilitate and promote safety to carry out the D&D activities. It will be necessary to implement confinement tents or barriers to prevent and control spread of contamination, and dust and airborne particulate in the work areas. Some areas will require use of installed ventilation systems prior and during work activities to maintain adequate breathing and temperature conditions. Other areas will require only portable ventilation systems. High radiation level areas will require shielding barriers to reduce radiation dose exposition. The environmental monitoring program inside the work areas will be intense, and workers will be submitted to strict radiological and conventional hazards controls.

The decontamination activities are usually iterative processes requiring intermediate surveys to be completed. For instance, to assess the effectiveness of a work on a contaminated concrete surface depends on checking the level of residual contamination remaining after having conducted it. The work process will be like to scrape off about 1 cm layer of concrete from the contaminated surface and survey the newly exposed surface. If the release criterion is not met, the process is repeated iteratively. The monitoring activity is thus an important part of the D&D process. The monitoring techniques will evolve as working conditions change from high levels to very low levels of radiation and contamination.

The waste processing will require radioactive monitoring. Direct dose rate of every package and some gamma energy spectroscopy will be conducted to estimate the waste radioactive content. It will be obtained based on a correlation between dose rate and gamma energy of emitters to the radioactive content, and the analysis will be carried out in the Environmental Monitoring Laboratory (LMA).

The S&M necessary for the decontamination and dismantling phases require diverse in-field surveys. Table 6.4 presents an initial list of surveillance items applicable for systems and equipment during the D&D phases for Angra 1, 2 and 3. More details about limits, technical specifications and necessary maintenances will be defined in future revisions of this PDP.

Table 6.4. Surveillance and maintenance planned for systems and equipment during the decontamination and dismantling phases.

Verification of functional conditions confinement tents and barriers
Area monitoring for dust and airborne particulate
Verification of ventilation systems for rooms and portable ventilation systems for tents and barriers
Verification of effectiveness of radiation shielding barriers
Radiological protection monitoring - the types of monitors include alpha monitor, direct beta monitor, collimated gamma radiations scanning (NaI), gamma spectroscopy for background issues. Different radiological protection meters such as dosimeters, area monitors, personal dosimeters, alarming dosimeters, hand and foot monitors, manual monitors, particulate air samplers, and liquid samplers.
Verification of conventional hazards
Monitoring surface contamination of concrete and metals
Direct dose rate of radioactive waste packages
Verification of adequate transport of large uncontaminated equipment (turbine generators, condensers, etc)
Verification of adequate removal and transport of miscellaneous systems
Verification of adequate dismantlement of uncontaminated electrical and mechanical systems
Verification of adequate ventilation systems for conventional work
Radiation protection monitoring

Verification of adequate disposal of large volumes of contaminated liquids
Verification of adequate decontamination and dismantling of radioactive structures and systems
Verification of adequate radioactive waste packaging
Verification of adequate ventilation systems for radiological work
General clean-ups and housekeeping of work areas

6.4 Surveillance and maintenance program during the demolition of buildings and site restoration

In the phase of demolition, the activities are related to conventional demolishment of buildings. The surveillance items will seek to ensure healthy conditions to workers and reduced impacts to the environment. These items will be detailed in future revisions of the PDP.

During the site recovery, surveys will be performed to ensure that it meets the end state requirements defined in its Final Decommissioning Plan. Details of these surveillance items are given in Chapter 15.

6.5 Schedule for surveillance and maintenance

Tables 6.1 to 6.4 present an initial set of S&M activities planned for the decommissioning of the CNAAA. For each S&M item it will be necessary to detail surveillance methods, surveillance requirements, specification of acceptance criteria, maintenance frequencies and schedules, spare part numbers, spare part storage requirements, and schedule equipment and systems for D&D.

The completion of surveillance items, the planned maintenances and their specific details will be defined in future revisions of the PDP.

7 WASTE MANAGEMENT

Normally this Chapter of the PDP would discuss only waste that is generated during the decommissioning activities but CNEN Standard NN 9.01 [1] requires that not only the management of decommissioning waste be addressed, but also the amount of waste that will be present at the end of the operational period be estimated. To fulfill this requirement, both types of waste will be addressed in this Chapter.

There are two types of waste associated with the operation and decommissioning of a nuclear facility. These are the radioactive waste produced during operation (operational waste) and the waste produced during decommissioning (decommissioning waste). This document estimates the amount of operational waste that will be generated during the operating period of the three Angra nuclear power plants. This waste will be removed as part of the transition phase and its cost is presented in Appendix 2. An estimate of the amount and cost for disposal of the decommissioning waste is also provided. This cost of disposing of this decommissioning waste is included in the preliminary decommissioning cost estimate (PDCE) in Appendix 1.

7.1 Operational Waste

Each of the Angra nuclear plants produces operational radioactive waste in the form of compactable waste (paper, plastic, cloth, ventilation filter elements, etc.), non-compactable waste (tools, wood, equipment, metallic parts), concentrates (sludge, filter residues, evaporator concentrates), ion exchange resins from the primary and secondary purification systems, and filter cartridges. Generally, the compactable and non-compactable wastes are considered Low Level Waste (LLW). The concentrates, resins and filter cartridges are normally considered to be Intermediate Level Waste (ILW) [50].

With no currently available radioactive waste disposal facility in Brazil; these waste types are being stored on the CNAAA site. It is anticipated that a near surface radioactive waste disposal facility will be available in 2025.

Spent fuel assemblies are also generated during operations and, as there is no currently available high level radioactive waste disposal site, these assemblies are currently stored at each of the Angra reactor plants in spent fuel pools. An estimated 7813 spent fuel assemblies will be produced during the lifetime of the three units [51] which will require an increase in on-site storage capacity beginning in 2021. The use of dry storage modules is anticipated to meet this on-site storage need. The cost for the management of the spent nuclear fuel is based on an estimated value, but may change based on the type of dry storage that is used and the final disposition of the spent fuel assemblies.

7.1.1 Operational Waste Assumptions

During the formulation of the information contained in this document, certain assumptions have been used, and they are listed below.

1. It is assumed that Angra 1, Angra 2 and Angra 3 will shut down in 12/31/2044, 9/30/2061 and 12/31/2082, respectively [52]. This

assumes a normal 40-year operating life and a 20-year license extension for each of the three plants.

2. A planned off-site government disposal facility will be available for receipt of low and intermediate level radioactive waste by 2025. [53]

3. A planned off-site government spent fuel and high level radioactive waste storage facility will be available for the receipt of spent nuclear fuel and high level waste by 2030. [53]

4. No waste volumes associated with major modifications or activities are included in this estimate, only the normal waste volumes are included. If any major modifications occur, the additional waste volumes must be incorporated into the next update to the Decommissioning Plan.

5. Compactable and non-compactable waste is considered Low Level Waste. The concentrates, resins and filter cartridges are considered Intermediate Level Waste [50].

6. Approved plant procedures for waste processing and packaging ensure compliance with CNEN NE 5:01, CNEN NN 6:09 and CNEN NN 8:01. [10, 28, 54]

7. Unit 1 annual low level waste generation is 34,14 m^3. [55]

8. Unit 1 annual intermediate level waste generation is 86,66 m^3. [55]

9. Unit 2 annual low level waste generation is 9,5 m^3. [55]

10. Unit 2 annual intermediate level waste generation is 7,6 m^3. [55]

11. Unit 3 waste and volumes are the same as Unit 2 [55] (Unit 3 annual low level waste generation is 9.5 m^3 and the annual intermediate level waste generation is 7,6 m^3).

7.1.2 Unit Specific Operational Waste Information

7.1.2.1 Angra 1

As of 2017, Angra 1 has generated approximately 3435,80 m3 of radioactive waste and has an expected future generation rate of 120,8 m3 per year. [55] This waste is currently stored in the Waste Management Centre (CGR) and the Initial Deposit of Steam Generators (DIGV). Assuming a 40-year licensed plant life with a 20-year license extension, Angra 1 is expected to generate a total of approximately 6697,40 m3 of radioactive waste at the completion of operations in 2044. Approximately 28%, or 1875,272 m3 of this waste is low level waste and 72%, or 4822,128 m3 is intermediate level waste [55].

Angra 1 processes waste in accordance with approved procedure "PO S 44 / System Treatment of Solid Waste" [56]. Angra 1 uses an in-drum compactor for packaging compressible waste in 200 liters drums and uses metal boxes, these being similar to B-25 boxes, for packaging non-compressible waste. Evaporator concentrates and resins are processed and packaged into liners having an external volume of 1.5 m3. Filters are packaged into smaller containers having an external volume of 0.208 m3.

A procedure for packaging hazardous chemical waste that are also radioactively contaminated (such as lubricating oils) is currently being prepared.

A computer software program named "REJAN" [57] is utilized to track waste container information such as weight, dose rates, contents, total activity, isotopes and location within the CGR.

7.1.2.2 Angra 2

As of 2017, Angra 2 has generated approximately 175,8 m3 of radioactive waste and has an expected future generation rate of 17,1 m3 per year. [55] This waste is currently stored within Unit 2. Assuming a 40-year licensed plant life and a 20-year license extension, Angra 2 is expected to generate a total of approximately 928,2 m3 of radioactive waste at the completion of operations in 2061. Approximately 56%, or 519,79 m3 of this waste is low level waste and 44%, or 408,41 m3 is intermediate level waste [55].

Angra 2 processes compactable wastes in accordance with approved procedure "Handling System of Solid Waste," section 4.2.9 of the Angra 2 Operation Manual [58]. Angra 2 uses an in-drum compactor for packaging compressible waste in 200 liters drums. Non-compressible waste is processed in accordance with approved procedure "Radioactive Concentrated Manipulation," section 4.2.11 of the Angra 2 Operation Manual [58]. Metal boxes or boxes similar to B-25 boxes are used for packaging non-compressible waste. Evaporator concentrate and resins are processed and packaged in accordance with approved procedure "Radioactive Concentrated Manipulation" section 4.2.11 of the Angra 2 Operation Manual [58]. This waste is packaged into containers having an external volume of 0.208 m3. Primary system filter waste is processed and packaged in accordance with approved procedure "Unit for Changing Filter," section 4.2.12 of the Angra 2 Operation Manual [58]. Filters are packaged into containers having an external volume of 0.208 m3.

A procedure for packaging hazardous chemical waste that are also radioactively contaminated (such as lubricating oils) is currently being prepared.

All Angra 2 radioactive waste is stored within Unit 2 Initial Waste Deposits (KPE). A computer software program named "REJAN" [57] is utilized to track waste container information such as weight, dose rates, contents, total activity, isotopes and location within the storage area.

7.1.2.3 Angra 3

Angra 3 is under construction and is planned to become operational in 2022. Unit 3 has an expected future generation rate of 17,1 m3 per year [55]. This waste will be stored within Unit 3. Assuming a 40-year licensed plant life and a 20-year license extension, Angra 3 is expected to generate a total of approximately 1026 m3 of radioactive waste at the completion of operations in 2082. Approximately 56%, or 574,56 m3 of this waste is expected to be low level waste and 44%, or 451,44 m3 is expected to be intermediate level waste.

Angra 3 will process waste in accordance with procedures to be developed. Angra 3 will use an in-drum compactor for packaging compressible waste in 200 liters drums; and use metal boxes or boxes similar to B-25 boxes for packaging non-compressible waste. Processing systems for evaporator concentrates, resins and filters are being considered at the present time and once determined will be included in this section.

A procedure for packaging hazardous chemical waste that are also radioactively contaminated (such as lubricating oils) will also be developed for Unit 3.

All Angra 3 waste will be stored within Unit 3. A computer software program named "REJAN" [57] will be utilized to track waste container information such as weight, dose rates, contents, total activity, isotopes and location within the storage area.

7.1.3 Operational Waste Summary

Table 7.1 provides a summary of operational wastes by Unit for low level waste and intermediate level waste.

Table 7.1 – Operational Radioactive Waste Summary

	Unit 1	**Unit 2**	**Unit 3**	**Total**
Low Level m^3	1875,272	519,79	574,56	2969,622
Intermediate m^3	4822,128	408,41	451,44	5681,978
Total m^3	6697,40	928,2	1026	8651,60
Spent Fuel Assy	2095	2873	2845	7813

The cost of this operational waste and the spent nuclear fuel is part of the cost of the transition period presented in Appendix 2 and will be included in the total cost of the decommissioning in Chapter 8.

7.2 Decommissioning Waste

To properly plan the decommissioning of a nuclear power plant and estimate the cost to perform the decommissioning, the amount of waste that will be generated during the decommissioning activities must be estimated. This Chapter provides an estimate of decommissioning waste and an estimated cost for the transport and disposal of this waste.

7.2.1 Identification of Decommissioning Waste Streams

Each of the Angra nuclear plants and support facilities will produce decommissioning waste in the form of paper, plastic, cloth, portable ventilation unit filter elements, tools, wood, metal (pumps, motors, piping, conduit and switchgear,), concrete, steel (reinforcing bars, crane pieces and structural components,) soil, liquids (water, PCBs, oils, Freon, greases,) and sludge, Generally, these waste types can be divided into Clean Waste, Hazardous Waste and Low Level Radioactive Waste (LLW) and Intermediate Level Radioactive Waste (ILW). However, some activated metals from the reactor internals and reactor pressure vessels may have higher activity levels and result in Low Level High Activity Radioactive Waste (LLW-HA), Intermediate Level High Activity Radioactive Waste (ILW-HA) and High Level Radioactive Waste (HLW). These higher activity waste streams will require special packaging and handling requirements that will include shielded transport containers.

All decommissioning waste material will require characterization, size reduction necessary for packaging, handling and temporary storage prior to disposal. The costs associated with the decommissioning work and waste management require adequate funds to be collected and set aside in a decommissioning trust fund during the operational period of the plants to ensure funds are available to safely dispose of the waste.

7.2.2 Decommissioning Waste Assumptions

1. It is assumed that Angra 1, Angra 2 and Angra 3 will shut down in 12/31/2044, 9/30/2061 and 12/31/2082, respectively [52]. This assumes a normal 40-year operating life and a 20-year license extension for each of the three plants.

2. A planned government disposal facility will be available for receipt of low level and intermediate waste by 2025. [53]

3. A planned government spent fuel storage facility will be available for the receipt of spent nuclear fuel and high level waste by 2030. [53]

4. The facilities that will be the source of waste included in this this discussion are:

   - Angra 1 including Reactor Building (ERE), North Auxiliary Building (EAN), South Auxiliary Building (EAS), Fuel Building (ECB), Safety Building (ESE) and Turbine Building (ETG)

- Angra 2 including Reactor Building (UJA, UJB & UJF), Auxiliary Building (UKA), Gas Discharge Chimney (UKH), Main Steam Valves Room (UJE) and Turbine Building (UMA).
- Angra 3 including Reactor Building (UJA, UJB & UJF), Auxiliary Building UKA), Gas Discharge Chimney (UKH), Main Steam Valves Room (UJE) and Turbine Building (UMA)
- Waste Management Center (CGR)
- Complementary Dry Storage Unit (UAS)
- Radiation Monitoring and Calibration Laboratory (LCMR)
- Environmental Monitoring Laboratory (LMA)

5. All decommissioning waste material from the site will be disposed of as either clean waste, low level radioactive waste (LLW), intermediate radioactive waste (ILW) or high level radioactive waste (HLW). The LLW and ILW may have a subcategory of waste identified as low level radioactive waste – high activity (LLW-HA) and intermediate level radioactive waste – high activity (ILW-HA).

6. All LLW and ILW will be packaged in either 200 liters drums or B25 boxes and disposed at the CNEN facility. Clean waste will be placed in 15 m^3 dump trucks and disposed at a local disposal facility.

7. All LLW-HA, ILW-HA and HLW will be packaged in metal liners and shipped to the disposal site in shielded overpacks or casks.

8. All costs are calculated in 2017 Brazilian Reais (R$) at an exchange rate of R$3.2 to 1 $US.

9. Waste volumes stated consider inefficiencies from packing various sized components to be offset by efficiencies from using a dedicated waste volume reduction crew.

10. All operational waste, spent and new nuclear fuel, asbestos, other hazardous waste and resins will be removed as part of operations during the transition period prior to the start of decommissioning.

11. The total cost for the disposal of clean waste will be R$45.70 per m^3. This value includes the rental of the truck, transportation costs, disposal costs and taxes. The distance to the disposal site is less than 200 kilometers.

12. The total cost for the disposal of low level radioactive waste will be R$17,379 per m^3. This value includes container, transportation and disposal costs; and taxes.

13. The total cost for the disposal of low level, high activity radioactive waste will be R$58,668 per m^3. This value includes liner, cask rental, transportation and disposal costs; and taxes.

14. The total cost for the disposal of low level radioactive waste packaged as its own container will be R$15,081 per m^3. This value includes transportation and disposal costs; and taxes.

