Calculation of radiation doses and restriction periods for persons coming into contact with I-131 and In-111 therapy patients

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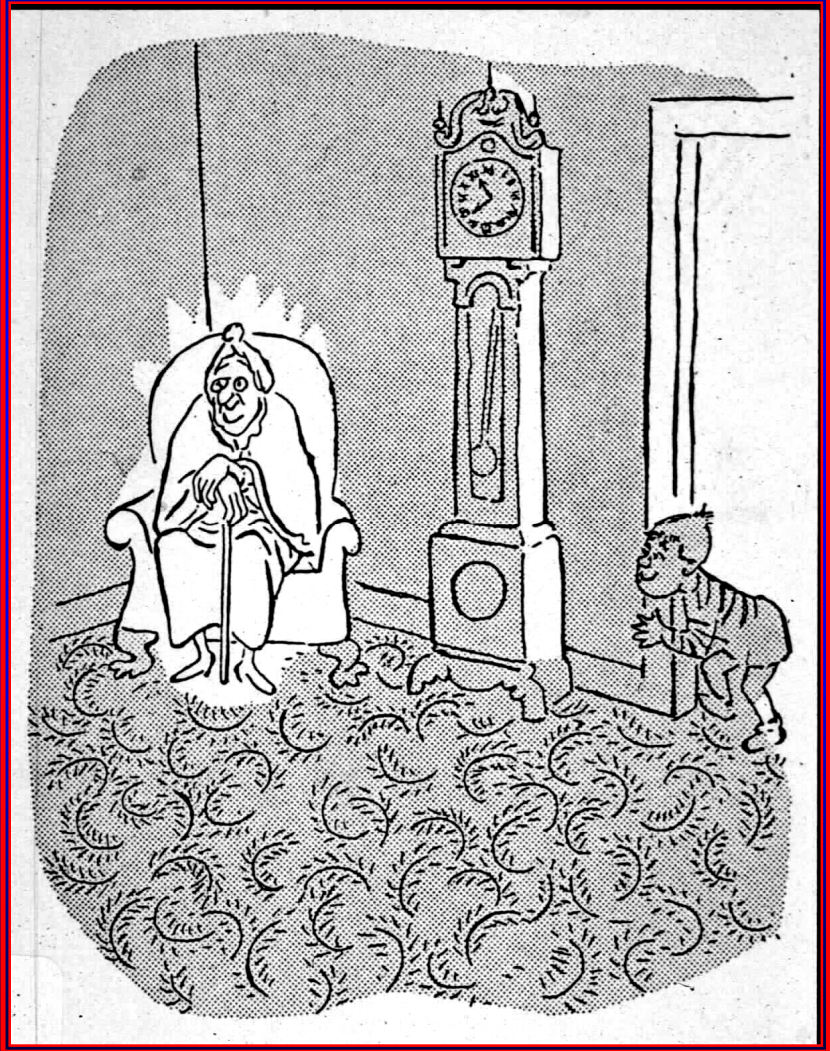
Human Radioactive Sources



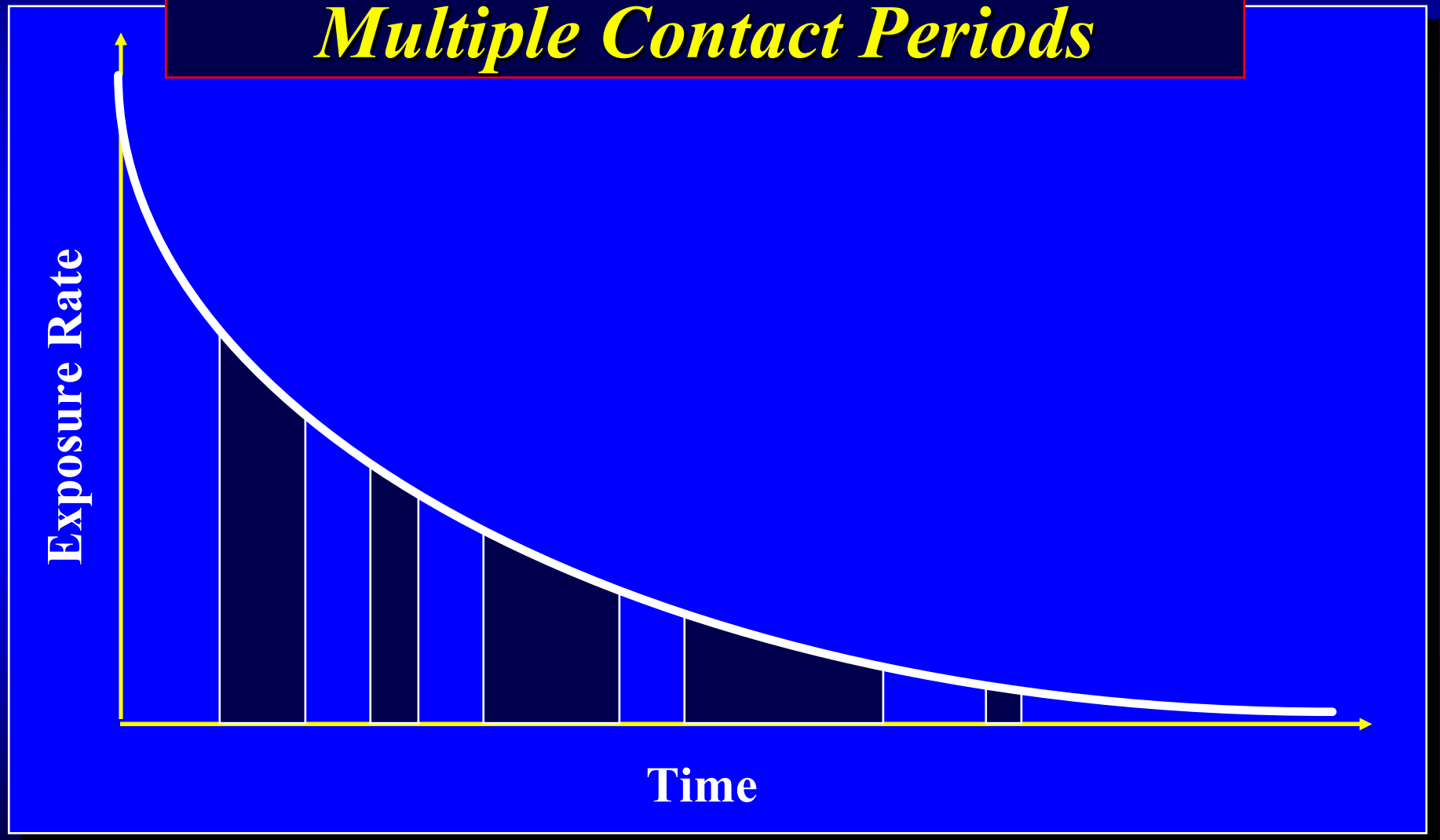
***In-vivo* radioactive sources are harder to control than *in-vitro* radioactive sources, and the radiation dosimetry is more complex.**

Little Willie, full of glee
Put radium in his Grandma's tea
Now he thinks it's quite a lark
To see her glowing in the dark!

