

CONTENTS

1.	INTRODUCTION	1
1.1.	Background	1
1.2.	Objectives and scope	2
2.	ENVIRONMENTAL AND REGULATORY ISSUES	3
2.1.	Problems associated with ^{14}C and tritium in waste	3
2.2.	Regulatory issues	4
2.2.1.	Argentina	6
2.2.2.	Canada	6
2.2.3.	France	7
2.2.4.	Russian Federation	7
2.2.5.	United Kingdom	8
2.2.6.	United States of America	8
3.	PRODUCTION AND EMISSION PATHWAYS	11
3.1.	Carbon-14 production and release	11
3.1.1.	Natural production in the atmosphere	11
3.1.2.	Production in nuclear explosions	11
3.1.3.	Production in and release from nuclear power reactors	11
3.1.3.1.	Light water reactors	14
3.1.3.2.	Heavy water reactors	1x
3.1.3.3.	Magnox reactors and advanced gas cooled reactors	21
3.1.3.4.	High temperature gas cooled reactors	23
3.1.3.5.	Fast breeder reactors	24
3.1.3.6.	Summary of waste containing ^{14}C produced by reactor operation	24
3.1.4.	Release during spent fuel reprocessing	25
3.2.	Tritium production and release	28
3.2.1.	Production and release in nuclear power reactors	29
3.2.1.1.	Light water reactors	31
3.2.1.2.	Heavy water reactors	31
3.2.1.3.	Other types of reactor	32
3.2.2.	Release during spent fuel reprocessing	33

3.3.	Categories of waste containing ^{14}C and tritium	36
3.3.1.	Reactor operation and fuel cycle waste	36
3.3.2.	Other waste	37
4.	REDUCTION OF PRODUCTION AND RELEASE	37
4.1.	Reduction of ^{14}C production and release	37
4.2.	Reduction of tritium production and release	39
5	TECHNOLOGIES TO CAPTURE ^{14}C AND TRITIUM FROM EMISSION STREAMS	41
5.1.	Removal of ^{14}C from gas streams	41
5.1.1.	Single-step chemical reaction involving absorption in an alkaline earth hydroxide slurry or solid	42
5.1.1.1.	Alkaline slurry scrubber	42
5.1.1.2.	Alkaline packed bed column	43
5.1.2.	Two-step chemical reaction involving sodium hydroxide and lime slurry	44
5.1.2.1.	Double alkali process	45
5.1.3.	Physical absorption	45
5.1.3.1.	Gas absorption by wet scrubbing	45
5.1.3.2.	Ethanolamine scrubbing	46
5.1.3.3.	Absorption in a fluorocarbon solvent	46
5.1.4.	Physical adsorption on an active surface	47
5.1.5.	Other methods	47
5.2.	Removal of ^{14}C from liquid waste	49
5.3.	Separation of tritium from spent fuel	51
5.3.1.	Voloxidation	51
5.3.2.	Pyrochemical processing	51
5.4.	Removal of tritium from gas streams	52
5.4.1.	Removal of HT	52
5.4.2.	Removal of HTO	52
5.4.2.1.	Molecular sieves	53
5.4.2.2.	Dehumidification	53
5.5.	Removal of tritium from liquid waste	53
5.5.1.	Tritium enrichment	54
5.5.2.	Other tritium removal technologies	58

6.	ANALYTICAL AND MONITORING METHODS	59
6.1.	Carbon-14 monitoring systems	60
6.1.1.	Carbon-14 sample collection	60
6.1.1.1.	Airsamples	60
6.1.1.2.	Water samples	61
6.1.1.3.	Vegetation and soils	61
6.1.2.	Carbon-14 sample preparation	61
6.1.3.	Analytical methods for ^{14}C	63
6.1.3.1.	Gas counting	63
6.1.3.2.	Liquid scintillation counting	63
6.1.3.3.	Accelerator mass spectrometry	63
6.1.4.	Carbon-14 monitoring methods	63
6.2.	Tritium monitoring systems	64
6.2.1.	Air samples	64
6.2.2.	Samples of liquids	66
6.2.3.	Tritium analytical methods and monitoring systems	67
6.2.3.1.	Ionization chambers	67
6.2.3.2.	Proportional counters	67
6.2.3.3.	Scintillation crystal detectors	6X
6.2.3.4.	Mass spectrometers	68
6.2.3.5.	Liquid scintillation counters	6X
6.2.3.6.	Portable room air monitors	69
6.2.3.7.	Fixed station ROOM air monitors	69
6.2.3.X.	Glovebox atmosphere monitors	69
6.2.3.9.	Hood and exhaust duct air monitors,	69
6.2.3.10.	Exhaust stack air monitors	70
6.2.4.	Specialized instrumentation	70
6.2.4.1.	Remote field tritium analysis system	70
6.2.4.2.	Surface activity monitor	70
6.2.4.3.	Breathalyser	71
7.	IMMOBILIZATION AND WASTE FORM EVALUATION	71
7.1.	Immobilization technologies for waste containing ^{14}C	72
7.1.1.	Cementation	73
7.1.2.	Other methods.	73
7.2.	Immobilization technologies for waste containing tritium	74
7.2.1.	Drying agents	75
7.2.2.	Hydraulic cements	75
7.2.3.	Organic agents	76

7.2.4. H y d r i d e s .	76
7.3. Assessment of immobilized waste form a n d q u a l i t y c o n t r o l .	77
7.3.1. W a s t e f o r m c h a r a c t e r i z a t i o n .	78
7.3.2. W a s t e f o r m t e s t i n g .	79
8. STORAGE AND DISPOSAL .	81
8.1. W a s t e a c c e p t a n c e r e q u i r e m e n t s .	81
X.1.1. F r a n c e	83
8.1.2. J a p a n	84
X.1.3. S p a i n .	85
8.1.4. U n i t e d K i n g d o m .	86
8.1.5. U n i t e d S t a t e s o f A m e r i c a .	86
8.2. Storage and disposal options for waste containing ¹⁴ C and tritium .	87
8.2.1. S t o r a g e o p t i o n s .	87
X.2.1.1. S t o r a g e o f H T O w a s t e	88
8.2.1.2. S t o r a g e o f t r i t i u m g a s .	XY
X.2.1.3. S t o r a g e i n e n g i n e e r e d s t r u c t u r e s .	89
X.2.1.4. S t o r a g e o f i r r a d i a t e d g r a p h i t e w a s t e .	90
8.2.2. D i s p o s a l o p t i o n s .	91
X.2.2.1. N e a r s u r f a c e d i s p o s a l .	91
8.2.2.2. L i q u i d i n j e c t i o n i n t o g e o l o g i c a l f o r m a t i o n s . .	92
X.2.2.3. D i s p o s a l i n g e o l o g i c a l f o r m a t i o n s .	93
8.2.3. O t h e r o p t i o n s . . .	93
X.3. Strategy for the management of waste containing ¹⁴ C a n d t r i t i u m .	94
Y. CONCLUSIONS .	94
REFERENCES	97
CONTRIBUTORS TO DRAFTING AND REVIEW	109