15. The total cost for the disposal of intermediate level high activity radioactive waste will be R$58,668 per m^3. This value includes liner, cask rental, transportation and disposal costs; and taxes.

16. The total cost for the disposal of high level radioactive waste will be R$208,461 per m^3. This value includes liner, cask rental, transportation and disposal costs; and taxes.

17. The removal of all spent nuclear fuel from the in-plant storage pools to temporary storage at an independent onsite storage facility will be part of operations and included in the cost of the transition period. The decommissioning of the independent spent fuel storage facility is included in this cost estimate.

18. The waste in the storage containers located in the Steam Generator Initial Deposit will be removed as part of the operational activities during the transition period. The removal of the steam generators, reactor pressure vessel head, heat exchanger, and other components will be included in preliminary the decommissioning cost estimate.

19. All waste will be moved by motor vehicle over the current road system.

20. Angra 2 and Angra 3 reactor vessel and internals are considered identical.

21. Angra 1, Angra 2 and Angra 3 reactor vessel and internals will be removed sequentially.

22. The following buildings are considered to contain contaminated or activated equipment, systems and components: 1) The Angra 1 Reactor Building, North Auxiliary Building, South Auxiliary Building, Fuel Building and Safety Building; 2) The Angra 2 Reactor Building, Auxiliary Building, Gas Discharge Chimney, and Main Steam Valve Compartment; 3) The Angra 3 Reactor Building, Auxiliary Building, Gas Discharge Chimney and Main Steam Valve Compartment, 4) The Waste Monitoring Building, and 5) Steam Generator Initial Deposit. All other buildings are considered free of contamination and will receive a final survey to verify this condition prior to clean demolition.

23. All removed soil is assumed to be uncontaminated and placed back in the excavations after surveying the excavations.

24. The taxes as shown in Table 7.2 will be applied to the material and services as indicated.

Table 7.2 – Tax Rates

	ETN Purchase		Contractor purchase	
	National Tax	**International Tax**	**National Tax**	**International Tax**
Material	29.25%	73.48%	29.25%	0.00%
Equipment	29.25%	73.48%	29.25%	0.00%
Staff and Workers	0.00%	0.00%	0.00%	0.00%
Service	14.25%	46.21%	14.25%	0.00%

The National tax to be paid by Eletronuclear will be added to all material, equipment and services purchased in Brazil. This will include disposal drums and metal boxes, metal liners, and waste transportation and disposal services. The International Tax that will be paid by Eletronuclear will be added to all material and services provided from outside Brazil. This will include the cost of waste overpacks and casks.

The National Tax paid by the Contractor will be added to any material, equipment and services purchased in Brazil. The International Tax paid by the Contractor will be included in the Contractor's agreement, and Eletronuclear will pay the taxes for international purchases in these cases. These taxes will amount to 46.21% for services and 73.48% for material and equipment.

No Tax is added to the Staff and workers for either Eletronuclear or the Contractor, no matter where they work.

7.2.3 Unit Specific Decommissioning Waste Information

It is anticipated that the waste processing systems located in the plants will be available until the last plant is decommissioned. The waste processing systems of Angra 3 will be available when Angra 1 and 2 are being decommissioned. Since waste will be shipped as it is generated, only a small holding area will be needed. One or two of the warehouses near Angra 1 can be used as temporary storage if needed. This will allow the decommissioning of the waste management storage facilities.

7.2.3.1 Angra 1

Angra 1 decommissioning waste will be processed in accordance with approved procedures. An in-drum compactor will be used for processing and packaging compressible waste into 200 liters drums. Non-compressible waste will be placed into B-25 or similar approved containers for disposal. Since Angra 1 will be the first plant to shut down, and be placed into safe storage, removed material will have a chance to decay (approximately 33 years) and reduce the waste classification. This will reduce the amount of HLW associated with the reactor internals and reactor pressure vessel. A computer software program named "REJAN" [57] is utilized to track waste container information such as weight, dose rates, contents, total activity, isotopes and location.

7.2.3.2 Angra 2

Angra 2 decommissioning waste will be processed in accordance with approved procedures. An in-drum compactor will be used for processing and packaging compressible waste into drums. Non-compressible waste will be placed into B-25 or similar approved containers for disposal. Since Angra 2 will be the second plant to shut down, and be placed into safe storage, removed material will have a chance to decay (approximately 18 years) and reduce the waste classification. This will reduce the amount of HLW associated with the reactor internals and reactor pressure vessel, but not as much as for Angra 1. A computer software program named “REJAN” [57] is utilized to track waste container information such as weight, dose rates, contents, total activity, isotopes and location.

A procedure for packaging hazardous chemical waste that are also radioactively contaminated (such as lubricating oils) is currently being prepared.

7.2.3.3 Angra 3

Angra 3 decommissioning waste will be processed in accordance with approved procedures. An in-drum compactor will be used for processing and packaging compressible waste into drums. Non-compressible waste will be placed into B-25 or similar approved containers for disposal. Since Angra 3 will not have a safe storage period, decay of the HLW will be minimal (approximately 3 years) and no reduction of waste classification based on decay is projected. A computer software program named “REJAN” [57] is utilized to track waste container information such as weight, dose rates, contents, total activity, isotopes and location.

7.2.4 Solid Radioactive Waste

The solid radioactive waste that will be generated during the decommissioning activities will be mostly facility structures, systems and equipment. There may be some decommissioning equipment that will also require disposal at the end of the project. The volume of radioactive waste will be minimized to the extent possible. Large items will be size reduced and care will be taken to ensure that clean material or waste is not mixed with radioactive waste. A waste minimization program will be implemented. Typical waste minimization processes will be used, such as compaction, waste segregation, and contamination and control procedures. Most solid radioactive waste will be size reduced and packaged in steel boxes, 200 liters drums or metal liners. The typical container will be the metal B25 or similar, box. It has been found that this size box provides a good balance between size and weight specifications.

Some LLW items may be shipped as their own containers. This might include slightly contaminated tanks, activated metal components or activated concrete blocks. When this option is used, the item will be made weather tight by welding plates over openings, sealing surfaces or other means.

All radioactive waste will be transported to a licensed waste disposal site for final disposition. LLW-HA, ILW-HA and HLW will be properly packaged and shipped in shielded containers or casks.

7.2.5 Liquid Radioactive Waste

The generation of liquid waste will be minimized as much as possible. Any liquid waste that is generated will be solidified and stabilized in approved containers, prior to shipment to an approved disposal site for disposition. Normally 200 liters drums will be used for the disposal of this type of processed waste.

7.2.6 Combined Radioactive and Hazardous Waste

It is not anticipated that any combined radioactive and hazardous waste will be generated during decommissioning. Special attention will be made to prevent this type of waste from being generated. If such waste is generated, it will be treated as radioactive waste. This might be the case with structure surfaces that might be covered with lead based paint or paint containing PCBs.

7.2.7 Decommissioning Waste Summary

The volumes of waste were estimated based on the facility, system and equipment drawings; radiological survey data; past incident reports and plant visits. Discussions with plant and engineering personnel in response to questions while preparing the decommissioning cost estimate provided additional information. These waste volumes were estimated as part of the decommissioning cost estimate [Appendix 1] process. Table 7.3 provides a summary of decommissioning wastes by Unit.

The total cost for the waste containers and overpacks or casks, transportation to the disposal site and disposal costs will be R$ 891.269.625. This includes appropriate taxes but no contingency. The total cost with the 15% project level contingency is R$ 1.024.960.069. The costs for each type of waste category are explained in detail in the Preliminary Decommissioning Cost Estimate [Appendix 1].

Table 7.3 – Decommissioning Waste Summary (m^3)

	Unit 1	Unit 2	Unit 3	Support Buildings	Total
Low Level	7.343,27	12.923,87	12.822,12	635,92	33.725,2
LLW High Activity	99,04	194,40	88,03	0	381,5
Low Level-own container	90,82	170,36	170,36	17,42	448,9
Intermediate Level – High Activity	29,34	7,34	227,42	0	264,1
High Level	11,00	62,16	298,51	0	371,7
Clean	312.939,88	428.144,97	428.144,97	65.701,62	1.234.931,4
Total	320.513,3	441.503,1	441.751,4	66.355,0	1.270.122,8

8 COST ESTIMATE AND FUNDING MECHANISMS

In 2012, the Brazilian National Commission of Nuclear Energy (CNEN) published CNEN Standard NN9.01 of November 8, 2012 [1] concerning the decommissioning of nuclear power plants (NPPs). This document establishes the basic nuclear safety requirements to be met during the planning and implementation of the decommissioning of nuclear power plants, which are within the licensing regime.

Article 6 of CNEN NN9.01 requires that the operating organization for nuclear power plants prepare a Preliminary Decommissioning Plan (PDP) and submit the plan to CNEN. As part of the PDP, a decommissioning cost estimate shall be prepared to identify the costs associated with the decommissioning of the NPPs and allow a financial mechanism be put in place that will ensure appropriate funds are available to decommission the plants in a safe manner.

The purpose of this Chapter is to establish the initial budget for the decommissioning of the NPPs located at the Central Nuclear Almirante Álvaro Alberto (CNAAA). This decommissioning cost estimate will be updated periodically to ensure that sufficient funds are being collected to allow proper decommissioning activities to be implemented when planned or due to unforeseen circumstances. The purpose of the decommissioning cost estimate (DCE) is to estimate the costs associated with removing the radiological hazards from the CNAAA and allow the identified end state of the decommissioning process to be achieved. The reporting structure for the DCE follows the International Structure for Decommissioning Costing (ISDC) of Nuclear Installations [21] as published by OECD/NEA. Waste amounts are also analyzed during the estimation process.

The Chapter also describes the mechanism Eletronuclear is using to collect decommissioning funds and the process to manage these funds to ensure that the necessary funds will be available when needed.

8.1 Cost Estimate

This Section provides the details of the initial decommissioning cost estimate. This cost estimate is derived from the "Preliminary Decommissioning Cost Estimate, Central Nuclear Almirante Alvaro Alberto (CNAAA), Angra 1, Angra 2 and Angra 3 Nuclear Power Plants", Appendix 1 and from "Cálculo Preliminar do custo do Período de Transição do desligamento permanente ao período de "estado seguro" (*safe storage*) das usinas nucleares de Angra 1, Angra 2 e Angra 3", Appendix 2.

8.1.1 Cost Estimate Boundaries

This cost estimate is for the decommissioning of the Angra 1, Angra 2, and Angra 3 NPPs; and certain support facilities. The support facilities include the Waste Management Center, the Complementary Dry Storage Unit, the Radiation Monitoring and Calibration Laboratory and the Environmental Monitoring Laboratory.

8.1.2 Decommissioning Approach

The basic decommissioning strategy for Angra 1 and 2 will be deferred dismantling, as defined by the International Atomic Energy (IAEA) Requirements Document GSR Part 6, "Decommissioning of Facilities" [15]. This strategy will place the two plants into an extended safe storage configuration. The two facilities will be left relatively intact with structures maintained in a stable condition. Systems that are not required to support the ventilation, safety systems, or site security are drained, de-energized, and secured. Minimal cleaning/removal of loose contamination and/or fixation and sealing of remaining contamination is performed prior to safe storage. The Angra 3 approach will be to implement the IAEA immediate dismantling strategy upon permanent shutdown.

This approach provides a relatively stable work force for a longer period once decontamination and dismantling (D&D) activities begin, than if the plants went into immediate dismantling as they permanently shutdown. By following this approach there will be less impact on the local economy once D&D begins. This approach also allows the continued collection and growth of decommissioning funds.

For this DCE, it is anticipated that Angra 1, Angra 2 and Angra 3 will shut down in 12/31/2044, 9/30/2061 and 12/31/2082, respectively. This assumes a normal 40-year operating period and an additional 20-year life extension for all three nuclear power plants. It is important to highlight that for the purpose of collecting decommissioning funds, possible life extensions of the nuclear power plants will not be considered, being limited to the useful life of the currently licensed plants. As previously stated, after the permanent shutdown of Angra 1 and 2, each reactor will be placed into a safe storage configuration until Angra 3 is permanently shutdown.

The critical path activity for the decommissioning of these three reactors will be the removal of the reactor internals and the reactor vessel. A specialized team with specialized equipment to perform these activities will be required. The dismantling of the reactor internals and vessel of Angra 1 is back calculated based on the shutdown date for Angra 3, doing Angra 2 second and Angra 3 third. The approach is to establish a dedicated team to perform the reactor internal and vessel removal activities from all three reactors in series. By starting with the removal of the reactor internals and vessel of Angra 1, the dose rates will have decayed during the safe storage period. This approach will provide a stable workforce during the remaining decommissioning activities and allow the team to gain experience as they move to the less decayed internals and vessels and newer systems. As the reactor internal and vessel removal activity is completed for one reactor, this specialized team moves to the next reactor and additional personnel can begin the decontamination and dismantling activities for the remaining reactor systems and buildings. If there are times when a crew is not completely utilized, they may be reassigned to perform activities at one of the support facilities.

By using this approach, the onsite workforce will be reduced during the period from the start of the Angra 1 safe storage period until the planning begins for the removal of the Angra 1 reactor vessel internals (approximately 33 years). At that time the work force will increase and become relatively stable until the Angra 3 decommissioning is completed. This approach also allows the decommissioning fund to grow based on the longer operational period of Angra 2 and 3, and the increase of the fund based on interest accrual and other long term financial growth methods.

Safe storage activities will include maintaining a security/guard force, preventive and corrective maintenance on safety and security systems, area lighting, general building maintenance, ventilation, routine radiological inspections, maintenance of structural integrity, fire protection, and environmental and radiation monitoring.

Prior to starting dismantling operations, site services will be reactivated, a decommissioning management organization will be assembled and planning will be performed. Planning will include engineering; additional facility and site characterization as necessary and the development of work plans, specifications and procedures.

Significant decommissioning activities include:

- Reconfigure and modify site structures and facilities, as needed, to support decommissioning activities. Modifications may also be required to the reactor or other buildings to facilitate movement of equipment and materials, support the segmentation of the reactor vessel and reactor vessel internals, and for large component removal.
- Design and fabricate temporary and long-term shielding to support removal and transportation activities, construction of contamination control envelopes and the procurement of specialty tooling.
- Procurement or leasing of shipping casks, cask liners and containers for the disposition of radioactive waste.
- Decontaminate components and piping systems, as required, to minimize worker exposure.
- Disposition of major components such as the turbine, condenser, main steam piping and associated equipment; with appropriate disposal based upon radiological surveys.
- Disposition of systems and components.
- Disassembly and segmentation of the reactor vessel internals.
- Segmentation of the reactor vessel.
- Disposition of the activated and contaminated portions of the concrete biological shield and contaminated concrete surfaces that exceed the material clearance criteria.
- Material below the clearance criteria may be surveyed and released for unrestricted disposition, e.g., as scrap, recycle, or general disposal.

A major component of the decommissioning work scope is the packaging, transporting and disposing of contaminated and activated equipment, piping, components and concrete. Brazilian law establishes that the responsibility for the final disposal of radioactive waste shall be of the Federal Government and carried out by the National Commission for Nuclear Energy (CNEN). A site selection process aimed at the construction of a Brazilian Repository for the low and intermediate level radioactive waste is currently being performed. Regions of interest have already been identified and areas are being considered as candidate sites. Once the final candidate sites are chosen, the next step will be the public acceptance program. This involves the identification and discussions with the appropriate stakeholders in the selected areas. CNEN is currently performing geological research in the candidate sites in order to achieve a final decision.

After decontamination and release of the buildings, clean demolition and site restoration activities will be performed. Affected areas would be backfilled with suitable fill materials.

8.1.3 DCE Assumptions

A DCE is only as good as the information available to prepare the cost estimate. This is a preliminary cost estimate that currently has two of the plants operating and one plant that has not completed construction. It is based on the most current information, but conditions may change over the life of the plants. There are other factors that might also cause the DCE to change during the life of the facility. These may include labor costs, general inflation, better defined waste transportation and disposal costs associated with the selection of a disposal site, change in regulatory requirements, changes in work approach or size of packaging, refined characterization data, inclusion of additional structures, radiological incidents and other factors. It is because of these uncertainties that the cost estimate should be updated periodically based on the regulatory requirements. For the purposes of this DCE, actual data has been used when available and the following assumptions were used during the development of this cost estimate.