Regulatory Requirements

- **In the USA the Nuclear Regulatory Commission (NRC) has already published amendments to its regulations pertaining to the release of radioactive patients which will necessitate an estimate of exposure to other persons to be made, in principle, for every patient.**
- **In Australia, release criteria in most states will probably be eventually based on the ARPANSA "*Recommendations for the Discharge of Patients Undergoing Treatment with Radioactive Substances*"**

Radiation Exposure from Multiple Contact Periods



Calculation of Cumulative Exposure

$$\begin{pmatrix}\text{Total}\\ \text{Exposure}\end{pmatrix} = \begin{pmatrix}\text{Initial}\\ \text{Exposure Rate}\end{pmatrix} \times \begin{pmatrix}\text{Effective}\\ \text{Exposure Time}\end{pmatrix}$$

$$E = E_0' T$$

E = Total exposure

E_0' = Exposure rate at time zero (initial exposure rate)

T = Effective exposure time

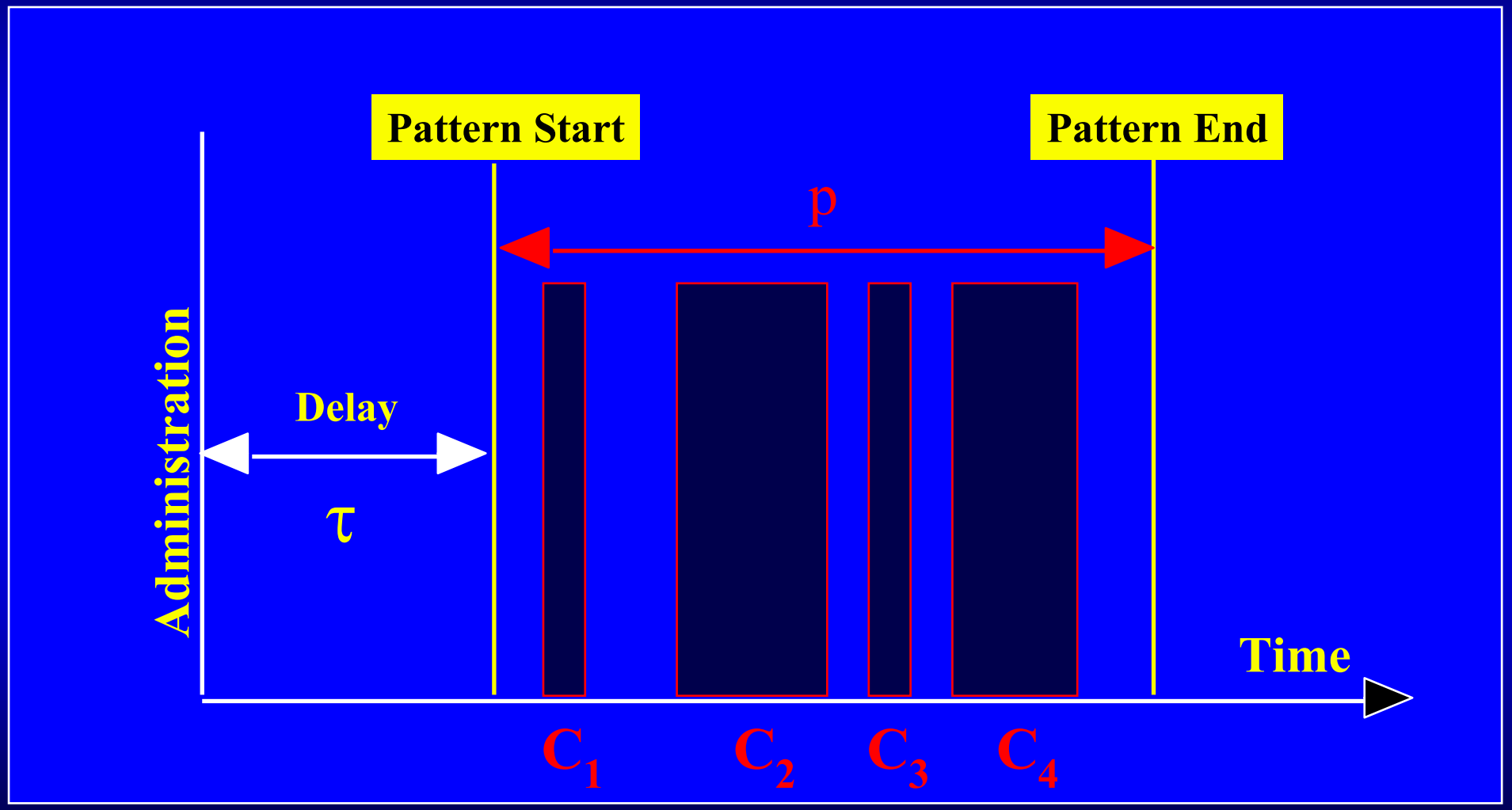
Calculation of Effective Exposure Time

$$\begin{pmatrix}\text{Effective}\\ \text{Exposure Time}\end{pmatrix} = \begin{pmatrix}\text{Sum over all exposure periods of}\\ \text{effective exposure time in each period}\end{pmatrix}$$

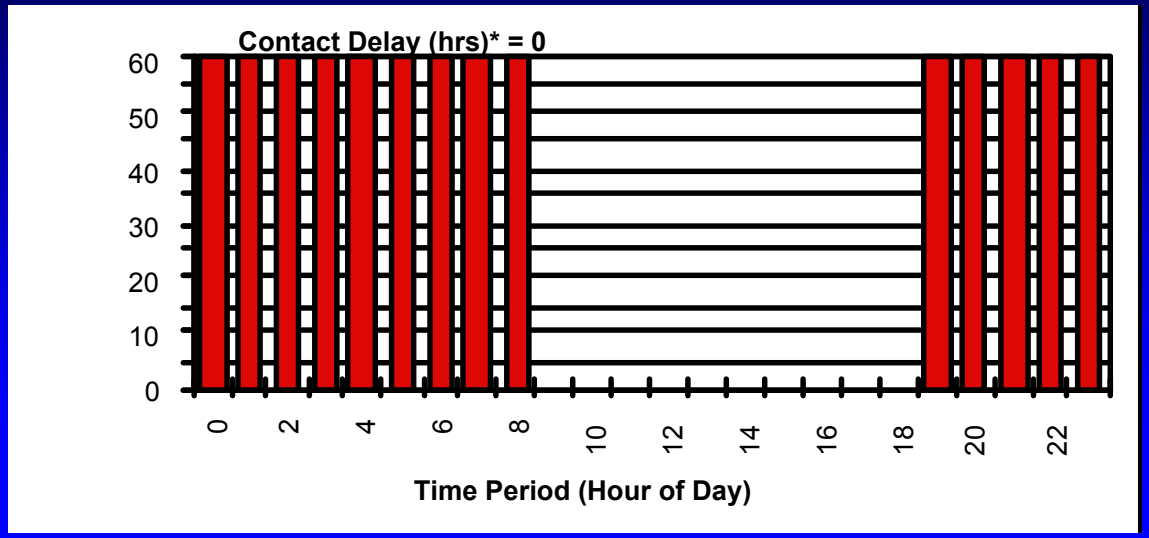
$$T = \sum_{\substack{\text{All exposure}\\ \text{periods}}} \left[\int_{\substack{\text{exposure}\\ \text{period}}} F(t)\,dt \right]$$

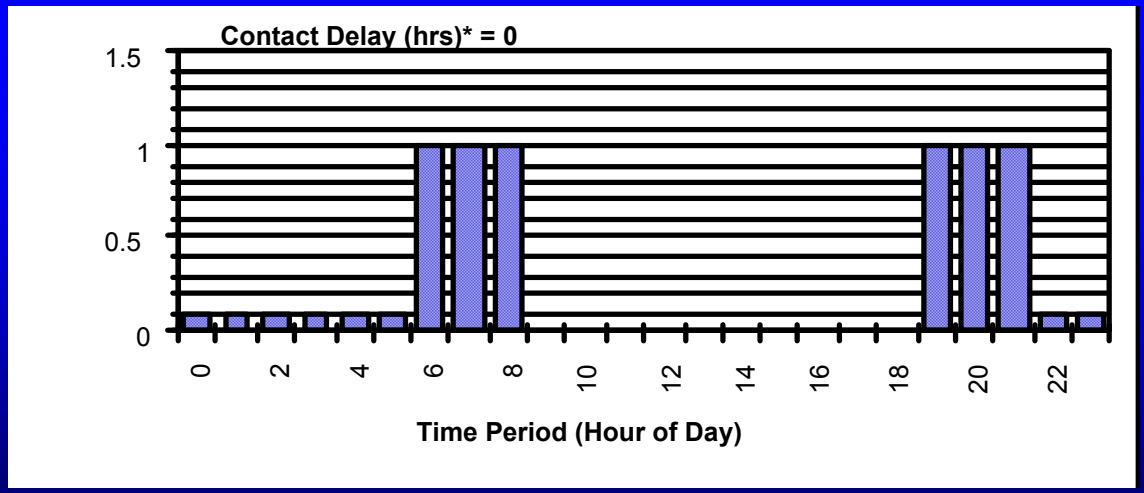
$$F(t) = \frac{E'(t)}{E'_0} = \frac{A(t)}{A_0}$$