1. The facilities included in this cost estimate are:

    a. Angra 1 including the Reactor Building (ERE), North Auxiliary Building (EAN), South Auxiliary Building (EAS), Fuel Building (ECB), Safety Building (ESE) and Turbine Building (ETG);

    b. Angra 2 including the Reactor Building (UJA, UJB & UJF), Auxiliary Building (UKA), Gas Discharge Chimney (UKH), Main Steam Valves Room (UJE) and Turbine Building (UMA);

    c. Angra 3 including the Reactor Building (UJA, UJB & UJF), Auxiliary Building (UKA), Gas Discharge Chimney (UKH), Main Steam Valves Room (UJE) and Turbine Building (UMA);

    d. Radiation Monitoring and Calibration Laboratory (LCMR);

    e. Waste Storage Buildings Unit 1, Unit 2 (Modules A and B) and Unit 3;

    f. Waste Monitoring Building (PMR);

    g. Steam Generator Initial Deposit (DIGV); and

    h. Environmental Monitoring Laboratory (LMA)

2. All material from the site will be disposed of as either clean waste, low level radioactive waste, intermediate level radioactive waste or high level radioactive waste.

3. Work will be performed 8 hours per day, five days per week by a contractor. Eletronuclear will provide oversight of the Decommissioning General Contractor's (DGC) activities.

4. Unescorted access to the work site will be permitted.

5. The cost of 20 hours of training has been included in the estimate. This training includes radiation worker training, general safety course and general employee and site training.

6. Coordination of decommissioning will not conflict with other work in the area.

7. Eletronuclear will perform all activities associated with the planning for the Safe Storage period, implementing Safe Storage and performing all activities during the Safe Storage period, for all facilities.

8. Eletronuclear will obtain appropriate environmental and licensing documents prior to the start of decommissioning activities.

9. There are no special permits or requests for shipping waste to burial sites or landfills. All shipments will follow the Eletronuclear procedures.

10. Office trailers and sanitary facilities will not be required. Warehouses available onsite will be used by the contractors for offices and storage.

11. All radioactive waste will be packaged in either 200 liters drums or B25 boxes (or similar metal boxes) and disposed at the CNEN facility. Clean waste will be packaged and transported in 30 cubic meter trucks and disposed at a local disposal facility.

12. All costs are calculated in 2017 Brazilian Reais (R$) at a rate an exchange rate of R$3.2 to 1 $US.

13. Decommissioning activities will be performed by an outside contractor.

14. The personnel hourly billing rates for project activities are as follows (referenced to February 2016):

a.	Project Manager	R$ 358.78
b.	Radiological Protection Technician	R$ 93.75
c.	Project Engineer (medium)	R$ 109.64
d.	Senior Engineer	R$ 147.56
e.	Site Supervisor	R$ 178.58
f.	Decommissioning Technician	R$ 56.41

g. Laborer (Junior Technician) R$ 46.75

h. Waste Specialist/Shipper R$ 109.64

15. Survey instruments for decommissioning activities will be supplied by and calibrated by the Decommissioning General Contractor (DGC).

16. The costs of all equipment needed for this project are included within this estimate.

17. Utilities such as electricity, phone, water and other needs required for the project will be provided by Eletronuclear at no cost to the DGC.

18. All subcontract work, purchased and rented equipment or material are subject to an 8.00% contractor markup.

19. All footings and foundations will be removed.

20. Pilings will be cut off at the lowest part of the foundation and will remain.

21. All decommissioning activities associated with the support facilities will be performed concurrently with the Angra plant decommissioning, as resources become available or during the Safe Storage periods.

22. The following waste assumptions are assumed (These costs do not include project contingency):

a. Waste volumes stated consider inefficiencies from packing various sized components to be offset by efficiencies from using a dedicated waste volume reduction crew.

b. All operational waste, spent and new nuclear fuel, asbestos and resins will be removed during the transition period prior to the start of decommissioning.

c. The total cost for the disposal of clean waste will be R$45.70 per m^3. This value includes the rental of the truck, transportation costs, disposal costs and taxes. The distance to the disposal site is less than 200 kilometers.

d. The total cost for the disposal of low level radioactive waste will be R$17,379 per m^3. This value includes container, transportation and disposal costs; and taxes.

e. The total cost for the disposal of low level, high activity radioactive waste will be R$58,668 per m^3. This value includes liner, cask rental, transportation and disposal costs; and taxes.

f. The total cost for the disposal of low level radioactive waste packaged as its own container will be R$15,081 per m^3. This value includes transportation and disposal costs; and taxes.

g. The total cost for the disposal of intermediate level high activity radioactive waste will be R$58,668 per m^3. This value includes liner, cask rental, transportation and disposal costs; and taxes.

h. The total cost for the disposal of high level radioactive waste will be R$208,461 per m^3. This value includes liner, cask rental, transportation and disposal costs; and taxes.

i. The following waste containers were assumed for this estimate:

- LLW and ILW – Metal boxes similar to B-25 boxes
- LLW-HA and ILW-HA – Metal liners and CNS-8-120 shipping casks*
- HLW – Metal liners and CNS-3-55 shipping casks*

*these casks will reduce dose rates to the public during shipping.

j. The removal of all spent nuclear fuel from the in-plant storage pools to temporary storage at an independent onsite storage facility will be part of operations and included in the cost of the transition period. The decommissioning of the independent spent fuel storage facility is included in this cost estimate.

k. The waste in the storage containers located in the DIGV will be removed as part of the operational activities during the transition period. The removal of the steam generators, reactor pressure vessel head, heat exchanger, and other components will be included in the decommissioning cost estimate.

23. Transition tasks prior to safe storage, such as 1) draining and drying systems, 2) decontamination for dose reduction and 3) removal of operational and legacy waste will be performed by the operations staff as part of the Transition Period.

24. The removal of the electrical switchyards and non-radioactive buildings are not included in this cost estimate.

25. All waste will be moved by motor vehicle over the current road system.

26. Component quantities were developed from site specific information such as a system database, piping and instrument drawings and/or construction reports.

27. Structure inventory quantities were developed for this estimate from general arrangement drawings and the site walk down.

28. No PCBs, asbestos, lead or other hazardous material is supposed to be on-site at the start of decommissioning.

29. The decommissioning will be performed under the current CNEN regulations. These regulations require a Final Decommissioning Plan to be submitted prior to implementing any decommissioning activities.

30. Angra 2 and Angra 3 reactor vessel and internals are considered identical.

31. Angra 1, Angra 2 and Angra 3 reactor vessel and internals will be removed sequentially.

32. It is assumed that Angra 1, Angra 2 and Angra 3 will shut down in 12/31/2044, 9/30/2061 and 12/31/2082, respectively. This assumes a normal 40-year operating period and an additional 20-year life extension for all three nuclear power plants.

33. The costs of all required decommissioning safety analyses, radiological programs, environmental programs, and safety measures for the protection of the general public, the environment and decommissioning workers are included in the cost estimates.

34. Any severance payment to workers at the time of plant shutdown and at the end of the transition period will be part of the transition period cost, Appendix 2. A 40% (FGTS penalty) severance payment will be made to decommissioning workers at the end of decommissioning activities plus .65% of the last year's salary times the number of years worked as a retirement incentive. An average of 30 years of employment and the current salary for the various labor categories will be used to calculate these costs.

35. The following buildings are considered to contain contaminated or activated equipment, systems and components: 1) The Angra 1 Reactor Building, North Auxiliary Building, South Auxiliary Building, Fuel Building and Safety Building; 2) The Angra 2 Reactor Building, Auxiliary Building, Gas Discharge Chimney, and Main Steam Valve Room; 3) The Angra 3 Reactor Building, Auxiliary Building, Gas Discharge Chimney and Main Steam Valve Room, 4) The Waste Monitoring Building, and 5) the Steam Generator Storage Building. All the other buildings are considered free of contamination and will receive a final survey to verify this condition prior to clean demolition.

36. The taxes as shown in Table 8.1 will be applied to the material and services as indicated.

Table 8.1 – Tax Rates

	Eletronuclear Purchase		**Contractor purchase**	
	National Tax	**International Tax**	**National Tax**	**International Tax**
Material	29.25%	73.48%	29.25%	0.00%
Equipment	29.25%	73.48%	29.25%	0.00%
Staff and Workers	0.00%	0.00%	0.00%	0.00%
Service	14.25%	46.21%	14.25%	0.00%

The National tax to be paid by Eletronuclear will be added to all material, equipment and services purchased in Brazil. This will include disposal drums and metal boxes, metal liners, and waste transportation and disposal services. The International Tax that will be paid by Eletronuclear will be added to all material and services provided from outside Brazil. This will include the cost of waste overpacks and casks.

The National Tax paid by the Contractor will be added to any material, equipment and services purchased in Brazil. The International Tax paid by the Contractor will be included in the Contractor's agreement, and Eletronuclear will pay the taxes for international purchases in these cases. These taxes will amount to 46.21% for services and 73.48% for material and equipment.

No tax is added to the Staff and workers for either Eletronuclear or the Contractor, no matter where they work.

37. Regrading and landscaping of the site will not be included.

38. No soil other than that necessary for exposing footings will be removed. All removed soil is assumed to be uncontaminated and placed back in the excavations after surveying the excavations.

8.1.4 Cost Estimate Approach

The preliminary decommissioning cost estimate for the Angra nuclear power plants considers site-specific data, cost estimating methodology, experience and catalog data, and relevant assumptions as described in this document. The site-specific data was obtained from drawings and documents; radiological survey information and discussions with Angra personnel. The information was reviewed for the cost estimate analysis and for determining material takeoffs.

The basic approach is to estimate activity based costs for performing decommissioning activities using unit cost factors for routine work and a specific estimate for special tasks. The activity based cost is complemented by period-dependent costs. Period dependent activities are associated with the project duration and include staffing for project management, security, engineering, safety, licensing, radiological protection, taxes, fees, energy and other general costs.

8.1.5 Results of Cost Estimate Analysis

Table 8.2 provides a summary of decommissioning costs by facility and ISDC phase. The information presented in this table is based on the "Preliminary Decommissioning Cost Estimate PDCE – CNAAA", Appendix 1 and on the "Cálculo Preliminar do custo do Período de Transição do desligamento permanente ao período de "estado seguro" (safe Storage) das usinas nucleares de Angra1, Angra2 e Angra3", Appendix 2.

The total cost to decommissioning the facilities included in this study will be R$ 7.990.823.165,0.

Table 8.2 – Cost Estimate Results

Activity Description	Angra 1 Cost (R$)	Angra 2 Cost (R$)	Angra 3 Cost (R$)	Support Buildings (R$)	Total Cost (R$)
Pre-Decommissioning Activities	R$ 65.147.715,37	R$ 64.631.044,50	R$ 62.600.914,88	R$ 443.492,84	R$ 192.823.167,59
Transition *	R$ 464.148.427,59	R$ 470.958.763,03	R$ 470.958.763,03	R$ -	R$ 1.406.065.953,66
Prepare for Safe Storage	R$ 223.000,00	R$ 223.000,00	R$ -	R$ 48.000,00	R$ 494.000,00
Dismantling Activities	R$ 271.308.629,00	R$ 438.444.618,50	R$ 423.790.072,12	R$ 9.111.004,29	R$ 1.142.654.323,91
Waste Processing, Storage, Disposal	R$ 179.266.389,85	R$ 314.026.261,07	R$ 382.390.673,74	R$ 15.586.300,06	R$ 891.269.624,73
Site Security, Surveillance, Maintenance	R$ 263.176.045,45	R$ 192.298.767,37	R$ 113.689.473,50		R$ 569.164.286,32
Conventional Dismantling, Demolition, Site Restoration	R$ 225.663.570,22	R$ 290.905.004,09	R$ 290.905.004,09	R$ 20.471.206,45	R$ 827.944.784,86
Project Management, Engineering, Site Support	R$ 502.294.533,88	R$ 482.039.948,28	R$ 459.575.778,80		R$ 1.443.910.260,97
Miscellaneous	R$ 165.857.810,19	R$ 188.333.160,19	R$ 120.024.510,19		R$ 474.215.480,57
Project Contingency (15%)	R$ 320.562.918,23	R$ 366.279.085,06	R$ 348.590.278,55	R$ 6.849.000,55	R$ 1.042.281.282,39
TOTAL COST (R$) **	**R$ 2.457.649.039,8**	**R$ 2.808.139.652,1**	**R$ 2.672.525.468,9**	**R$ 52.509.004,2**	**R$ 7.990.823.165,0**
TOTAL COST (US$)	**R$ 768.015.324,9**	**R$ 877.543.641,3**	**R$ 835.164.209,0**	**R$ 16.409.063,8**	**R$ 2.497.132.239,1**

* Based on Appendix 2
** Currency Conversion Rate 3,20 R$/US$

Based on the current study, the cost to decommissioning Angra 1 will be R$2.457.649.039,8, Angra 2 will be R$2.808.139.652,1, Angra 3 will be R$2.672.525.468,9 and the support buildings will be R$52.509.004,2. These values include a normal 15% contingency.

8.2 Decommissioning Funding

8.2.1 Funding Mechanism

There are several types of financial mechanisms that can be used to fund a decommissioning plan. The mechanism that is used to fund the CNAAA decommissioning fund is direct monthly contributions based on the amount of electricity sold. This fund is internal in the federal financial system. The holder of the fund is ELETROBRAS Holding, by a determination of the National Council of Energy Policy, according to Resolution nº 8 of 17/09/2002 – CNPE [59]. The fund is managed and controlled by ELETROBRAS Holding. The financial investments of the proceeds from the own income of the mixed economy companies in an extra market investment fund of a federal financial institution, pursuant to Central Bank of Brazil Resolution nº 4034 of 30/11/2011 [60] and Resolution of the National

Nuclear Energy Commission No. 204 of 10/26/2016 [61]. ELETROBRAS ELETRONUCLEAR does not have full control of the fund. The national legislation prohibits the use of resources in activities not linked to decommissioning, ensuring that this money will not be used for other purposes.

The funds are collected during the useful life of the plant, through a standard revenue approved annually by the National Electric Energy Agency (ANEEL), according to the PRORET Tariff Regulation Procedures Sub-module 6.7 Angra 1 and 2 Generation Plants [62]. The amount collected each year is approved by ANEEL in the fixed revenue in annual quotas are collected in twelve installments, monthly in the account of the financial fund of Bank of Brazil with ownership of the ELETROBRAS Holding, specific to decommissioning. The current 2017 collection rate is R$ 4.56 per MWh, based on the contracted energy production of 13,778,835.15 MWh.

The collected funds are deposited in the Bank of Brazil, in public bonds, tied to a benchmark of 2% per year above the US Consumer Price Index (CPI), a procedure defined by ELETROBRAS in 2008 and maintained.

8.2.2 Current Fund

For 2016, the ANEEL Homologation Resolution 2006/2015 [63] established in the fixed revenue the quota of R $ 25,869,523.00 and for 2017 the established quota is R$ 62,889,619.56, according to RH 2193/2016 [64].

There is a current balance of R$ 566,409,548.34 in the Financial Fund of Bank at Brazil on 06/30/2017. Table 8.3 shows the accumulation of the decommissioning fund for the past three years.

Table 8.3 – Current Decommissioning Fund

Non-current assets - Accumulated financial resources			
Balance of Funds in the Bank of Brazil R$			
Description	31/12/2015	31/12/2016	30/06/2017
Balance at the Beginning of the Year	334,869.384.36	492,937,885.82	494,715,006.20
Deposits in the fiscal year	26,621.276.10	55,631,322.73	44,153,035.81
Net income	131,447,225.36	(53,854,202.35)	27,541,506.33
End of year balance	492,937,885.82	494,715,006.20	566,409,548.34

9 SAFETY ASSESSMENTS

The safety assessment required in decommissioning activities, normally include the safety analysis and the evaluation of the potential hazards during the decommissioning process and their possible consequences. The safety assessment considers the identification of the different aspects relevant to the planning of decommissioning process (such as safety criteria, operational limits and conditions, hazard analysis of normal and abnormal decommissioning activities, potential consequences, preventive and mitigating measures and risk assessment) detailing the individual components or elements that affect the safety [2].

The removal of the radiological and non-radiological hazards associated with decommissioning of nuclear facilities must be established to protect the workers, general public and the environment during the process. Assessment of environmental consequences is provided in Chapter 10. The term hazard is used to denote an intrinsic property of an activity or a facility that represent a potential damage to human health or the environment.

In the context of the safety assessment the following actions [65, 66] must be considered:

- Calculations of source term of radiation fields and release;
- Fire protection considerations;
- Simulation of release, added to its possible consequences (Generally the most conservative scenario);
- Structural analysis to the intermediate configuration of plant;
- Acceptance criteria in terms of consequences of hazards.

Assumptions and clarifications stated that are applicable for safety assessment of the decommissioning process include:

- All low and intermediate level radioactive waste will be packaged in either 200-liter drums or B25 boxes (or similar metal boxes) and disposed at the CNAAA facility.
- All LLW-HA and ILW-HA will be packaged in metal or polyethylene liners which will be transported to disposal in 8-120 shipping casks.
- All operational waste, spent and new nuclear fuel and resins will be removed during the transition period.
- Some ILW-HA radioactive resins and filters will be generated during the decommissioning.
- No polychlorinated biphenyls (PCBs), asbestos, lead or other hazardous material will be on-site at the start of decommissioning. The safety assessment will not consider impacts from these materials and waste.
- The site will be released to international standards criteria.