Radiation Exposure Pattern

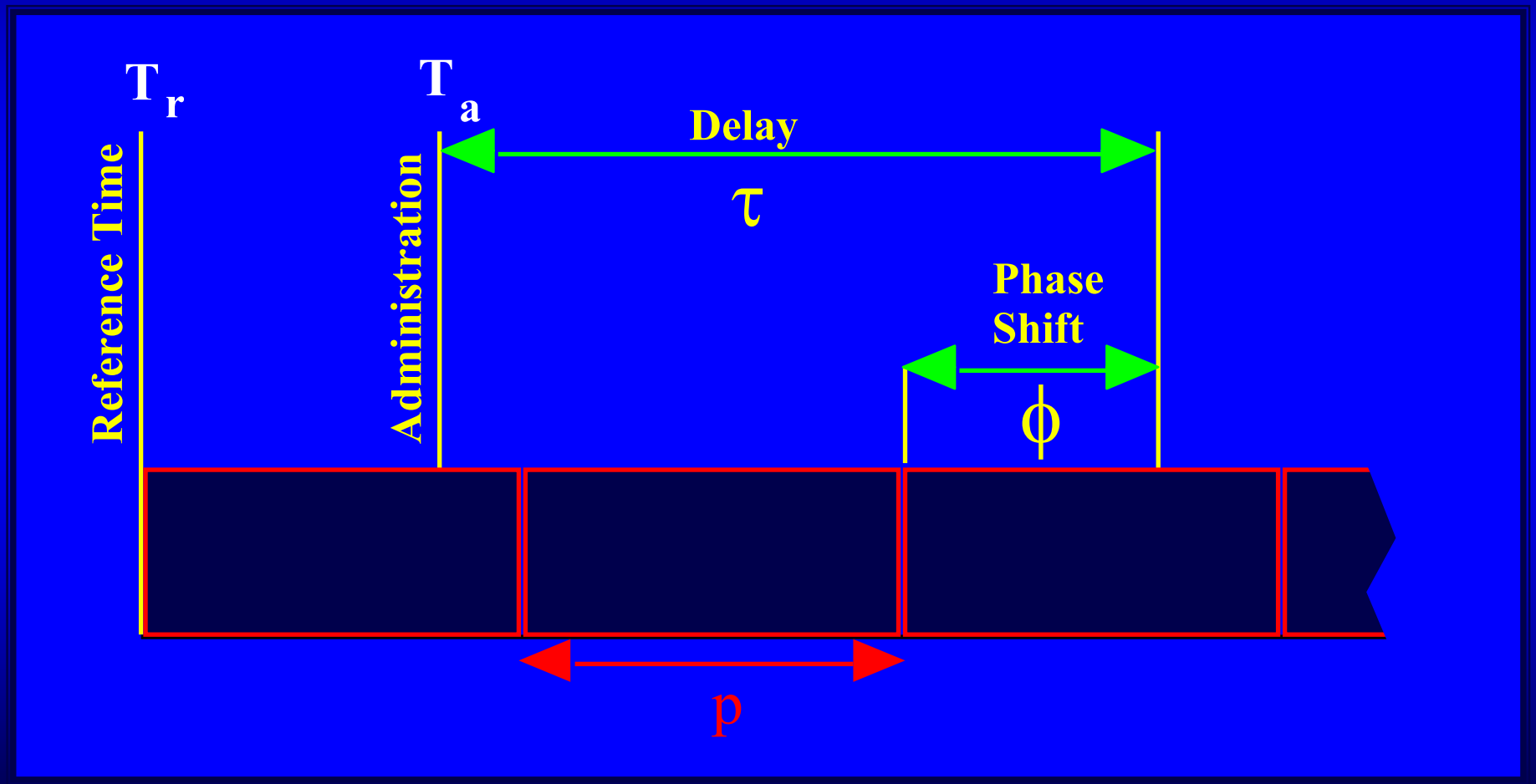


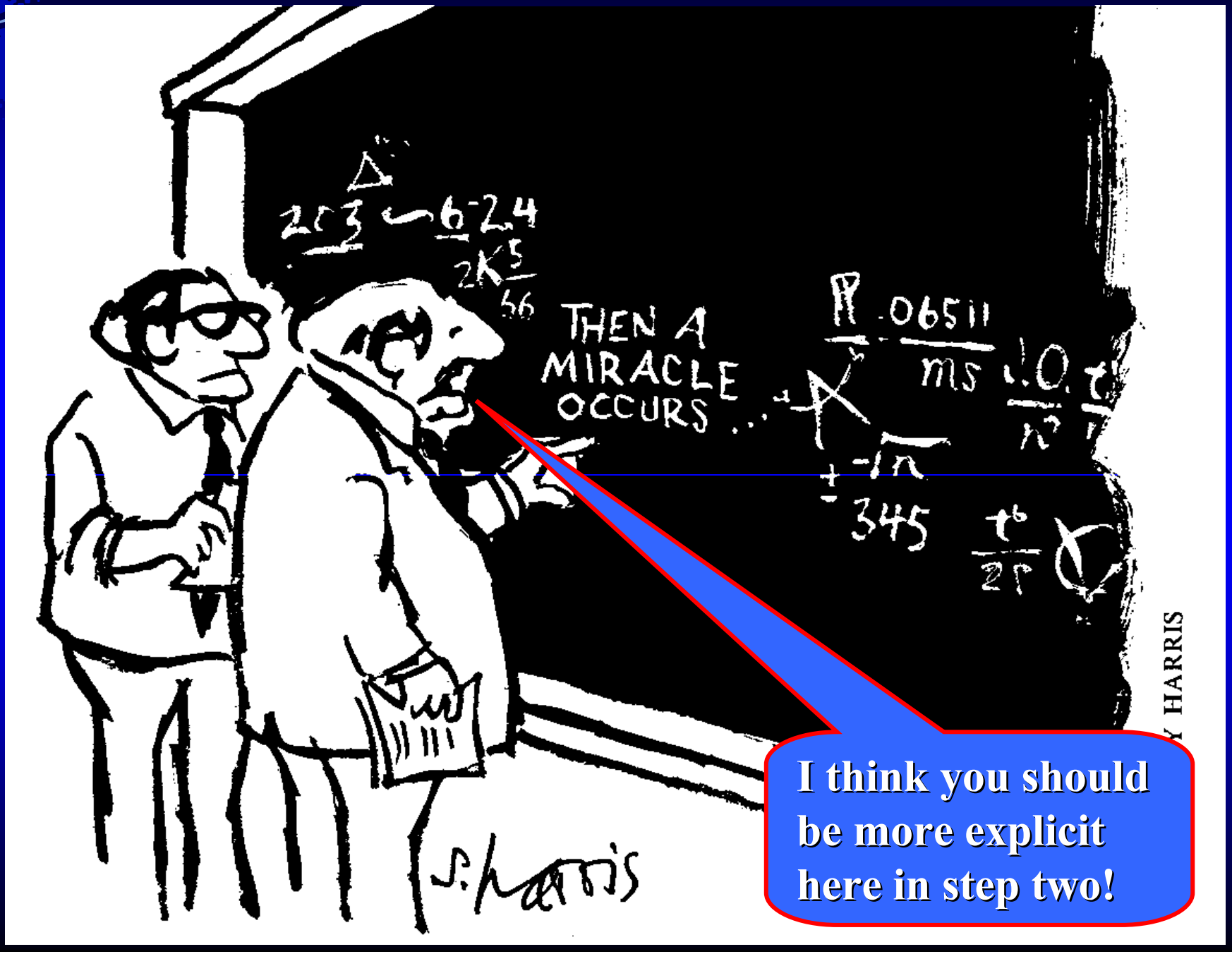
Pattern #5
Partner or Spouse





Phase Shifting Pattern




THEN A MIRACLE OCCURS ...
I think you should be more explicit here in step two!
HARRIS

Calculation of Effective Exposure Time

(Multi-exponential clearance, multiple exposure, single pattern phase locked)

$$T = \sum_{i=1}^{n} a_i \frac{e^{-\lambda_i \tau}}{\lambda_i} \sum_{j=1}^{m} e^{-\lambda_i \theta_j} \left(1 - e^{-\lambda_i C_j}\right)$$

T = effective exposure time

C_j = duration of jth period of contact

θ_j = time lapse between start of contact pattern and jth period of contact

τ = time delay between administration and start of close contact pattern

m = number of periods of close contact

λ_i = decay constant for ith component of decay

a_i = fraction of decay occurring through ith component

Calculation of Time Delay Required to Limit Effective Exposure (and hence Dose) to a Specified Value (Inverse Calculations)

- **Analytical solution possible for single exponential clearance**
- **Numerical techniques must be used for multi-exponential clearance**

Approximate Calculation

$$D = k\dot{D}_0 \int_{t_s}^{\infty} \left\{ ae^{-\lambda_1 t} + be^{-\lambda_2 t} \right\} dt$$

D is the total accumulated dose

$\dot{D}_0$ is the initial dose rate at 1 metre

λ_1 and λ_2 are the two decay constants associated with the clearance

a and b are the proportions of each clearance component

t_s is the time at which exposure starts

k is an exposure factor which relates the actual accumulated exposure from a given exposure pattern to that received from continuous exposure at one metre

Exposure Factor, k

$$k = \frac{\text{Accumulated radiation dose from a given pattern of exposure}}{\text{Total dose resulting from exposure at 1 metre in the same time}}$$

$$k = \frac{D}{\dot{D}_0 \int_{t_s}^{\infty} \left\{ a e^{-\lambda_1 t} + b e^{-\lambda_2 t} \right\} dt} = \frac{D}{\dot{D}_0 \left[\frac{a}{\lambda_1} e^{-\lambda_1 t_s} + \frac{b}{\lambda_2} e^{-\lambda_2 t_s} \right]}$$

Exposure Factor, k - Note

Note that for exposure patterns where there are periods of exposure at distances less than 1 metre, the exposure factor may have a value exceeding 1. It should not be confused with occupancy factor.

Note also that the exposure factor, k , is not a constant for a given exposure pattern, and will, in fact, vary with the start time of the exposure t_s as well as the clearance rate of the radionuclide from the body; however, this variation is small for radioactive materials which have an overall clearance rate which is slow compared with the period of the exposure pattern.