9.1 Identification of relevant safety criteria

The potential hazards should be classified according to their frequency or probably of occurrence, to associate them with the appropriate acceptance criteria. Consequently, an analysis of causes, evolution and consequences can be analyzed for the most representative event, always considering the adopted design criteria [65-67].

The criteria used to evaluate the safety assessment applied in decommissioning activities can be classified as below [2]:

- Dose and safety to workers;
- Dose and safety to members of the public;
- Discharges to the environment;
- Exposure to chemical and other non-radiological hazards (when applicable);
- Hazards as consequences of Industrial activities.

9.2 Operational limits and conditions

In the decommissioning process, it is necessary to perform a review of the existing operational limits and conditions during the normal operation of plant, identifying which of them continue, and performing a review and providing a justification for their applicability during decommissioning activities (new criteria can be defined, if applicable). More importantly, it is necessary to consider that some of the operational limits and conditions would be unnecessary impediments during decommissioning activities as the risk level reduces significantly after the spent fuel is moved from the site to interim or final storage. The safety case could be modified to exclude those operations, and the safety mechanisms designated as protection for faults associated with those activities can be formally removed from service and the safety case and technical specification modified accordingly. The objectives of task specific limits in the process will establish an optimization in the decommissioning plan [65-67].

The table 9.1 identifies some differences between operation of plant and decommissioning activities.

Table 9.1 - Differences between activities of operation and decommissioning. [65]

	In operation process	In decommissioning process
Hazard profile	• Stable	• Frequently changing.
	• Radiological hazards dominants.	• Significant industrial safety issues.
	• High potential for off-site consequences.	• Low potential for off-site effects.
Hazard analysis	• Often-stable focus on off-site effects.	• Dynamic and changeable. • Focus on site effects.
Work planning	• Frequently is performed a routine.	• Activities planning for workplace critical safety.
	• Focus on operation and maintenance, normally short activities.	• Task oriented having some of them new task, first of a kind.
Workforce Experience	• Focused in operation of plant, routine work.	• News activities with limited experience. • Subcontractors may not have knowledge of the process or the plant operations. • Knowledge may need to be maintain for long periods.
Contract management	• Licensee managed and operated.	• Is necessary for strong project management.
		• High dependence on contractors performance.

Transportation radiation and contamination limits for radioactive shipments are currently defined and will continue to be applied during decommissioning. Effluent discharge limits will continue to be applied for radioactive aerial and liquid discharges. The routine dose limits and action levels are appointed and justified, with bases on the Basic Safety Standards and national regulatory requirements.

9.3 Hazard identification for decommissioning activities

The main hazards during the decommissioning process includes industrial hazards and potential exposures to worker and members of the public from activities of dismantling, decontamination, surveying, handling and moving, and packaging of components. This subsection provides the identification and analysis of the radiological and non-radiological hazards and it must be performed for individual activities (According to the decommissioning strategy, "anticipated activities and the results of characterization survey"). In addition, standard external events and hazards relative to decommissioning process must be evaluated, if applicable [66].

For main radiological hazards, should be considered at least the following items [66]:

(i) Criticality: Not applicable as the fuel has been completely removed from the reactor and placed into interim storage.

(ii) Direct exposure: The presence of source materials, activation products and contaminants can pose direct radiation hazards during decommissioning activities. For example, irradiated stainless steel internal components of a reactor pressure vessel can cause direct radiation exposure of workers.

(iii) Internal exposure: If radionuclides are present in the work area in the form of removable surface contamination, workers and the public can be subjected to internal radiation exposure by ingestion or inhalation. The hazard from inhalation is of particular concern in the case of activities carried out in areas or premises contaminated with alpha emitting radionuclides.

(iv) Liquid and gaseous radioactive effluents: Some of the waste generated during the decommissioning of a facility can have different forms and characteristics to those generated during operations. This is because the materials involved in decommissioning and some associated activities (e.g. cutting and decontamination) can be different from those employed during the operating stage. In addition, the amounts of liquid effluents generated from decontamination operations can be larger during decommissioning than in the operational phase, while the amount of gaseous effluent generated from ventilation of work areas is usually smaller than during the operational phase.

(v) Erroneous free release of materials: Some materials, such as concrete and metals, can be freely released, i.e. removed from regulatory control, if their activity content is below clearance levels. The potential for erroneously releasing material with activity content in excess of these clearance levels has to be identified in the safety assessment.

For main non-radiological hazards, consider the following items [67]:

(i) Combustible and flammable materials: Fire is the conventional hazard that is of most common concern in facility decommissioning projects. The methods used for certain equipment dismantling operations (e.g. thermal cutting techniques) or for decontamination of surfaces (e.g. use of aggressive decontaminating solutions) are often the cause of local fires. Moreover, while dismantling activities are in progress, the temporary accumulation of combustible materials and waste (e.g. plastic and cotton) is common, thus increasing the potential for fires in the area. In addition, explosions can occur during decontamination and dismantling as a result of the chemical reagents and equipment used. Some materials generated in the process of dismantling a facility, such as inflammable dusts, can, in certain circumstances, acquire explosive characteristics.

(ii) Toxic and otherwise hazardous materials: The dismantling of facilities sometimes reveals that they were built using materials that are now forbidden and the removal of which requires special measures because of their toxic or otherwise hazardous properties. It is common, for example, to find asbestos in thermal insulation or in fire barriers, lead in paint, counterweights and shielding, and PCBs in oils and electrical insulation. Furthermore, some of the materials used in the decommissioning process, such as decontamination chemicals, may be toxic and hazardous.

(iii) Electrical hazards: The use of power sources and electrical equipment during decommissioning can be a general hazard to workers, which must be recognized and addressed effectively. Temporary electrical equipment used during decommissioning activities can increase this potential hazard.

(iv) Physical hazards: During decommissioning work, physical hazards exist that are typically associated with demolition activities or with the construction and use of temporary facilities, for example, collapse of structures, falling of heavy objects, injury from sharp objects, occurrence of abnormal events during the use of material handling equipment and hazards due to falling from heights.

(v) Natural hazards: The natural hazards that were considered for the operational phase of the facility may still be relevant, and some, for example, flooding, may, at some phases of decommissioning, present a higher risk than they did during operation.

The elimination or reduction of radiological and non-radiological hazards is necessary to protect the workers and the public during decommissioning activities. These hazards need to be identified and their consequences (doses to the workers and the public along with industrial impacts) determined to provide an assessment of risk and provide preventive and mitigation strategies.

Potential hazards are identified in Table 9.2 for specific events that could occur during decommissioning, and safety assessments will be performed to determine consequences of event. Each event indicates whether a radiological or industrial assessment should be performed. In several cases both radiological and industrial assessments need to be performed for the single event.

Table 9.2 - Hazard Identification for Decommissioning Activities [67]

GENERAL EVENT	SPECIFIC EVENT
Decontamination	Radioactive Vacuum Filter Bag Rupture for dose consequences.
	Loss of supporting systems such as electricity, service water or air during radioactive decontamination activities for dose consequences and industrial hazards.
	Gross Leak during in-situ and surface decontamination for dose consequences and industrial hazards.
Dismantlement	Concrete shaving and bulk debris removal for radiological dose consequences and industrial hazards.
	Segmentation of irradiated and radiologically surface contaminated metal components and Reactor Coolant System piping for dose consequences and industrial hazards.
Material Handling	Drop of a radioactive waste package for dose consequences.
	Drop of a contaminated component or filter for dose consequences.

	Drop of a heavy load for industrial hazards.
	Security of contaminated components and radioactive material packages.
	Accidents during off-site transportation of radioactive packages and un-packaged materials for dose consequences.
	Erroneously releasing materials with radioactivity content in excess of clearance levels.
Electrical Power, Service Air or Water	Loss of any HEPA filtration or integrity of ventilation enclosure for dose consequences.
	Crane and equipment stoppage during heavy lift of radioactive component for dose consequences and industrial hazards.
	Sudden interruption of the operation of decontamination / dismantlement equipment during cutting and dismantling for dose consequences and industrial hazards.
	Electrical industrial hazards.
Fire	Fire / Explosion of Ion Exchange Resin in Polyethene Liner for dose consequences.
	LLW or ILW fire in a B25 box or 200 liters drum for dose consequences.
	Fire in the radioactive waste package storage building for dose consequences.
	Fire in work areas (contaminated PPE and combustible wastes) during dismantlement activities for dose consequences and industrial hazards.
Explosion	Explosion of LPG, or other gas that leaks from material handling equipment or equipment used for dismantlement for dose consequences and industrial hazards.
	Explosion of oxyacetylene tank in radiological area for dose consequences and industrial hazards.
Abnormal (Natural events)	Effects of flooding, tornados, earthquakes, on decommissioning activities.

9.4 Assessment of potential consequences

This subsection provides the description of the assessment process of potential consequences to workers, public and the environmental from the hazard scenarios during the decommissioning activities. The radiation doses to workers and the public, as well as the activity content in releases to the environment from decommissioning activities will be determined by these assessments.

The assumptions and methods for input into the assessments for hazard consequences must be described and justified. In addition, potential physical injuries to workers, from industrial hazards will be described. Reference to any data sources applied will be identified. The assumptions that have been made in the assessment of consequences must be clearly stated and justified. [2].

Modeling and calculation of consequences [66] in hazard analysis establishes a link between activities or activity concentrations in materials and radiation doses to people. The calculated doses will be compared with dose limits/dose constraints to identify the level of risk from the event. Alternatively, the authorities may prescribe activity concentrations in environmental media with which the results of the models have to be compared. The level of complexity of these models will vary according to the initiating decommissioning event, source term inventory, mechanisms for radionuclide release and industrial safety issues.

To evaluate radiation exposures from planned activities and potential accidents, the calculation models need to incorporate the following main components:

- The radioactive source inventory available upon initiation of hazard event (i.e. dimensions and weights, radionuclide constituents and specific activities, total radioactivity is identified and justified);

- Initiating event that occurs during a decommissioning activity listed in table 9.2;

- Fraction of radioactive source inventory that is subject to release;

- Location of event (i.e. inside the building and ventilation filtration control boundary or outside of this boundary) is identified;

- Time frame that workers and members of the public are exposed is identified and justified;

- Radionuclide transport processes; produced by initiation of event (e.g. explosion), plant ventilation systems, transfer into the atmosphere, hydrosphere and soil are identified and justified;

- Exposure pathways for worker, members of the public and environment (i.e. external exposure, inhalation of the plume, external exposure to deposits from the plume, ingestion of contaminated food and water) are identified and justified.

For environmental consequences, Chapter 10, Environmental Assessment will assess the impact of discharges of radionuclides to the environment through air, water, and terrestrial and aquatic foods.

The assessments of potential consequences must define conditions in decommissioning which lead to the event initiation. For example, oxyacetylene is used to thermally cut and remove steel and flashbacks or nozzle tip obstructions can occur resulting in an explosion and physical injury to workers. These events can lead to other hazards including fires of nearby radioactive wastes and packaging. The subsequent fire must also be analyzed for dose consequences to the workers as well as consideration of off-site doses to members of the public. The location of the event is also important. The event must be analyzed for occurrence inside the building with the resultant plume exhausted through the plant ventilation system which would minimize off-site dose consequence if filtration is in place. The event could also occur outside the building and have a direct path to members of the public. The dose consequence to members of the public needs to be calculated at the site boundary to determine the maximum-exposed individual.

The source term available for release during these events will be based on size, weight and maximum radioactivity that could be packaged into either a 200 liters drum B-25 box or 8-120 polyethylene liner. The maximum radioactivity is limited by waste classification and/or allowable dose rates on package during transportation.

The time frame to get the fire under control and extinguish is based on plant fire system actuation and/or brigade response. In lieu of response time an assumption on total time before the fire self-extinguishes can be made.

With the conditions defined, the assessment for dose consequences can be conducted. Calculations will be performed as described in the Decommissioning Plan, Chapter 11; Health and Safety.

9.5 Most limiting credible events

Table 9.2 lists general events that are performed in the conduct of facility decommissioning. Specific events are then identified as potential scenarios during performance of the general events. All events will need a level of effort to assess potential consequences however, two events will provide bounding consequences for decommissioning events. These events are the most limiting credible events.

The first event is the explosion and subsequent fire of an Ion Exchange Resin Polyethene Liner (model number PL 8-120). The source of this waste stream is from the demineralization of liquid wastes and collection of sludges generated during decommissioning. The radioactivity available for release should at the upper limit for ILW-HA. This event should be assessed for external and internal dose consequences to worker(s) in the general area and to members of the public at the site boundary. The member of the public dose assessment should include dose consequences from

1) Stack release with credit taken with installed ventilation filtration;

2) Stack release with no credit taken from the filtration;

3) Outside yard event with no filtration.

The member of public dose consequences should include exposures from external, internal inhalation and ingestion and external exposure from deposition.

The second event will consider a crane lift malfunction. In this event the reactor building polar crane is performing a lift of the radiologically activated core barrel with baffles and formers intact. Although it would be expected that this lift would occur underwater, for purposes of determining dose consequences, it would be assumed that the lift continues until the core barrel completely breaches the surface of the water and then stops, leaving the activated metal exposed in the reactor building. The mitigating action would be to lower the core barrel back into the water however this would not be possible until corrective actions are taken to repair the crane to restore proper operation.

The dose consequence to workers will need to be assessed including external and possible internal from airborne contamination. It can be assumed that no member of the public will be exposed from the polar crane failure event.

9.6 Risk Assessment

The risk assessment for workers and members of the public must be performed considering the consequences of radiological and industrial hazards. The degree of potential hazards (considering likelihood, frequency and calculated consequences) and results of the risk analysis will help minimize them. The risks will be classified accordingly of their potential hazards and, for the higher levels it should demonstrate that the preventive and mitigation measures can assure the development of decommissioning activities with sufficient defense in depth, and provide the hierarchy of preventive and control measures that will be employed in engineered as well as administrative actions.

For the lower levels of risks, appropriate analysis can include performance of cost-benefit analysis, which will help the optimization of the decommissioning process. For these reasons, the boundary of risk assessment as well as any deductions and important assumptions that could be made from it are identified and provided.

Table 9.3 provides the basis for classifying decommissioning event scenario risks based on consequences [66]. A preliminary safety assessment is used to assess unmitigated radiological consequences and a frequency band for occurrence determined on a conservative basis. From the table, the appropriate risk class can be determined for each scenario. Facility classification can be allocated on the basis of the highest risk class determined. When accident scenarios become complicated (because multiple outcomes are possible), it may be necessary to use event trees or fault trees to adequately track and describe frequencies and illustrate dominant scenarios, though the need for this will be rare in decommissioning safety assessment. The frequency of the event should be taken into consideration, not merely a single element of the fault tree. For example, although the frequency of a vehicle accident may be anticipated, an accident that strikes and breaches radioactive waste containers, and catastrophically ruptures the fuel tank and ignites would not be considered anticipated.

The definitions and requirements in the safety assessment for each of the four risk classes are as follows:

(a) Risk class I events are essentially those that could have a significant off-site consequence; therefore, the public must be protected with higher integrity engineered safety measures (SSCs) and administrative safety measures (with engineered measures being preferred). Events resulting in high off-site radiological consequences must be subject to detailed safety assessment, irrespective of the assessed frequency of occurrence.

(b) Risk class II events are those that have lesser off-site consequences than risk class I, but significant on-site effects. Both classes I and II must also be considered for protection with high level SSCs and administrative safety measures. The consideration of control(s) should be based on the effectiveness and feasibility of the considered measures. Further controls for class I and II accident sequences should be considered over and above the requirements of the accident safety criteria, if it is justified on ALARA grounds. This is sometimes described as defense in depth.

(c) Risk class III events are those with localized consequences. They are generally considered to be adequately protected by the operator's safety management program. Class III accidents may be considered for defense in depth safety measures, if justified on ALARA grounds. A formal safety assessment would not normally be required, unless required by the regulatory body.

(d) Risk class IV events are those with low consequences and do not require additional safety measures, but are considered to be adequately protected by the operator's safety management program, and consequently a documented safety assessment is not usually required.

It is common practice to classify an event based on the highest risk class arising from the unmitigated accident safety assessment. This classification can then be used to define the level of independent review and the regulator's review of the safety assessment. For example, a risk class I event safety assessment would be subject to full internal independent review, as well as regulatory review. A risk class II facility may only be subject to internal review, unless the regulator specifically chooses to carry out a review.