For I-131 and In-111 therapy, therefore, an averaged exposure factor for each pattern can be utilized, allowing the approximate equation to be used in estimating accumulated doses

Standard Exposure Patterns

Exposure Pattern	Activity
1	Public transport travel
2	Return to work not involving prolonged close contact with others
3	Return to work involving prolonged close contact with others
4	Close contact with adult friends and family/carers
5	Close contact with pregnant women
6	Caring for infants (demanding or sick)
7	Caring for infants (normal)
8	Close contact with 2-5 year old children
9	Close contact with 5-15 year old children
10	Sleeping with spouse or partner, or a child
11	Work with radiosensitive materials

Calculated exposure factors for various clearance rates and patterns of exposure

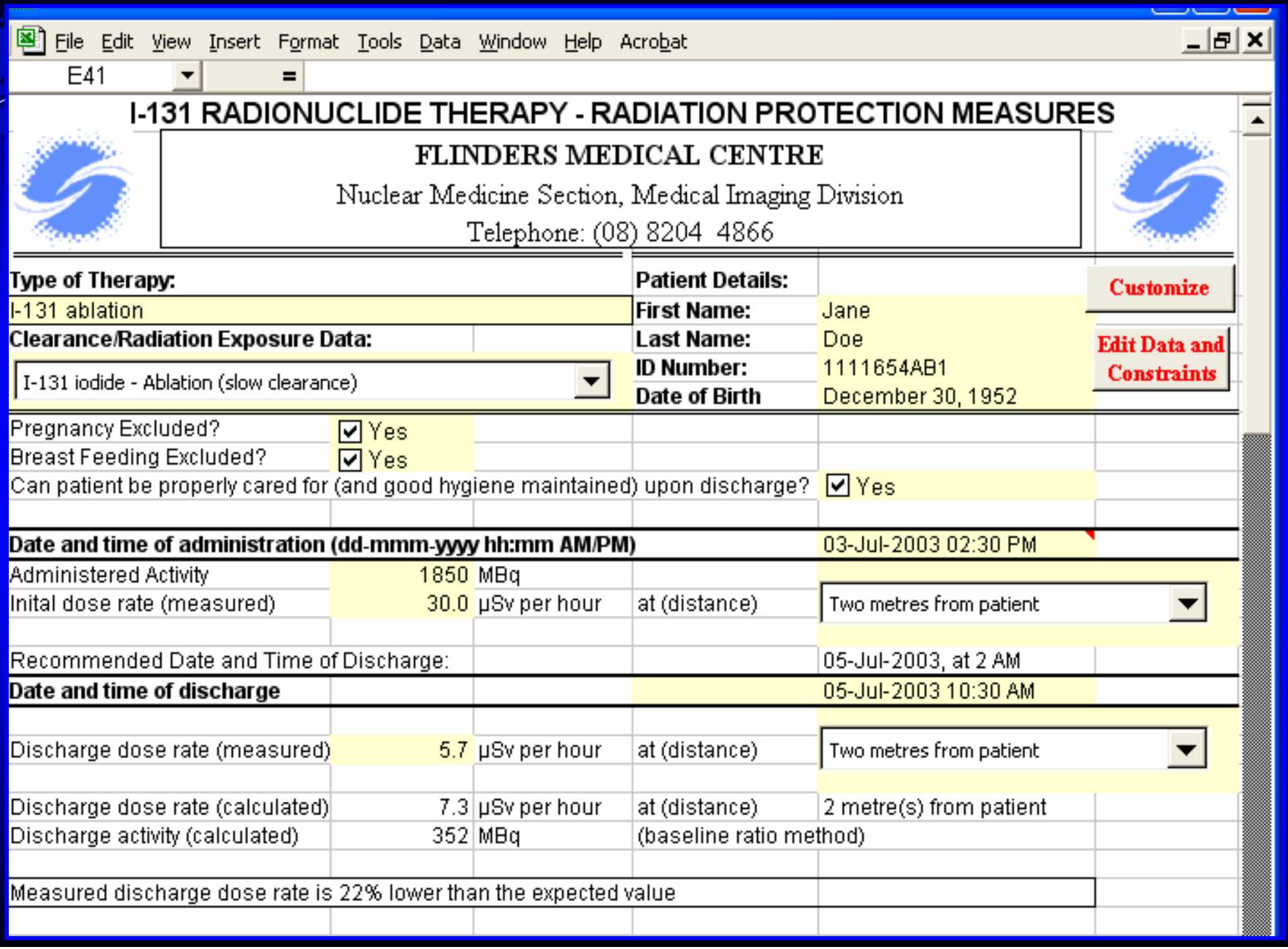
	I-131 iodide	I-131 iodide	I-131 iodide	I-131 iodide	In-111 octrocide		
Exposure Pattern	Thyrotoxic Patients	Ablation - slow clearance	Ablation - fast clearance	Euthyroid patients	"Normal" clearance rate	Mean	CV(%)
1	0.68	0.67	0.62	0.68	0.67	0.66	3.8
2	0.35	0.36	0.42	0.34	0.36	0.37	8.3
3	0.65	0.68	0.77	0.64	0.66	0.68	7.9
4	1.26	1.28	1.33	1.26	1.27	1.28	2.4
5	0.98	1.01	1.09	0.98	1.00	1.01	4.5
6	5.26	5.36	5.69	5.24	5.31	5.37	3.4
7	1.73	1.75	1.80	1.73	1.74	1.75	1.8
8	2.95	2.89	2.71	2.96	2.91	2.89	3.5
9	1.33	1.30	1.20	1.33	1.31	1.29	4.1
10	4.86	4.69	4.15	4.89	4.76	4.67	6.5
11	0.35	0.36	0.42	0.34	0.36	0.37	8.3

Calculated restriction times using approximate and rigorous models

		Calculated Restriction (hours)		
Exposure Pattern	Set Dose Constraint (μSv)	Approx Model	Rigorous Model	Discrepancy
1	1000	62	63	-1
2	1000	13	5	8
3	500	149	144	5
4	3000	22	21	1
4	5000	0	0	0
4	10000	0	0	0
5	1000	112	105	7
6	1000	320	315	5
7	1000	180	177	3
8	1000	242	248	-6

Calculated doses using approximate and rigorous models

		Actual Dose Received (µSv)		
Exposure Pattern	Set Dose Constraint (µSv)	Approx Model*	Rigorous Model	Discrepancy
1	1000	1034	1000	34
2	1000	864	1000	-136
3	500	444	500	-56
4	3000	2955	3000	-45
4	5000	4530	5000	0
4	10000	4530	10000	0
5	1000	936	1000	-64
6	1000	943	1000	-57
7	1000	987	1000	-13
8	1000	1030	1000	30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E41
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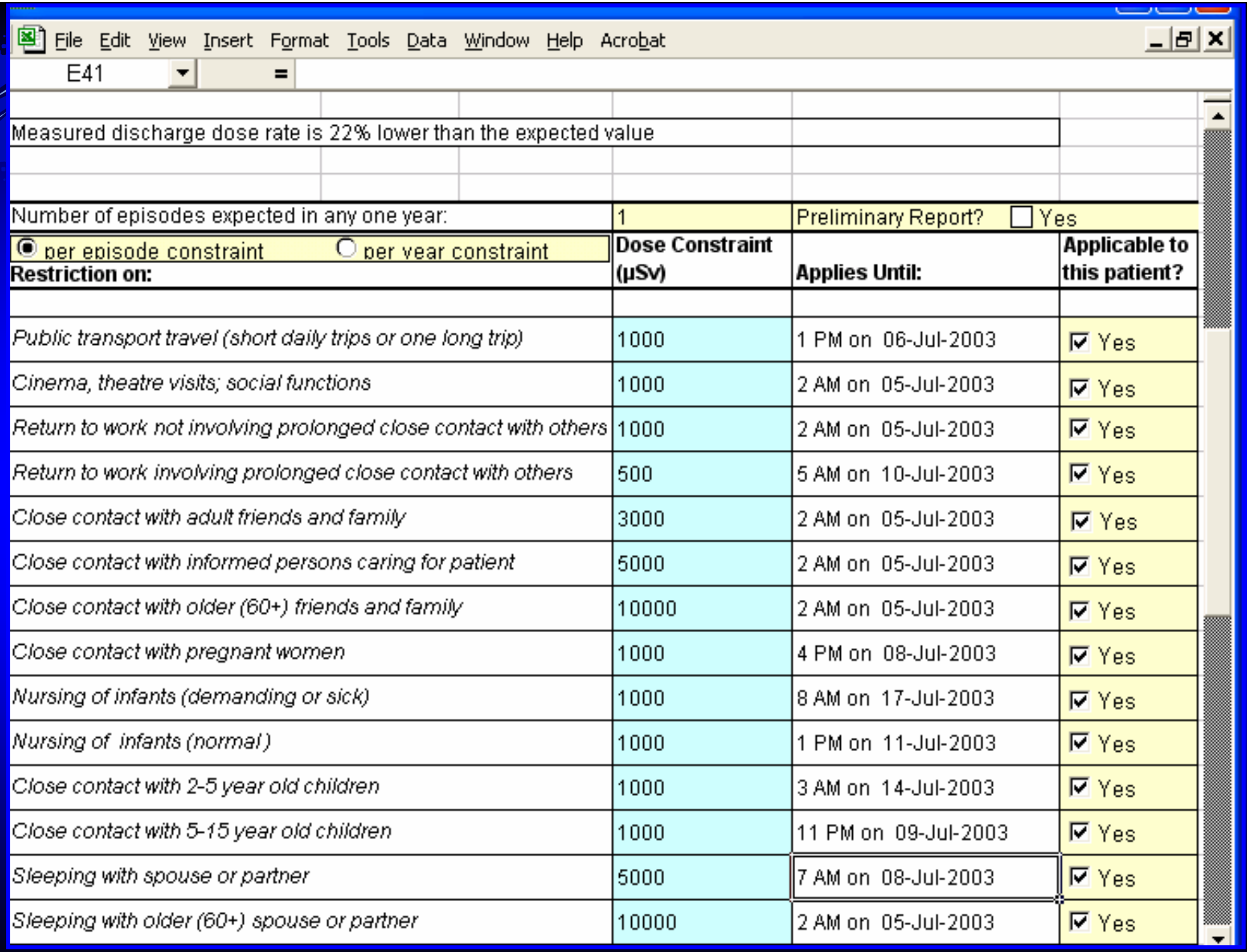
I-131 RADIONUCLIDE THERAPY - RADIATION PROTECTION MEASURES
FLINDERS MEDICAL CENTRE
Nuclear Medicine Section, Medical Imaging Division
Telephone: (08) 8204 4866
Type of Therapy:
I-131 ablation
Clearance/Radiation Exposure Data:
I-131 iodide - Ablation (slow clearance)
Patient Details:
First Name: Jane
Last Name: Doe
ID Number: 1111654AB1
Date of Birth December 30, 1952
Customize
Edit Data and Constraints
Pregnancy Excluded? Yes
Breast Feeding Excluded? Yes
Can patient be properly cared for (and good hygiene maintained) upon discharge? Yes
Date and time of administration (dd-mmm-yyyy hh:mm AM/PM) 03-Jul-2003 02:30 PM
Administered Activity 1850 MBq
Inital dose rate (measured) 30.0 µSv per hour at (distance) Two metres from patient
Recommended Date and Time of Discharge: 05-Jul-2003, at 2 AM
Date and time of discharge 05-Jul-2003 10:30 AM
Discharge dose rate (measured) 5.7 µSv per hour at (distance) Two metres from patient
Discharge dose rate (calculated) 7.3 µSv per hour at (distance) 2 metre(s) from patient
Discharge activity (calculated) 352 MBq (baseline ratio method)
Measured discharge dose rate is 22% lower than the expected value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E41
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Measured discharge dose rate is 22% lower than the expected value
Number of episodes expected in any one year: 1
Preliminary Report? Yes
per episode constraint per year constraint
Restriction on:
Dose Constraint (µSv)
Applies Until:
Applicable to this patient?
Public transport travel (short daily trips or one long trip) 1000 1 PM on 06-Jul-2003 Yes
Cinema, theatre visits; social functions 1000 2 AM on 05-Jul-2003 Yes
Return to work not involving prolonged close contact with others 1000 2 AM on 05-Jul-2003 Yes
Return to work involving prolonged close contact with others 500 5 AM on 10-Jul-2003 Yes
Close contact with adult friends and family 3000 2 AM on 05-Jul-2003 Yes
Close contact with informed persons caring for patient 5000 2 AM on 05-Jul-2003 Yes
Close contact with older (60+) friends and family 10000 2 AM on 05-Jul-2003 Yes
Close contact with pregnant women 1000 4 PM on 08-Jul-2003 Yes
Nursing of infants (demanding or sick) 1000 8 AM on 17-Jul-2003 Yes
Nursing of infants (normal) 1000 1 PM on 11-Jul-2003 Yes
Close contact with 2-5 year old children 1000 3 AM on 14-Jul-2003 Yes
Close contact with 5-15 year old children 1000 11 PM on 09-Jul-2003 Yes
Sleeping with spouse or partner 5000 7 AM on 08-Jul-2003 Yes
Sleeping with older (60+) spouse or partner 10000 2 AM on 05-Jul-2003 Yes

Microsoft Excel - RNRTScratch

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C53 =

After you have been given the radioactive substance to treat your medical condition, you will be a potential source of radiation exposure to other persons around you, particularly if they approach closer than one metre. You will have already been given some quite detailed instructions on the general precautions which you should take in order to minimise the radiation contamination and exposure of other persons. Specific instructions which relate to your particular circumstances are given here. The time for which each of the listed restrictions applies is based on the amount of radioactive substance given to you and (where possible) actual measurements of the radiation coming from your body. If you follow these restrictions for the specified time, the radiation dose to persons around you will be very small and need not be of concern.