Table 9.3: Accident Consequence x Frequency - Risk Classification System [66]

Consequence	Beyond extremely unlikely	Extremely unlikely	Unlikely	Anticipated
level	($<10^{-6}$ /y)	(10^{-4}–10^{-6}/y)	(10^{-2}–10^{-4}/y)	(10^{-1}–10^{-2}/y)
High consequence	III	II	I	I
Off-site public		SAR, safety	SAR, safety class controls for the public, safety significant for workers	SAR, safety class controls for the public
(>100–1000 mSv)		significant		
On-site		controls		
(>1000 mSv)				
Moderate consequence	IV	III	II	I
Off-site public			SAR	SAR
(>10–100 mSv)				
On-site				
(>100–1000 mSv)				
Low consequence	IV	IV	III	III
Off-site public				
(<1–10 mSv)				
On-site				
(>10–100 mSv)				

The results of the safety assessment are compared with the relevant safety criteria, and, where necessary, the limits, controls and conditions needed to secure the safe conduct of decommissioning will be identified. In establishing the limits, controls and conditions, it should also be demonstrated that the associated risks are ALARA [66].

9.7 Preventive and Mitigate Measures

The preventive and mitigation measurements for radiological and industrial hazards and consequences to the workers, members of the public and the environment as well as the administrative preventive measures, will be developed performing an identification considering two groups: the first include those that make a significant contribution, and the second include those that present little or no additional contribution. To achieve the required safety function of the administrative preventive measures it is necessary to identify and provide the specific actions, taking into account reference to checking supervision. These can help to ensure that the specific actions were developed correctly.

The safety function and performance of each structure, systems and components must be considered for preventive and mitigation of the consequence; and the degree of redundancy diversity and segregation for each one as well as detail of the performance requirements and specific actions for the administrative measures included. The national regulatory requirements identify examination, maintenance, inspection and testing requirements in all systems, structures and components. It is necessary to ensure that the responsibilities for each one as well as the administrative preventive measures are described in detail.

To mitigate the potential effects and reduce the impacts on the workers, members of the public and the environment, the preventive and mitigation actions will be developed for potential hazards scenarios. In addition, a description of how the requirements will be continued (satisfied) during decommissioning activities [2].

9.8 Comparison of analysis results with relevant safety criteria

The main objective of the safety assessment during the decommissioning process is to identify potential hazards, estimate their consequences, and propose the adequate measures to prevent and mitigate its impacts, to guarantee the safety of the decommissioning activities in all different scenarios [66]. The comparison of assessment results with the relevant safety criteria previously identified will be presented in this section. This comparison process includes the both of following aspects [66]:

(i) Appropriate hazards management strategies selected to eliminate potential hazards, if applicable.

(ii) Adequate safety control measures will be identified to support delivery of the chosen decommissioning strategy.

The safety criteria may require that the radiological effects on workers and members of the public should be evaluated (including dose limits to workers; limits on radioactive discharges from liquid or aerial releases; dose limits to the critical group; limits on concentrations of chemical and toxic substances). Then, the total radiological effects (total effective dose) to workers and members of the public will be evaluated and compared with relevant limits will be presented in this section.

It is important to demonstrate that the safety control measures will be robust and can reduce the risks [66].

The impacts related with environmental area and the comparison of analysis results with relevant safety criteria are shown in Environmental Assessment; Chapter 10 of the Decommissioning Plan.

10 ENVIRONMENTAL ASSESSMENT

This Chapter provides a summary of the environmental monitoring program for the facilities that will be undergoing decommissioning and identifies differences that are required to support the decommissioning activities. This information is based on the current environmental monitoring program [28, 68-71].

10.1 Background data

The decommissioning of the CNAAA is the final phase in the life-cycle of facilities that use or handle radioactive material after siting, design, construction, commissioning and generation of energy. It is a complex process with the objective of reaching the end state of the site allowing termination of the facility license. This includes the removal of all radioactive material from the site that is above the unrestricted release criteria. This process involves activities such as decontamination, dismantling and demolition of equipment, structures and buildings, and management of resulting radioactive and conventional waste [1]. During this process, radioactive and non-radioactive pollutants may be discharged to the environment. These discharges will be controlled and monitored to ensure the health and safety of the operating personnel and general public, and protection of the environment.

The nuclear and radiation protection regulations and requirements applicable to the decommissioning of the CNAAA are enacted by the Comissão Nacional de Energia Nuclear (CNEN) [1, 7, 28]. The environmental protection regulations and requirements applicable to the decommissioning of the CNAAA are enacted by the Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais (IBAMA) and are consolidated in the document ELPN/IBAMA no. 017/99 [68]. To meet these requirements, Eletronuclear has prepared an Environmental Impact Assessment (EIA) for Angra 3 presenting the environmental impacts, monitoring systems and means to mitigate these impacts [72] during decommissioning. Much of the information in the EIA describing the systems and procedures are also applicable during decommissioning. Eletronuclear will decommission the CNAAA considering relevant Brazilian and international regulations, standards and handbooks [1, 2, 7, 23, 28, 30, 32, 68, 73-76].

10.2 Description of the project

The strategy for decommissioning the CNAAA is described in Chapter 3 and the main decommissioning activities are described in Chapter 5. The decommissioning activities that could potentially cause hazards to workers, public and the environment involve both radioactive material and conventional material. As presented in Chapter 5, the higher risk activities occur during the transition and the decontamination and dismantling phases. Electronuclear considers the transition phase as part of the operational activities of the plants, but the cost is considered in this plan. During transition, all spent fuel (the majority of the radiological inventory) and operational radioactive waste will have been removed, and all systems not required for the decommissioning will have been deactivated. In summary, the remaining higher risk decommissioning activities are associated with the decontamination and dismantling of structures and equipment, and the packaging and transportation of the resulting radioactive waste. The environmental media which may be impacted by these activities are air, soil and water.

Most activities dealing with contaminated or activated materials occur inside buildings with some type of engineered confinement systems to prevent the release of radioactive material to the environment. The decontamination and dismantling activities use jets of gaseous, solid and liquid substances and produce different types of airborne particulate, solid, liquid and gaseous effluents. These effluents are monitored and released only if they comply with legal radiological or chemical release limits.

10.2.1 Decommissioning tasks that could result in environmental releases

The activities that could release radioactive material to the local environment are presented in Table 10.1. The activities that may cause industrial hazards to the public, workers and to the local environment are presented in Table 10.2.

Table 10.1 – Activities that could potentially release radioactive material to the environment

a) Reconfiguration in the reactor and other buildings to facilitate movement of equipment and materials, and decommissioning activities;
b) Insufficient ventilation capacity;
c) Malfunction of effluent control equipment;
d) Waste transportation accidents;
e) Damage to underground piping and tanks; and
f) Release of material exceeding the unrestricted release criteria.

Table 10.2 - Activities that may cause industrial environmental hazards to the public, workers and to the local environment.

a) Demolition of buildings with improper dust control measures;
b) Transportation accidents involving conventional waste to proper disposal sites;
c) Use of chemicals during decontamination activities with improper ventilation equipment.

10.2.2 Potential pathways for radioactive releases

The number of effluent release points will be minimized from the controlled areas. There are two major pathways for release of radioactive and industrial effluents from inside the controlled areas, the chimney and the liquid waste discharge point for each building or site. New pathways may be formed as the confinement structures are modified to allow equipment to be removed. This will be the case when a large opening is made in the containment structure to allow the removal of waste and equipment. Also new pathways will be formed when the buildings are demolished. This will provide new pathways for industrial effluents (dust).

10.2.3 Characteristics of the discharged radioactive materials

There are three main types of effluents: particulate (solids), liquid and gaseous material. All three of these effluents can have a radiological and industrial hazardous component.

The particulate effluents can be captured with HEPA filters. The gaseous effluents can be captured with various other filters used in conjunction with the HEPA filters based on the contaminants being released (i.e., charcoal). The liquid effluents can be filtered or evaporated to reduce material being released.

10.3 Environmental protection program

This environmental monitoring program monitors and evaluates levels of radiation in various pathways of air, water and soil media during the decommissioning period. It defines instrument and sampling procedures to monitor the environment, methods for data reduction, validation, and reporting requirements. The annual results of this program during the decommissioning of the 3 units and support facilities will be analyzed and compared with the results of the pre-operational period of the CNAAA. If the level of radioactivity observed in local samples or instruments exceeds the notification levels, they will be reported to CNEN [30]. If the level of other hazardous pollutants are exceeded, they must be reported to IBAMA.

The locations of current on-site and off-site monitoring stations are shown in Figure 10.1. Monitoring of ground and surface water, beach sand, alga, precipitation and fishes are also performed in more distant locations not shown in this figure. Table 10.3 reproduces the information from the Manual of Radiological Control of the Environment (MCRMA) [69] related to the location of on-site radioactive monitoring stations in the CNAAA. The quantity and number of monitoring stations in each nuclear power plant will be evaluated and revised, if necessary, before the decommissioning activities begins.

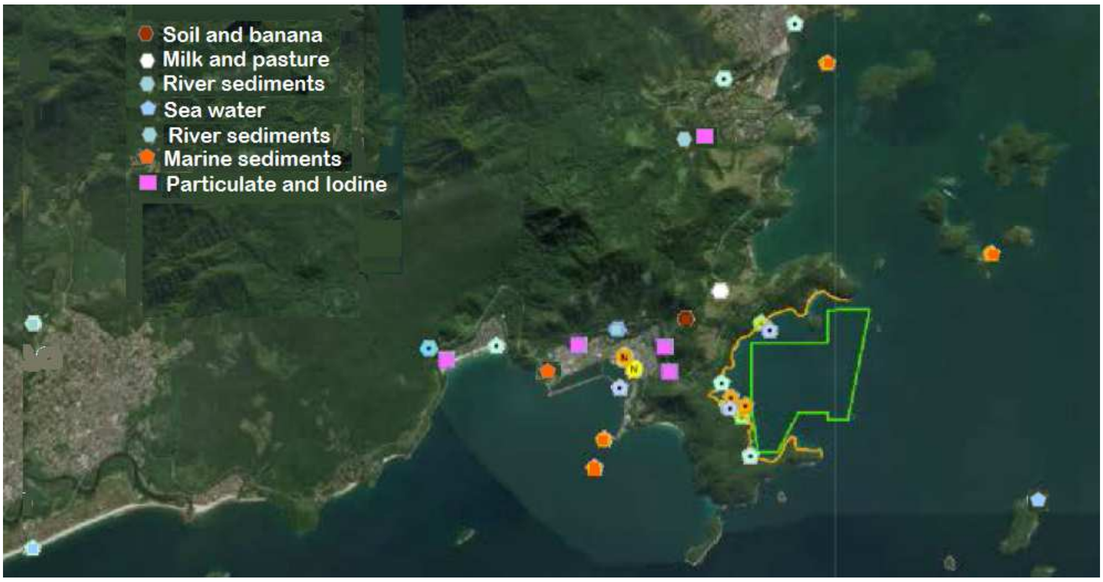

Figure 10.1 – Map showing the type of environmental monitoring at on-site and off-site locations in the CNAAA [61].

Table 10.4 presents the types of monitor systems for liquid and gaseous effluents. Their capability and detection limits for decommissioning monitoring will follow the requirements established for the operation of the power plants [69]. The frequency for performing monitoring, sample collection, replacement of filters and dosimeters are described in Table 10.5 [70]. The analytical procedures used for collecting samples, and perform measurements are described in Refs. [71, 72]. The background and baseline concentrations of radionuclides are presented in Ref. [71].

Table 10.3 – Location of on-site radioactive monitoring stations in the CNAAA [69].

Location	Types of monitoring
Angra 1 • Reactor Building (ERE) • North Auxiliary Building (EAN) • South Auxiliary Building (EAS) • Safety Building (ESE) • Fuel Handling Building (ECB) • Turbine Building (ETG) • Main entrance to the Angra 1 complex • Angra 1 fence	• Monitoring of radioactive liquid effluent lines in the buildings • Monitoring of radioactive gaseous and airborne particulate lines in the buildings • Monitoring of openings in the buildings • Area monitoring
Angra 2 • Reactor Building (UJA) • Auxiliary Building (UKA) • Turbine Building (UMA) • Stack (UKH) • Other buildings (UST, UBA, ULD) • Main entrance to the Angra 2 complex • Angra 2 fence	• Monitoring of radioactive liquid effluent lines in the buildings • Monitoring of radioactive gaseous and airborne particulate lines in the buildings • Monitoring of openings in the buildings • Area monitoring

Table 10.4 – Instruments utilized in the on-site environmental monitoring system during decommissioning [70].

Instruments	Observations
Total gamma radiation monitors for liquid and gaseous effluents	• For continuous monitoring liquid lines, gaseous lines and airborne particulates. • Some are connected to automatic systems for discharge interruption if radiation levels exceed limit values.
Flow rate meters for liquid effluent	• For measuring the volume of liquids being discharged
TLD monitors	• For monitoring ambient radiation levels around the decommissioning site
HEPA filters	• For air and particulates
Charcoal filters	• For measuring iodine in gaseous and airborne discharges
Terrestrial, water and air sampling	• For monitoring radioactivity level in milk, pasture, water from rainfall, and water from rivers and sea
Radiochemistry measurement for I, Cs and Sr, ^{3}H and alpha emitters	• For sample analysis
Gamma spectrometry	• For sample analysis
Beta radiation	• For sample analysis

Table 10.5 – Frequency for performing monitoring [70].

Monitoring	Frequency
Marine fish and algae	Once every 6 months
Marine sediments	Depending on locations, once every 6 months or 3 months
Sea water	Depending on location, once every month to once every 6 months. Mostly are once every 3 months
Milk, pasture, banana and soil	Once a year
Surface water	Once every 3 months
Water from the Frade and Manbucaba rivers	Once every 3 year
Water from the Itaorna bay and river sediments	Once every year
Airborne particulate	Once every week and analyzed every 3 months
Iodine	Once every week
Rain fall	Once every month and analyzed every 3 months
TLD	Once every 3 months

10.4 Effluent monitoring program

Neutrons escaping from the reactor core may result in the activation of reactor components and surrounding areas. The expected radionuclides generated by neutron activation are shown in Table 10.6 [32]. It is divided in three different types of activated materials: metal, concrete and other materials [32].

The contamination process occurs in the reactor core internals, primary loop piping, steam generator and auxiliary systems. Contamination deposited on internal and external surfaces of the plant is due to the transport and/or leaching of activated corrosion and erosion products or fission products and actinides. Table 10.7 shows radionuclides of concern that are deposited on inner surfaces of components [32]. They are divided into two types: fission products and actinides. Actinides are not expected since no fuel element failures have been observed. If fuel element failures are seen in the future, actinide sampling will be included in the environmental monitoring program.

Table 10.6 – The expected radionuclides generated by neutron activation [32].

Materials	Radionuclides	Information
Metal	^{54}Mn	^{54}Mn comes from ^{54}Fe present in steel construction of the vessel, fuel support structures and in primary circuit.
	^{55}Fe	^{55}Fe comes from ^{54}Fe present in larger relative amounts of carbon steel.
	^{63}Eu	^{63}Eu comes from ^{62}Sm present in copper-nickel alloy used in heat exchangers.
	^{60}Co	^{60}Co comes from ^{59}Co is tracer constituent in both carbon and stainless steels (80 to 150 and 230 to 2600, respectively).
	^{93}Zr	^{93}Zr comes from ^{92}Zr present in Zircaloy is used as cladding.
	^{94}Nb ^{93m}Nb	They come from ^{93}Nb present in relatively high levels in stainless steel (5 to 300 ppm).
	^{108m}Ag	^{108m}Ag comes from ^{107}Ag use of large amounts of silver in control rods.
	^{39}Ar	^{39}Ar comes from ^{39}K abundant in natural potassium which is present stainless steel and carbon steel at levels of hundreds of ppm.
Concrete	^{14}C	^{14}C comes from ^{14}N present in air and in most reactor materials, particularly in concrete.
	^{39}Ar	^{39}Ar comes from ^{39}K abundant in natural potassium which is present in concrete at levels of thousands of ppm.
Others	^{3}H	^{3}H can be produced in a reactor by various mechanisms. It comes from ^{6}Li produced by nuclear fissions. The concrete bioshield is also a source of production from the ^{6}Li.

Table 10.7 – The typical radioactive contamination on inner surfaces [32].

Materials	Radionuclides	Information

Fission products	^{90}Sr	^{90}Sr is the one of the most abundant fission products.
	^{99}Tc	^{99}Tc is also produced by $\bar{\beta}$ decay from ^{98}Mo.
	^{106}Ru	^{106}Ru can form volatile species in high temperature conditions and it can be present on metallic surfaces, forming quite strongly adherent layers.
	^{129}I	^{129}I is also produced by decay of ^{129}Te.
	^{137}Cs	^{137}Cs may cause inhalation hazards to the decommissioning work force.
	^{144}Ce	Because of its short life (half-life: 285 days), it is not a radionuclide critical for disposal.

The equipment currently used to monitor the effluent points will be like those identified in Table 10.4. It is recognized that equipment may change as technologies progress, but for the purposes of this plan, it is expected current equipment will be used.