If you have any difficulty in complying with these restrictions, or there are special circumstances you would like to be taken into consideration, please let your doctor know before you are discharged from hospital. You may also contact the Nuclear Medicine Section at Flinders Medical Centre at any time if you have any worries or queries regarding your therapy.

The restriction on:	applies up to, and including :	Expired?
Close contact with older (60+) friends and family	Saturday morning, July 5, 2003	
Close contact with informed persons caring for patient	Saturday morning, July 5, 2003	
Cinema, theatre visits; social functions	Saturday morning, July 5, 2003	
Return to work not involving prolonged close contact with others	Saturday morning, July 5, 2003	
Close contact with adult friends and family	Saturday morning, July 5, 2003	
Sleeping with older (60+) spouse or partner	Saturday morning, July 5, 2003	
Public transport travel (short daily trips or one long trip)	Sunday afternoon, July 6, 2003	
Sleeping with spouse or partner	Tuesday morning, July 8, 2003	
Close contact with pregnant women	Tuesday afternoon, July 8, 2003	
Close contact with 5-15 year old children	Wednesday evening, July 9, 2003	
Return to work involving prolonged close contact with others	Thursday morning, July 10, 2003	
Nursing of infants (normal)	Friday afternoon, July 11, 2003	
Close contact with 2-5 year old children	Monday morning, July 14, 2003	
Work with radiosensitive materials	Tuesday morning, July 15, 2003	
Sleeping with pregnant spouse or partner, or a child	Wednesday afternoon, July 16, 2003	
Nursing of infants (demanding or sick)	Thursday morning, July 17, 2003	

Measured Clearance Data

Print

Enter new Data

Measured Clearance Data

Jane Doe 12234A.12

Dual Exponential Fit				
Initial Value	Half-life (h)	Amount (%)	Correlation	mse %
60.258	6.68	63.702	0.99990978	3.99
Max Half-Life	192	30.96	36.298	

Units of Measurement:

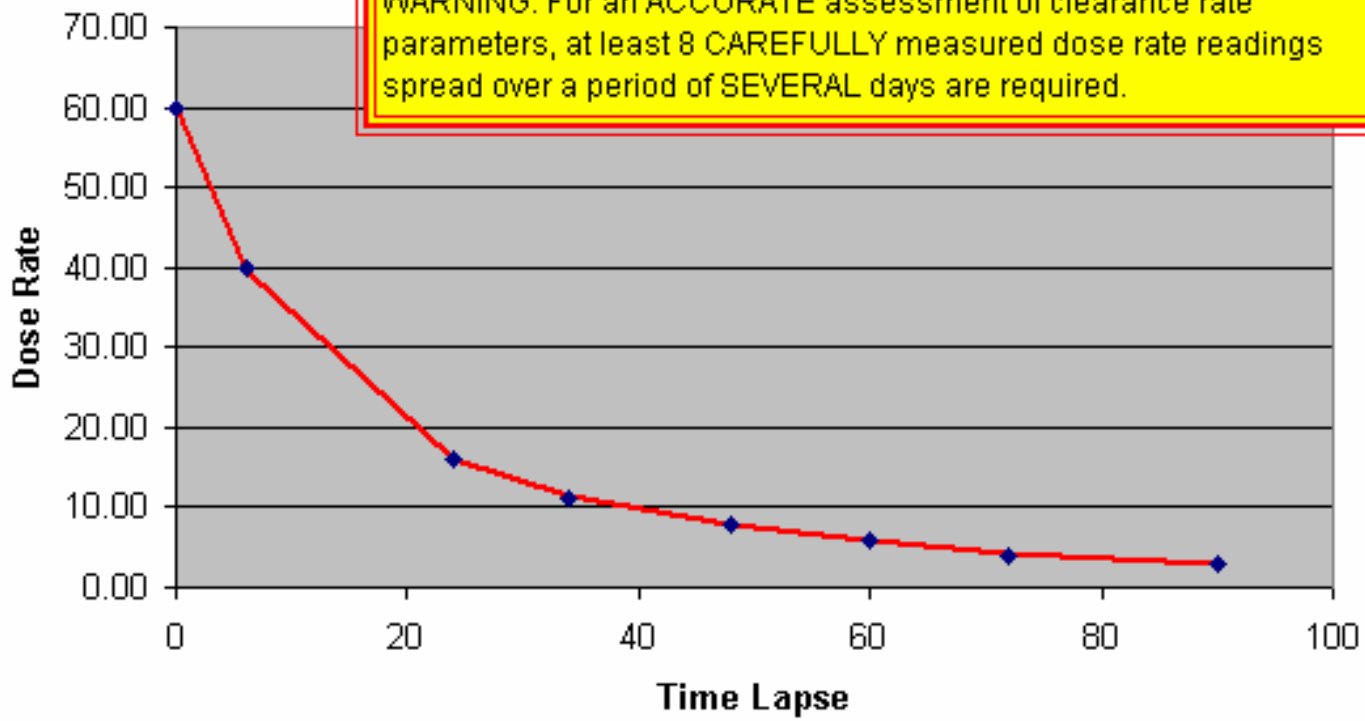
microsieverts/hour

Measurement Distance:

Three metres from patient

Time Lapse(h	Dose Rate (Measured)	Dose rate (Fitted)
0	60.00	6.03E+01
6	40.00	3.97E+01
24	16.00	1.60E+01
34	11.00	1.13E+01
48	8.00	7.73E+00
60	6.00	5.78E+00
72	4.00	4.38E+00
90	3.00	2.92E+00

WARNING: For an ACCURATE assessment of clearance rate parameters, at least 8 CAREFULLY measured dose rate readings spread over a period of SEVERAL days are required.