10.5 Effluent control program

During decommissioning, the plant complex will be modified to have only one point of radioactive liquid effluent release and one point of radioactive gaseous effluent release to the environmental. These two points will be monitored according to the current CNAAA procedures [69]. To control and minimize releases, local portable ventilation, containments for liquid collection and fixatives will be used. The local ventilation systems will be connected to the plant lines directed to the unit release stack. In general the liquid effluent will be evaporated to concentrate the radioactive waste in the solid form. The evaporated effluent will be treated and released as gaseous or liquid effluents. The solid radioactive material will be disposed as solid radioactive waste.

These radioactive effluent monitoring systems will follow strict procedures regarding number of monitoring instruments, calibration and operation conditions, if these systems fail or some condition is not met, actions are defined in the MCRMA to circumvent these problems [69].

There are no known underground tanks or pipes containing radioactive material at the CNAAA.

The methods utilized to estimate of doses to the public are described in the MCRMA [69] and are based on national regulation and international guide [7, 77].

11 HEALTH AND SAFETY

Health and safety is governed by two programs: the radiation protection program and the industrial health and safety program. The program in place during the operating period form the basis for the continuing programs required throughout the decommissioning period. This information may be included in the decommissioning plan or be summarized in the plan with reference to these documents.

In these phases a collection of all information is needed to describe the characterization and survey requirements. The general information is:

- The hazards present in the facility;
- The condition of the facility structure as it may affect workers health and safety;
- The extent, nature, and concentration of radiological and hazardous chemical contamination;
- The internal, legal and technical restraints on decommissioning alternatives.

These phases are interactive processes that precede actual decommissioning.

This Chapter describes the radiological and industrial protection measures to be followed in all phases of the Central Nuclear Almirante Álvaro Alberto (CNAAA) decommissioning. The radiation protection basic standards to be followed are intended to ensure the safety of workers and members of the public as well as the environment [7, 78-85]. These standards and criteria aim at ensuring that workers involved in decommissioning operations are subject to ALARA (As Low As Reasonably Achievable) radiation level conditions, and the measured radiation levels outside the facility should be within the established limits as well.

By international recommendation, the decommissioning activities should be of practice and not of intervention, except in the event of incidents or accidents during decommissioning operations. Table 11.1 presents the CNEN criteria for Occupationally Exposed Individual and the values utilized by Eletronuclear which are lower. Below the Eletronuclear limit it is recommended an optimization process, e.g., the reduction of doses to levels considered ALARA.

Table 11.1 - Operational dose limit for occupationally exposed individual [78].

Whole Body	CNEN Limit	Eletronuclear Limit
	Effective dose	
Yearly	50,000 μSv	20,000 μSv
Average In 5 years	20,000 μSv	15,000 μSv
Public individual	1,000 μSv	1,000 μSv
	Equivalent dose	
Lens	20,000 μSv	20,000 μSv
skin	50,000 μSv	40,000 μSv
Feet and hands	50,000 μSv	40,000 μSv

Note: The average limit dose is 20,000 μSv over a period of 5 years with an acceptable exposure of 50,000 μSv in only one year.

As long as the fuel elements are in the plant storage pools the installation is considered a nuclear facility. However, after the transfer of all fuel to the UAS, the areas under decommissioning can be classified as radioactive facilities containing only low and medium levels wastes. Thus, there will be no criticality risks in the decommissioning areas.

The industrial hazards are regulated by various laws and regulated by the ABNT [79, 80]. These regulations are implemented by Eletronuclear through a safety policy, manuals and procedures [81-84].

11.1 Responsibilities

The purpose of this Chapter is to establish basic guidelines for occupational safety and health in order to preserve the physical integrity of people when operating or performing the decommissioning, service and works activities in the areas of responsibility of ELETROBRAS ELETRONUCLEAR.

Industrial accidents can be avoided based on the following principles:

1. To safeguard the health and safety of all its employees, service providers in the area of its responsibility, providing a healthy and safe working environment;

2. Ensure that its activities comply fully with the current legislation and guidelines on Occupational Safety and Health;

3. Monitor the results of Occupational Health and Safety, implementing actions that aim at continuous process improvement;

4. Promote training and awareness programs for all employees to safely carry out all their activities, preventing accidents, and correcting the unsafe acts and conditions assessed in audits and inspections;

5. Ensure, prior to commencement of any work, that the conditions necessary for the safe execution of the task are known and established;

6. Be ready to clarify any additional information regarding the safety requirements, through the immediate supervisor or SESMT – Serviços Especializados em Engenharia de Segurança e em Medicina do Trabalho.

The common attributions and responsibilities inherent to the directors, managers and employee in relation to work safety and health at Eletronuclear are briefly described below. Figure 11.1 shows the departments of all three directorates involved in the health and safety of the CNAAA.

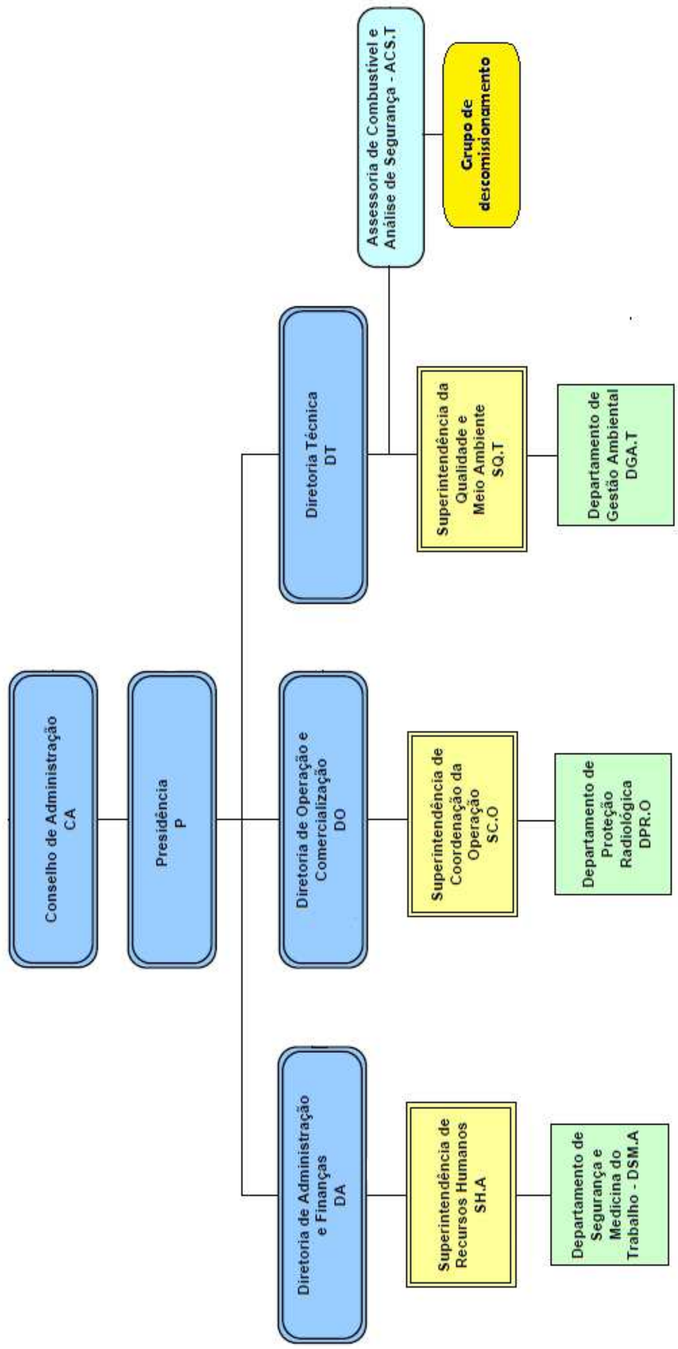

Figure 11.1 – Simplified chart of the CNAAA showing the two departments responsible to carry out radiation protection and radiation monitoring of the environment

The safety actions are distributed among the three directorates: industrial hazards and legal compliance with labor regulations are under the responsibility of the Directorate of Administration and Finance; radiation protection, under the responsibility of the Directorate of Operations and Trade, and environmental monitoring, under the responsibility of the Technical Directorate.

The president and directors must comply with corporate policies and strategies with the aim of minimizing the impact of activities on employees' health and taking into account the applicable economic and social aspects.

The superintendents and department heads should promote awareness of the policies defined by the company to implement safety and health at Eletronuclear. It is necessary that they permanently ensure that the activities associated with ELETRONUCLEAR are carried out with high safety standards by implementing, disclosing and fully complying with the safety policy in their areas of responsibility, according to the Occupational Health and Safety Manual [83].

Supervisors have a responsibility to require their employees to perform their duties in accordance with safety requirements. They are responsible for the safety conditions always seeking ways to eliminate or mitigate the potential risks of any type of accident. In addition, they should also make sure that work teams use all personal protective equipment. Inspections and audits are performed by supervisors, who provide management with a tool to be used as an immediate and corrective action of deficiencies observed in each of the work areas.

In relation to the general employees, individually, they are responsible for their own safety, always watching over the company's assets and obeying the norms that establish the correct methods of work. They must keep their immediate management informed of their physical and mental conditions that may interfere with the safe performance of their tasks and ensure that the conditions necessary for a safe execution of the task are established.

In the case of activities carried out by companies providing services to ELETRONUCLEAR, the contracts must contain clauses establishing, with rigor, the obligation to comply with all the Occupational Health and Safety Standards, according to [82].

In order to comply with radiological protection standards and procedures, the activities performed by employees must be performed while keeping radiation exposure as low as reasonably acceptable. For this the areas of radiological risk must be monitored and identified, and a strict dose control of the worker must be carried out frequently.

In relation to violations, non-compliance with the Labor Safety Manual and its norms characterizes an act of indiscipline and/or insubordination, subject to the application of disciplinary measures, according to current legislation; it is up to HR (Human recourses department) to analyze the occurrence and to assess the application of the [84].

11.2 Radiation Protection Plan

The radiation protection plan addresses several topics that include, but not be limited to workplace air sampling, respiratory protection, internal and external exposure monitoring, contamination control and instrumentation.

The CNAAA radiological protection and radiological monitoring of the environment are performed by two departments: the Department of Radiological Protection, under the Directorate of Operations and Trade, and the Department of Environment Management, under the Technical Directorate. These departments will perform these activities for the CNAAA decommissioning program. Figure 11.1

shows these two departments. The radiological protection plan to be used for decommissioning should not differ from those used during plant operation and will be described in later versions of this PPD or in specific documents.

The CNEN will be responsible for audit and inspection of radiological protection procedures. These activities can be summarized, briefly, as follows:

- Maintain and implement radiation protection program;
- Set procedures and administrative policies to meet the ALARA principle;
- Develop procedures for personal monitoring, for plant employees and contractor personnel working for the plant decommissioning;
- Ensure compliance with the decommissioning operations technical specifications, as well as supervise and authorize the operations to be conducted by employees and contractors for the decommissioning operations;
- Manage solid, liquid and gaseous effluent releases, as well as monitoring, treatment, packaging and transport of the low and medium level wastes to the final disposal facility. A separate and proper procedure will be executed to manage High Level waste;
- Evaluate and recommend the training for Radiological Protection Division staff regarding the decommissioning activities in order to keep their technical competence and proficiency in these activities; the technical personnel of any hired companies shall also be trained for the decommissioning operations;
- Ensure 24 hours availability of at least one radiation protection technician in each plant during all decommissioning phases;
- All workers should take actions in order to stop operations in any condition that endangers the health and safety of workers in the performance of any activity during the decommissioning;
- Perform monitoring of environmental radiation levels in the places surrounding the area under decommissioning.

The Radiological Protection Division will have radiation protection technicians who will be responsible for radiometric surveys, instrument calibration, keeping control points, preparing permissions for operation in radioactive environment, providing personal protective equipment such as protective clothing, respiratory protective equipment, shields etc., and ensuring effective radiation protection for safe working environment. The Radiological Protection Division will also have a team of radiological protection analysts who will be responsible for providing technical support in dosimetry, implementation and review of ALARA procedures and implementation of emergency procedures.

The start of decommissioning of a nuclear installation is preceded by a comprehensive operational environmental monitoring program that aims to assess impacts to the local environment. This program is maintained during decommissioning, therefore allowing detection of any change that may occur regarding the environmental radiation levels. Environmental monitoring is conducted according to the standards in force either for monitoring radioactive material and polluting material of nuclear facilities or for basic recommendations regarding monitoring nuclear plants. The measurement program should mainly involve the surrounding area of the places under decommissioning process. The Department of Environment Management will be responsible for these activities.

The radioactive inventory is described in Chapter 7 of this PPD. However, for purpose of radiation protection measures it is summarized in this Chapter and identified the main sources of radiation that should be monitored during all decommissioning stages. Taking into account the strategy to be adopted for the CNAAA decommissioning, Angra 1 and Angra 2 plants will be subject to delayed decommissioning condition of safe storage by the end of their operating licenses.

All operational waste, spent and new nuclear fuel, asbestos and resins will be removed from the plant in the first stages of transition phase by the plant's operations staff. At the start of decommissioning phase, during the decontamination and dismantling activities, these materials will not constitute sources of radiation or other hazards for workers. Also, the Radiological Protection Division will review all decommissioning procedures to assure that radiation protection procedures are adequate and safety requirements will be properly incorporated.

During the decontamination and demolition activities, radiation and contamination is present in equipment and structures contaminated or activated during the plant commercial operation, in deposition of radioactive fluid from piping, primary cooling system equipment and auxiliary systems that exchange fluid. Thus, the radiation sources can be classified into three groups:

- The reactor pressure vessel and biological shielding whose materials are activated during the power station operation;
- The cooling circuits and auxiliary systems that are contaminated by deposition of radioactive materials;
- Contaminated structures or land from spills or other operational incidents.

11.2.1 Workplace air sampling

An overview of the workplace air sampling program is provided. The criterion used for selection of the placement of air samplers in work areas where there is a potential for airborne hazards is described. The criteria applied that will demonstrate that air samplers with appropriate sensitivities are being used and that samples are being collected at appropriate frequencies are discussed. The use of constant air monitors, general zone samplers and breathing zone samplers is explained and a description of their readouts, annunciators and alarm set points is included. The use of portable air sampling or 'grab' samples is discussed. The specific types of equipment used are identified. The calibration frequency for all air sampling equipment, including flow meters, is provided. The procedures for responding to action and alarm levels are described. An explanation is provided of how the minimum detectable activity (MDA) for each specific radionuclide that may be collected is determined for each analytical procedure.

11.2.2 Respiratory protection

An overview of the respiratory protection program is provided. The process controls, engineering controls and procedures that will be used to control the concentrations of radioactive material in the air are described. The procedure that will be followed if and when it is not feasible to use engineering controls or procedures is provided. The use of respiratory protection equipment is the optimized solution.

The assigned protection factor for each type of respiratory protection device is listed and an explanation provided as to how the equipment will be selected on the basis of the specific task to be performed. The medical screening and fit testing procedures that will be used to ensure that personnel are capable of using the equipment is described. A list of the procedures that are maintained to address all elements of the routine and emergency respiratory protection programs is provided. The use, maintenance and storage procedures for the respiratory protection equipment are described. Procedures to ensure proper air quality, quantity, and respiration flow for supplied air is included. The users training program for the equipment is discussed. The procedure that will be used to select the appropriate respiratory protection equipment, considering both radiological and non-radiological hazards, is described.

11.2.3 Internal exposure monitoring

The internal dose deposition comes from one of the following processes [84]:

i. Ingestion: occurs through contact of contaminated objects with the mouth, or consumption of contaminated food or liquids.

ii. Inhalation: Occurs when breathing contaminated air. Aerosols, water vapor and radioactive gases, highly contaminated surfaces, etc.

iii. Absorption: Occurs through the skin or open wounds. Direct contact of radionuclides with tissue beneath the skin on open wounds may allow transfer to the internal organs via extracellular fluids.

Controlling contamination in the air must be carried out mainly through decontamination and the use of engineering controls. Respiratory protection is used only when engineering controls or decontamination are not practicable or efficient.

The Radiation Protection Division defines the processes, systems, equipment and tools to minimize the likelihood of unplanned incorporation of radioactive material. Airflow control, respiratory protection equipment, exhaust fans, portable monitoring, decontamination of areas are examples of Radiation Protection Division controls.

A whole body count for each operationally exposed individual must be performed before performing any work in the Controlled Area and upon termination of employment. Workers are monitored for contamination upon exit from controlled areas. Routine exams are scheduled as well in order to determine the presence of possible contamination.

Additional measurements of whole-body count could be performed in laboratories, bioanalyses through collection of fluids, tissues and excretes in order to complement and better determine the type of contamination [7, 85].

11.2.4 External exposure monitoring

Acceptable levels of external radiation are ensured through direct monitoring and control of exposure of individuals to external radiation. The exposure is monitored with individual dosimeters. Calibration and operation of dosimetry is certified by the Radiation Protection Division, which also provides the training necessary for the proper use of the instrument.

Direct reading dosimeters also will be used in order to allow immediate dose control when necessary, and special dosimeters for specific activities such as dosimeter rings, end dosimeters, neutron dosimeters, and other devices that may be needed [7, 78].

External doses will be maintained within the ALARA philosophy by monitoring and controlling radiation levels. The engineering controls and the application of time, distance and shielding concepts will be used whenever possible. In addition to the dosimetry, radiation monitoring will be performed by the performance of periodic radiometric surveys by radiation protection technicians.

During activities in the Controlled Area, the workers will be able to control their doses through the direct reading dosimeters, which provide indication of accumulated dose, in addition to emitting audible alarms when they reach the predefined conditions for dose and dose rate limits.

The monitoring of the Controlled Area will be one of the controls established by the Radiological Protection Division to perform the assessment of the radiological conditions of the areas, which includes measurement of quantities related to external radiation fields, surface and airborne contamination. Radiological conditions will be monitored and analyzed to give the optimized dose control.

Contamination monitoring can be used as information in determining internal and external doses.

11.2.5 Contamination control program

The objective of radioactive contamination control is the minimization of contamination areas, equipment and workers. The main actions to prevent the spread of contamination are to confine the contamination in the source; minimize the extension of contaminated areas; and reduce the level of transferable contamination contained in contaminated areas (insulation, containment and decontamination).

The application of contamination control is provided by procedures; including the isolation and posting of contaminated areas, control on the movement of materials, use of appropriate protective clothing, containment devices and supervision.

The specific reference levels were established by the CNAAA to perform the control of the contamination [78]. The following levels were established as reference for personal contamination, equipment and surfaces of the Controlled Areas.

The reference levels for radiation in several elements should be defined, such as:

i. Reference Levels for Personal Contamination;

ii. Reference Levels for Contamination on Equipment, Materials and Tools;

iii. Reference Levels of Contamination on surface areas;

iv. Reference Levels for Protection Equipment.

When the level of contamination exceeds the established reference levels, decontamination should be preferred over reclassification of the area. If this is unsuccessful or impractical, then the contamination area, equipment or material will be isolated and reclassified and posted as a contamination area.

11.2.6Instrumentation

As a practical matter, radiation monitoring is the logical first step in radiological characterization. It is a nondestructive procedure for establishing an overview of large spaces with a relative small effort. The gathered information, however, is limited by a sensitivity of the instrument regarding the type of radiation and level of detection. Radiation detectors are selected with these limitations in mind, and the survey design must be adjusted to the characteristics of the radiation type emitted by the radionuclides of interest. Table 11.2 provides a listing of the important radiation detection instruments.

Table 11.2 - Radiation detection instruments

Detector type	Radiation
Ion Chamber	beta, gamma, x-ray
Geiger-Mueller	beta, gamma, x-ray
Scintillation	alpha, gamma, x-ray
BF_3 gas proportional counter	neutron
Gas flow proportional counter	beta, gamma, x-ray

11.3 Nuclear Criticality Safety

It is assumed that all operational waste, spent and new nuclear fuel will be removed during the transition period prior to the start of decommissioning.

11.4 Industrial Health and Safety Plan

Decommissioning activities can pose different types of industrial hazards and risks for the workers.

Industrial activities that may be considered hazardous taking into account their nature or working methods are those that involve permanent contact with flammable or explosive substances in conditions of marked risk (according to the provisions of Law No. 7369/85) and the worker who acts and is exposed in activities that involve electric energy. (In the case of dangerousness, the duration of exposure is not important, but the intensity and imminence of the risk to which the worker is exposed).

The handling of the different types of dangerous products can be classified in chemical substances; flammable liquids and hazardous chemicals, the specific actions that must be taken in accordance with the same procedures used to protected areas of the Angra 1 and Angra 2 power plants according to [81, 83].

Any other type of activities related to the decommissioning process are described in accordance with [84], such as: work in electrical installations; preventive measures; services inside metallic equipment; electrical grounding; portable power tools and lighting work in confined spaces; ergonomics; material handling, traffic in areas of ELETROBRAS ELETRONUCLEAR responsibility; temporary blocking of roads and accesses; use of cargo handling equipment; assembly and use of scaffolding; handling of dangerous products; use of compressed air; underwater diving operations; laboratory practices; cylinders of compressed gas; portable ladders, protection of openings in floors; non-routine tasks; work on machines and fall protection equipment.

This section also describes the personnel protection measures and systems that will be provided, which may include training, personal protective equipment and clothing, occurrence reporting and accident investigation, warning signs, postings and devices, lockout / tagout, chemical control program, hazards communication, noise monitoring and abatement, hazard and employee monitoring. It provides details of how the non-radiological health and safety concerns will be factored into the work procedures. A work permit system or other similar system which provides a systematic approach to identifying hazards and ensuring that staff are properly qualified and equipped for the workplace is described.

11.5 Audits and Inspection

Audit and inspection activities are necessary to ensure managers, supervisors, incumbents and employees safely perform their tasks with the elimination or prevention of any type of accidents. A general description of the annual review of the radiation protection program and the industrial health and safety program is conducted by executive management. The types and frequency of surveys and audits performed by the Radiation Safety Officer and his/her staff are described. The records that are retained to support the audits and corrective actions are identified. The process that is used in evaluating and dealing with violations of regulatory requirements or license commitments identified during the audit is explained.

11.6 Record Keeping Program

The record keeping program for the radiation protection and safety programs are is described. The records that must be obtained are identified and their retention period and eventual disposition are discussed. The organizations responsible for the maintenance of the records are identified and the location where the records will be kept is also identified. The method for storing the records (for example, electronically on CD or paper copies) is described.

11.7 Optimization Analyses and Program

The administrative system for evaluation of the work performed to determine that safety was optimized and that doses and occupational hazards have been minimized is discussed. The procedure for documenting and investigating significant findings is discussed and the procedure for communicating these findings through a "lessons learned program" is explained.

11.8 Dose Estimation and Optimization for Major Tasks

If a specific job presents a significant dose commitment or radiological hazard, the procedures for performing a detailed dose estimate incorporating ALARA (as low as reasonably achievable) principles are explained.

11.9 Clearance Criteria

The release criteria to be used for the release of material and equipment, and for the reuse of buildings during and after decommissioning is provided, including a reference to applicable regulatory requirements. The procedure that will be used to ensure that the clearance criteria have been met for material, equipment and buildings being released from regulatory control is explained.

11.10 Final Release Criteria

This section provides the final site radiological criteria to be achieved at the end point of the project. The procedure for verifying that these criteria have been met is explained. A discussion is included that explains how the optimization process was considered during the development of these criteria.

12 QUALITY ASSURANCE

12.1 Introduction

Eletronuclear, recognizing its overall responsibility for the Central Nuclear Almirante Álvaro Alberto decommissioning, will describe its Quality Assurance System in a specific Quality Assurance Program (QAP) for the decommissioning project. This program is based on the current quality assurance of the plants in operation [86]. This program will ensure that all activities are designed and implemented without damaging worker or public safety and the environment.

Quality assurance will be integrated in the entire decommissioning project, including all applicable sections required by the CNEN NN 1.16 regulation [26]. The quality assurance activities to be implemented include the necessary design and preparation of facilities for decommissioning, decontamination, treatment, packaging, transportation and temporary storage of package and radioactive components.

12.2 Organization

Eletronuclear has the responsibility for preparing and implementing a global Quality Assurance Program for this enterprise. The purpose of this program is to ensure compliance with the requirements of CNEN NN 1.16 regulation [26]. Eletronuclear will set the policy to be followed by the enterprise in the global QAP, covering its activities and responsibilities, and will establish the guidelines to be followed by contractors.

The Superintendence of Quality and Environment is responsible to conduct the quality assurance policy of Eletronuclear. Figure 12.1 presents a simplified organization chart of Eletronuclear showing this superintendence under the Technical Directorate (DT). The responsibilities of each organization as well as the coordination between them shall be clearly defined.

12.3 Quality Assurance Program Implementation

All activities influencing the quality of items and services important to safety during the decommissioning such as decontamination, demolition, dismantling, waste treatment, packaging, transportation and temporary storage of radioactive waste and components in the CNAAA shall be performed in accordance with documents such as: procedures, instructions, plans and /or drawings. These documents shall include qualitative and/ or quantitative acceptance criteria for all activities performed [86].

The activities influencing the quality of items and services important to safety cannot be started before the required procedures and/or instructions are duly approved and accepted.

12.4 Document Control

The documents prepared for the decommissioning, which are essential for performance and verification of activities that influence quality, shall be controlled through written procedures. They will ensure that only appropriate and approved documents will be used to perform decommissioning activities in the CNAAA.

This control system will ensure that appropriate documents, duly updated, are used and that outdated documents have been withdrawn from circulation, destroyed, stamped or identified correctly in order prevent their undue use.

Modifications in documents shall be submitted to verification and approval in accordance with written procedures.

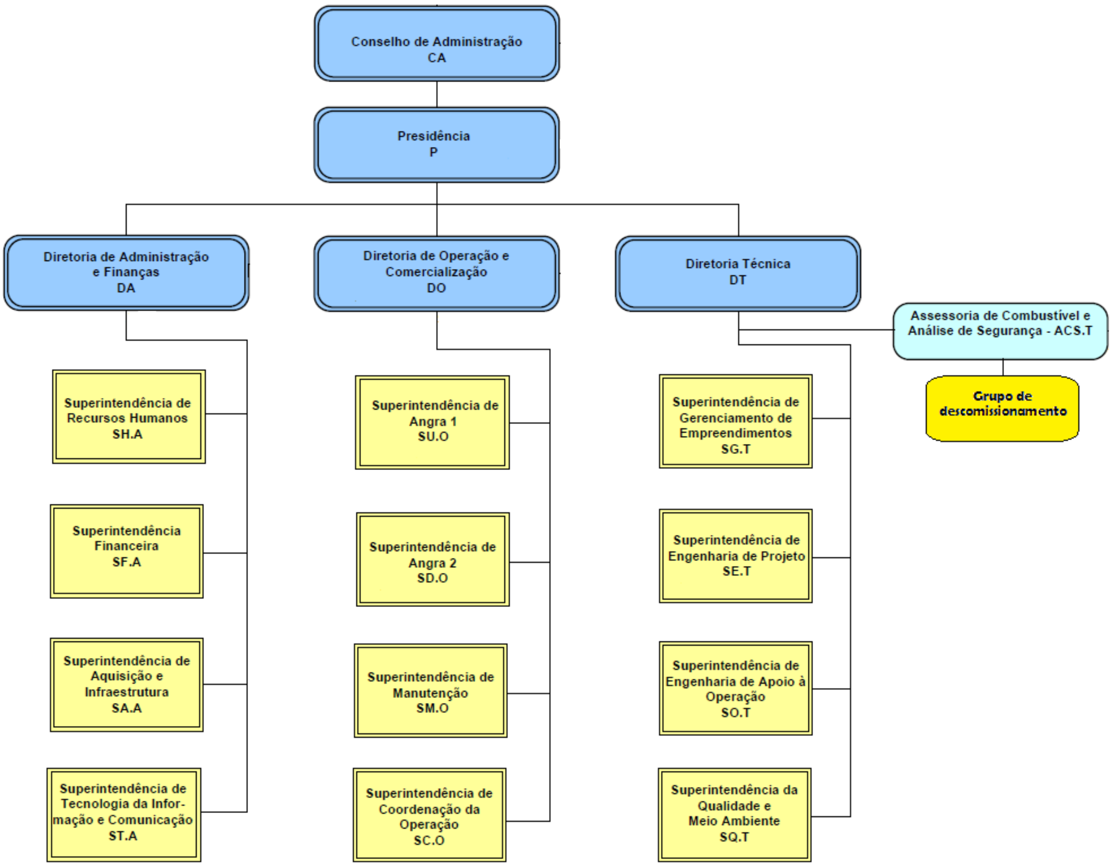

Figure 12.1 – Simplified Eletronuclear organization chart showing the Superintendence of Quality and Environment under the Technical Directorate (DT).

12.5 Measuring and Test Instruments

Procedures shall be prepared to ensure the control of measuring and test instruments used during the decommissioning.

All test and measuring instruments shall be identified in such a manner that calibration status information is immediately provided. The identification will allow correlating them to control records in order to assure that the accuracy is maintained within the necessary limits.

The methods and time intervals for instrument calibration shall be defined in written procedures and will be based on the type of instrument, precision, accuracy, and other conditions which affect measurement.

12.6 Corrective Actions

Procedures shall be prepared to ensure that significant conditions adverse to quality are promptly identified and corrected. These conditions include failures, malfunction, deficiencies, defective or incorrect material, equipment or services, and any other non-conformity detected during the decommissioning phase.

The procedures shall include follow-up measures to verify the implementation of corrective actions and control of non-conformance closing. The identification of significant conditions adverse to quality, together with corresponding causes and corrective actions adopted, shall be documented and reported to the involved organizations.

12.7 Audits and Surveillance

During decommissioning, audits and surveillance shall be performed in accordance to written procedures. These audits shall be performed by qualified and certified auditors, having adequate knowledge about the activities being audited, but with no direct responsibility for them. Audit and surveillance results shall be recorded in reports and distributed to all people involved for analysis and implementation of the required corrective actions.

Auditing and surveillance groups shall be responsible for planning of activities for follow-up of the implementation of corrective actions.

12.8 Lessons Learned

Procedures shall be prepared for capturing and recording the lessons learned from the decommissioning of Angra 1, which can help the decommissioning of Angra 2 and 3 and associated facilities. These procedures shall include provisions to make these lessons learned available for people involved in this subject, inside and outside Eletronuclear.

13 EMERGENCY PLANNING

The Emergency Plan has the objective to address an accident or malfunction in the decommissioning plant through a specifically designed contingency measure. Although the decommissioning phase has less emergency situations than the operational phase due the absence of nuclear fuel in the plant and many plant systems, the Emergency Plan in use during the operational phase will be used as the basis for the decommissioning phase. It will be adapted and kept most of the organization and infrastructure already in place to deal with emergencies on the plant's site.

The reference documents for the Decommissioning Emergency Plan will be the same in use by the operation of CNAAA:

- Local Emergency Plan (PEL) for the Units 1 and 2 of CNAAA [87];
- Organization, Assignments, Responsibilities and Training of Emergency Team [88];
- Performance Indicators of the processes and activities of Local Emergency Plan (PEL) [89].

Before the start of decommissioning activities, the current Local Emergency Plan will be revised and adapted for the new conditions of the site.

13.1 Organization and responsibilities

The Eletronuclear Superintendence of Operations Coordination (SC.O) will be responsible for the preparation and the execution of Emergency Plan. Figure 13.1 shows the superintendence position in the Eletronuclear organizational chart.

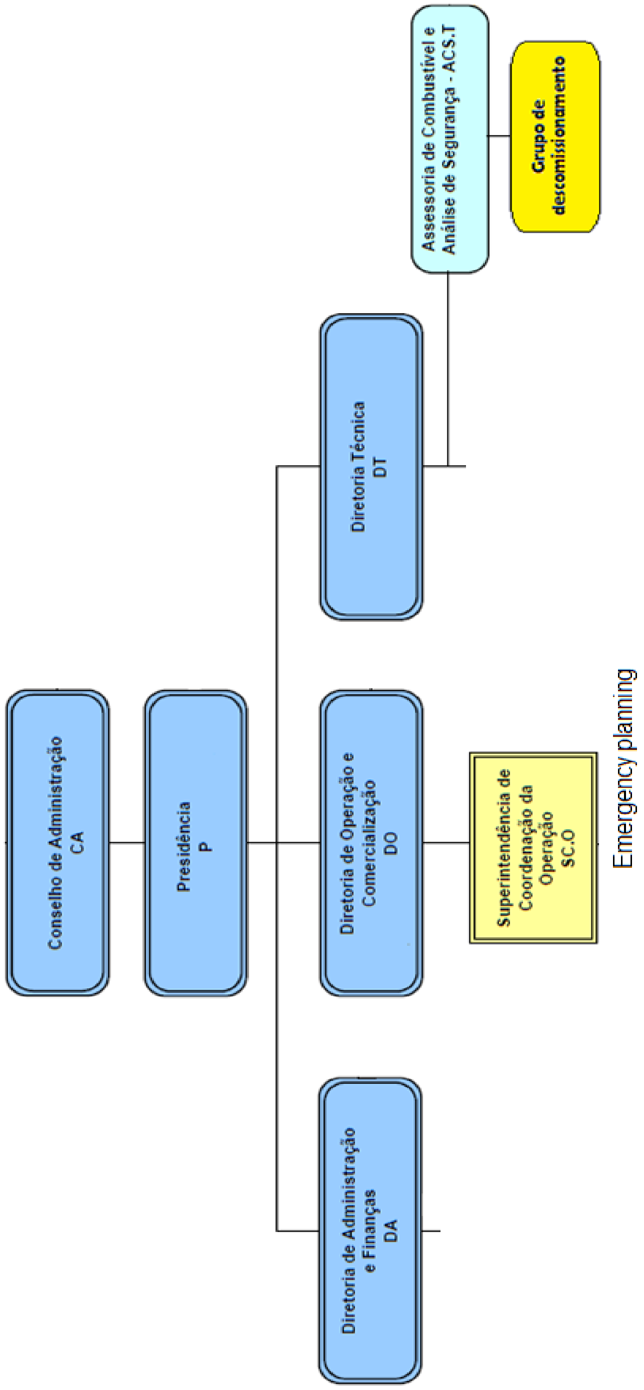

Figure 13.1 – Simplified Eletronuclear organization chart with the SC.O as responsible for the CNAAA emergency planning.