Single Exponential Fit

Dual Exponential Fit

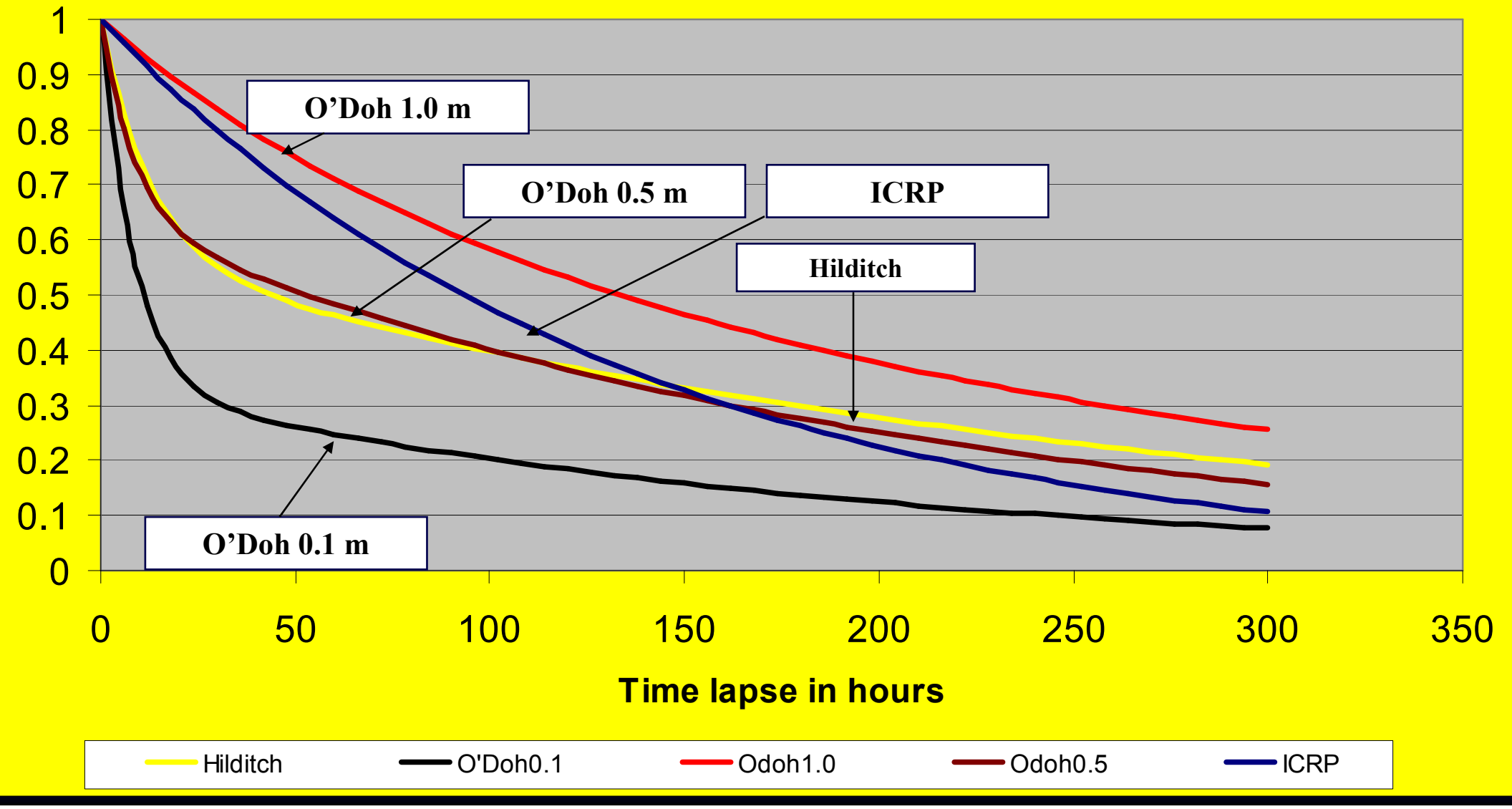
Incorporated Clearance Data
(can be modified by user)

Radiopharm/Clearance Data	Half-life of first component in hours	Percent of first component	Half-life of second component in hours	Percent of second component	Default dose rate at 1 metre in µSv/hr per MBq	Discharge Dose Rate Limit (µSv/h at 1 metre)	Normal Discharge Activity Limit (MBq)	Ancillary Discharge Activity Limit (MBq)
MEASURED CLEARANCE DATA	6.68	63.70	30.96	36.30	0.0500	50	600	100
I-131 iodide - Thyrotoxicosis	6.70	73.00	139.00	27.00	0.0500	50	600	100
I-131 iodide - Ablation (slow clearance)	12.70	75.00	86.30	25.00	0.0500	50	600	100
I-131 iodide - Ablation (fast clearance)	18.00	100.00	1000000.00	0.00	0.0500	50	600	100
I-131 iodide - Euthyroid	5.90	73.00	172.00	27.00	0.0500	50	600	100
I-131 RituxiMab	72.00	100.00	1000000.00	0.00	0.0500	50	600	100
I-131 MIBG	3.00	36.00	33.60	63.00	0.0500	50	600	100
I-131 Lipiodol	124.80	100.00	1000000.00	0.00	0.0500	50	600	100
In-111 Octreotide	2.94	74.00	65.20	26.00	0.0700	50	400	100
Not used								
Not used								
Not used								
Not used								
Not used								
Not used								
Not used								
Not used								
Not used								
Not used								
Not used								

Issues to be Resolved

- **Choice of appropriate data for the decay in exposure rate with time.**
- **Exposure rate versus time curves for each patient can be obtained, but (beware!) propagated errors in calculated restriction times and doses can be very large.**
- **Some consensus is needed on realistic exposure patterns for various patient activities.**
- **Some consensus is needed on the dose limits to be applied to various groups of persons.**
- **Effective dose conversion factors.**
- **Mean or maximum doses?**

Published Clearance Data for Thyrotoxic Patients



Errors in Using Fitted Clearance Data for Individual Patients

Modelled using Monte Carlo methods

Calculated restriction times for sleeping with spouse or partner. 2000 MBq ablation dose

Exposure rate measured at 0, 12, 24, 48 and 96 hours post administration

Measurement Precision (%)	Restriction Time (h)	CV (%)	Minimum	Maximum
1	131	11	112	171
10	197	69	60	469

Exposure rate measured at 0, 12, 24, 96 and 360 hours post administration

Measurement Precision (%)	Restriction Time (h)	CV (%)	Minimum	Maximum
1	134	1	132	138
10	132	10	109	166

Effect of Exposure Pattern and Dose Limit on Calculated Restriction Times

Calculated restriction times for sleeping with spouse or partner. 2000 MBq ablation dose

Exposure Pattern	Dose Limit (microsieverts)	Effective Exposure Time (hours)	Required Restriction (days)
Normally Used 8 h @ 0.1 m 6 h @ 1 m	1000	199.1	13.9
Normally Used 8 h @ 0.1 m 6 h @ 1 m	5000	199.1	5.7
? More Realistic? 1 h @ 0.1 m 5 h @ 0.3 m 2 h @ 0.5 m 6 h at 1 m	5000	11.5	2.7

Further Information

Full paper and spreadsheets available from authors

E-mail

John.Cormack@fmc.sa.gov.au

Effective Dose Conversion Factors

- **About 0.7 Sv per Gy air kerma**
- **Hp(10) a rough surrogate for effective dose**

Mean or Maximum Dose – Or Both?

- **Regulations generally specify a maximum dose.**
- **However, there will always be a finite error in calculated doses. Maximum dose may be considerably larger than the mean dose.**
- **Use mean dose in conjunction with 95th percentile value as regulatory criteria?**