13.2 Emergency situations

When the operator observes that characteristic parameters of the systems of the unit are with values outside the normal ranges of operation, they must immediately report the occurrence to their shift supervisor. Together, they should begin evaluating the available data to identify the event. Even if the problem has not been identified, the shift supervisor must verify that the unit's safety conditions are maintained and report this fact to the Unit Superintendent and initiate the actions provided for in [2, 87].

1.Check if it can lead the Unit to an emergency situation.

2. Classify the type of emergency according to the specific procedures, as described in item 2.2.1 of [65, 76].

3. From the assessment made, declare an emergency situation, according to the nature and magnitude of the event, and make the notifications provided for in specific procedures.

Once the Emergency Situation has been declared, the Shift Supervisor shall immediately notify the Unit Emergency Group (GEU) Coordinator of the Unit and the Shift Supervisor of the other Unit. The GEU Coordinator shall notify the Emergency Coordinator of the Angra, the CNEM, the GEEC Coordinator (Central Office Emergency Group) and the Heads of the GEU Emergency Teams, according to their own procedures [87].

The Emergency Coordinator of Angra Central must notify, within the scope of ELETROBRAS ELETRONUCLEAR, the Coordinator of the Infrastructure Emergency Group and the Chief of the Emergency Medical Support Team, in addition to notifying from the declaration of alert situation to CNEN, the Angra dos Reis City Hall (Special Secretary for Civil Defense and Transit) and the Nuclear Emergency Coordination and Control Center (CCCEC), according to their own procedures, based on table 5.2.1.2 witch lists the actions of procedures for each member of emergency team [87].

The actions of ELETROBRAS ELETRONUCLEAR, planned to be carried out in support of Civil Defense and the National Nuclear Energy Commission, should be detailed in reports with specific procedures with their respective plans.

In addition, there should be simulated emergency drills, under the responsibility of the Superintendent for Coordination of Operation, in which a meeting of the Superintendent of Coordination of the Operation should be held and a respective report issued. Records of Emergency Exercises must be archived by the Training Division.

The Team Leaders and Coordinators shall ensure that there are general procedures, specific procedures and instructions clearly defining with the actions to be performed by their respective bodies, groups and teams. These procedures should be clearly specified and documented to effectively implement them.

Required and trained teams for safety procedures, each with its particular function as shown in [87]:

- Emergency Repair Team;
- Internal Physical Protection Team;
- Fire Fighting Team;
- Materials Team;
- Engineering Team;
- General Services Team;
- Construction team;
- Emergency Medical Support Team.

The return of the workers and the population removed will be transmitted by the Company's Management. It will only occur after the total normalization of the conditions in Itaorna and Brava Beach and according to the determination of the Nuclear Operation Analysis Committee - CAON, which will meet to evaluate the radiological surveys of the Internal and External Monitoring Teams and the operational conditions of the plant affected.

13.3 Records

The procedure for keeping records of the emergency events is described, including the reports to the regulatory bodies. The procedures are discussed for investigating the emergency causes and insure that corrective actions are implemented and verified [87].

14 PHYSICAL SECURITY

The purpose of this section is to establish the system of physical security and safeguards for the power reactors and facilities under decommissioning in the CNAAA according to the regulatory requirement [90-93]. The structures and procedures of this system are based on the current physical security system of the CNAAA, but will be modified for the decommissioning period where appropriate.

14.1 Organization and responsibilities

The Division of Enterprise Security is responsible for the physical security and safeguards of the CNAAA. It will also be responsible for the physical security and safeguards of the areas under decommissioning. This division is part of the Superintendence of Operation Coordination under the Directorate of Operations and Trade, as shown in Figure 10.1. Each power plant entering decommissioning will have assigned a Physical Security Supervisor and security personnel to carry out its physical protection. The Physical Security Supervisor will respond to the Head of the Division of Enterprise Security.

14.2 Physical security program and measures

The purpose of physical protection program of the CNAAA decommissioning is to provide security and physical protection for the facilities and the necessary adjustments to carrying out CNAAA decommissioning activities. This program complements the physical protection program that already exists for the operating CNAAA plants, adding the decommissioning specific facilities and the adequacy to the original program. This program is in accordance with the document about physical protection of the CNAAA power plants [91], following the same guidelines and procedures set out in item 13.6 of the FSAR of Angra 2 [91].

These referenced documents meet the physical protection requirements set in the current regulations [90, 92, 93].

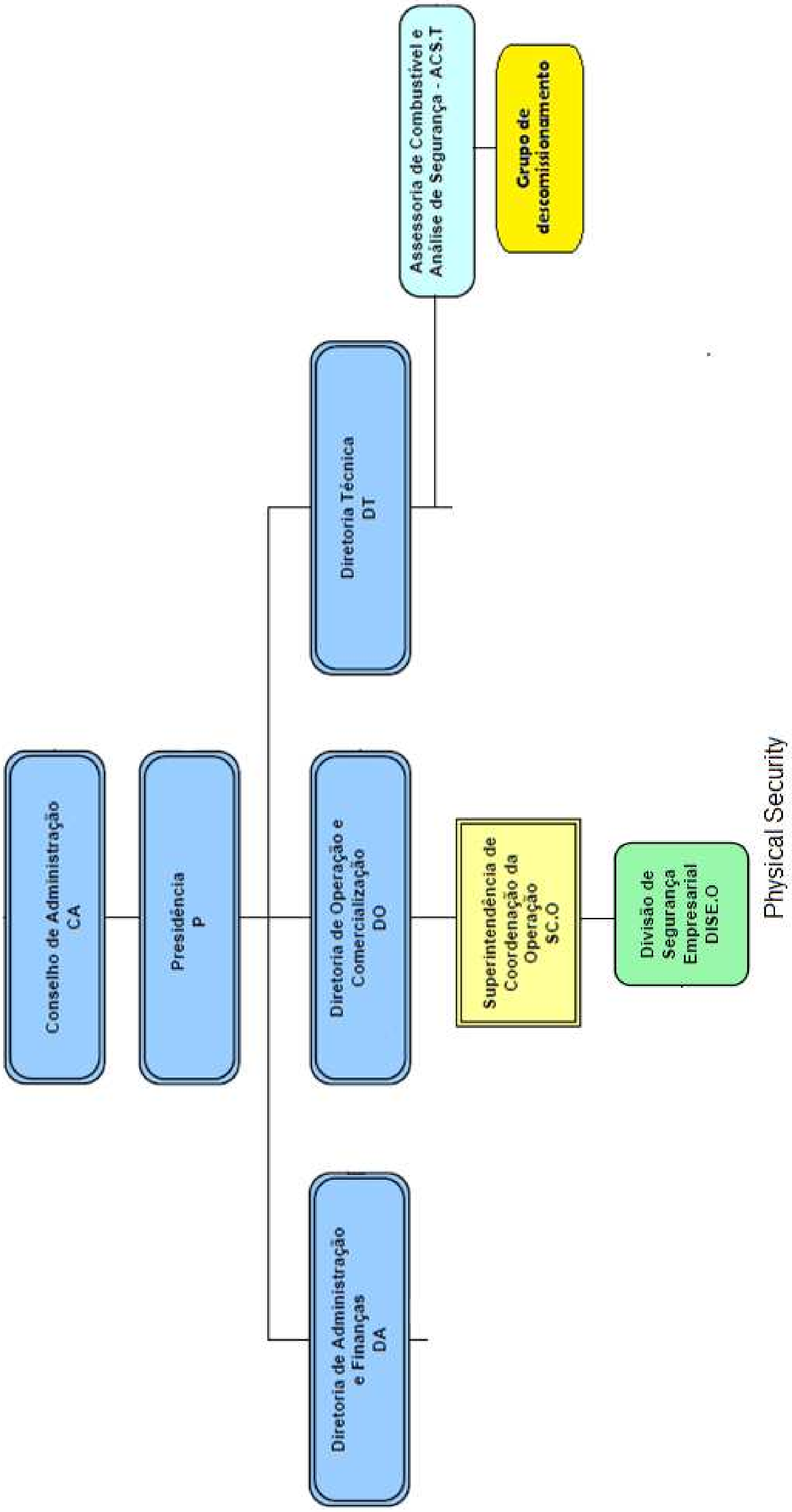

Figure 14.1 –Eletronuclear simplified flow chart showing the division responsible for the physical security and safeguards under the Directorate of Operations and Trade.

Physical Protection Plan security measures include or cover the following topics:

- Initial inquiry, continuous evaluation and revisions of the staff;
- A security force;
- Illuminated physical barriers;
- Locks system / latches and keys;
- Intrusion detection system;
- Contact and redundant communication with local police authorities;
- Routine operational and administrative procedures that adequately monitor the conditions of the vital areas and equipment;
- Movement control of personnel, materials and vehicles entering and within the plant protection area in order to ensure a proper security program;
- Physical protection written procedures.

The security level of the decommissioning areas is downgraded because they do not have new or spent nuclear fuel inside them and because many of the systems which were operative previously are deactivated. The main tasks are control the area, verify the integrity of the fences, locks etc., periodically and observe access controls to avoid not allowed personnel to enter the area.

14.3 Safeguards program

Until the spent fuel or other material within the scope of international non-proliferation policy applied to peaceful uses of nuclear energy, subject to safeguards, remains in place during decommissioning operations, the Security Force presence must be kept [93, 94]. Once the material is removed, the safeguards functions are completed.

15 FINAL RADIOLOGICAL SURVEY

The final survey is the activity that will confirm that the end state criteria has been met. Once the final survey is completed and verified by CNEN, the site can be released from regulatory control with restrictions [1, 2, 15, 44, 95].

15.1 Organization and Responsibilities

The organization that will be responsible for the developing the final survey plan and performing the survey will be the Radiation Protection organization as described in Chapter 11. Support will be needed from the decommissioning operations organization for equipment that might be needed for accessing areas [2].

15.2 Final Survey Implementation

The final survey will be performed for discrete areas as they have been decontaminated and available for unrestricted release. Once released, these areas will be isolated from other decontamination and dismantling activities that could cause cross contamination. It is anticipated that the survey will be performed prior to demolition of the major buildings. This allows better control of building debris and minimizes the cross contamination of clean material and areas [2].

15.2.1 Final Survey Plan

The final survey will be based on a Final Survey Plan that will be developed as part of the final planning for decommissioning. It is not realistic at this time to provide a Final Survey Plan because equipment, end state criteria, regulatory requirements and radiological conditions in the facilities might change before the facilities are permanently shutdown. However, this plan will include the following information [15, 44, 95]:

- General Information to include the legal address, license numbers, site location and layout. The identification of the areas and facilities that are included in the final survey will be provided, along with a brief history of the site and each facility. This section will include drawings and maps that show the major buildings and areas that will be included in the final survey.

- Documentation and Historical Information Review will provide historical information that is applicable for the final survey. It will include a description of operating and decommissioning events that could have an impact on the final survey results. These events may include the operational history of the reactors that would have led to activation of buildings, structures and systems. It will also include a discussion of any events or accidents during either operations of the plant or during decommissioning that could have spread contamination outside normal radiological boundaries. Any documents that were reviewed will be referenced.

- Identification of Potential Contaminants, Sources and Locations will be provided. These isotopes of concern will be identified which is important when identifying the instruments that will be used during the survey, the sampling and analysis protocols and the end state criteria. The normal isotopes of concern are 3H, 41Ca, 54Mn, 55Fe, 57Co, 60Co, 60Fe, 59Ni, 63Ni, 93Mo, 125Sb, 137Cs, 152Eu, 154Eu and 210Pb. If fuel element failures have occurred during any of the plant's life, then transuranic radionuclides may also be present.

Any areas that were not completely decontaminated or remediated during the decontamination and dismantling activities due to their location that might cause instability of the structure and must wait until demolition takes place will be identified. Areas where activation had or may have occurred will be identified since this will require different survey protocols.

Survey information that was collected during the decommissioning activities will be reviewed and maps and drawings will be prepared to indicate where potential areas above the end state criteria may be located.

- Survey Implementation will be described in procedures that will be used when performing the final survey. These procedures will be included as attachments or appendices to the Final Survey Plan. The types of surveys that will be performed for remaining structures will include general area radiation surveys, loose contamination swipe surveys, fixed contamination surveys and airborne surveys. The methods that will be used to perform each of these types of surveys will be provided.

The types of physical samples will be discussed and possible locations identified on maps or drawings. This may include concrete or metal samples to validate activated material removal. The procedures for taking, preserving and analyzing these samples will be provided.

Specific instruments that will be used will be identified, and their MDAs, conversion factors, efficiencies and characteristics will be provided. These instruments cannot be identified at this time because of changes in technologies between now and when needed. Any grid system or area classification systems will be described. Maps and drawings of the survey units that will be included in the final survey will be provided as an attachment or appendix to the Final Survey Plan. These will be the actual drawings that will be used when performing the survey to indicate survey and sample locations.

The process for establishing background conditions will be described in detail. This will include the locations selected for the background determinations, their locations indicated on maps or drawings and the rational for selecting these locations. These background surveys need to include all of the criteria that will support the various types of surveys that will be performed, including the samples that will be taken.

The process that will be used to verify or confirm buried or subsurface radioactivity is not present will be described. The equipment and methodology that will be used will be described and the capabilities and limitations of this approach will be discussed. Procedures that will be used during this activity will be provided as an attachment or appendix to the Final Survey Plan.

The Quality Assurance provisions that will be implemented during the final survey will be described. This will include training requirements; the disposition of smears, samples, filters and other media that were collected during the survey process; and records and data management.

- Health and Safety Concerns will be described in this Section of the Final Survey Plan. This will include all radiological, chemical and industrial hazards. A job hazard analysis for performing the survey will be provided as an attachment or appendix to the Final Survey Plan. Prevention and mitigation procedures and methods will be identified and discussed. At the time of the final survey, most of the radiological hazards should be eliminated. The most common hazards will be industrial safety concerns.

- Data Interpretation and Results methods will be described in this Section. This will include the format for the presentation of the data in the final report. The process that will be used to convert the raw data collected in the field to units comparable to the end state criteria will be provided. The methodology that is used to calculate the MDA of the instruments or the analytical techniques and standard deviation will be discussed. The disposition of the records once data interpretation is completed will also be discussed.

- Comparison of Results with Site End State Criteria will be provided, normally in graphical or spreadsheet form. Areas that do not meet the end state criteria will be identified on maps or drawings. Three dimensional representation of subsurface contamination will be provided. The reason for not meeting the end state criteria will be provided along with a discussion of future actions to be taken for these areas to meet the end state criteria.

15.2.2 Final Survey Plan Implementation

Once the Final Survey Plan has been reviewed and approved and the associated decommissioning activities have been met, it will be implemented with Eletronuclear staff. The survey plan will not be implemented until the end state criteria have been met through decommissioning operational surveys. When the Final Survey has been completed, any areas that do not meet the end state criteria will be remediated and resurveyed. Once all of the survey activities have been completed, a Final Survey Report will be prepared. This report will be provided to CNEN.

15.2.3 Final End State Validation

Upon receipt of the Final Survey Report, the report will be reviewed by CNEN to ensure the end state criteria have been met so they can terminate the license for the facility.

15.3 Data Collection and Evaluation

The survey results will be recorded on survey sheets that indicate where the survey points and samples were located. These survey sheets will be reviewed by a supervisor to ensure the data is complete and accurate.

At the end of every day, the survey sheets and sample results will be forwarded to a data management specialist. The data will be entered into a spreadsheet that will ensure the data is properly recorded and maintained. The spread sheet will be designed to perform many of the statistical calculations required to ensure that the end state criteria has been met. The software will be designed to flag any survey points or sample results that exceed the end state criteria.

The spreadsheet will be reviewed and evaluated by decommissioning management and areas that exceed the end state criteria will be identified, evaluated and remediated if necessary.

The data collection system with results will be part of the final decommissioning report and will be archived for future use.

15.4 End State Criteria

The final site state of the CNAAA is of unrestricted release meaning that the site will be released from its license. Upon meeting this criterion, the site can then be used for any purpose.

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