SECONDARY PARTICLE DOSE AND RBE MEASUREMENTS USING HIGH-ENERGY PROTON

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Dosimetry Techniques:

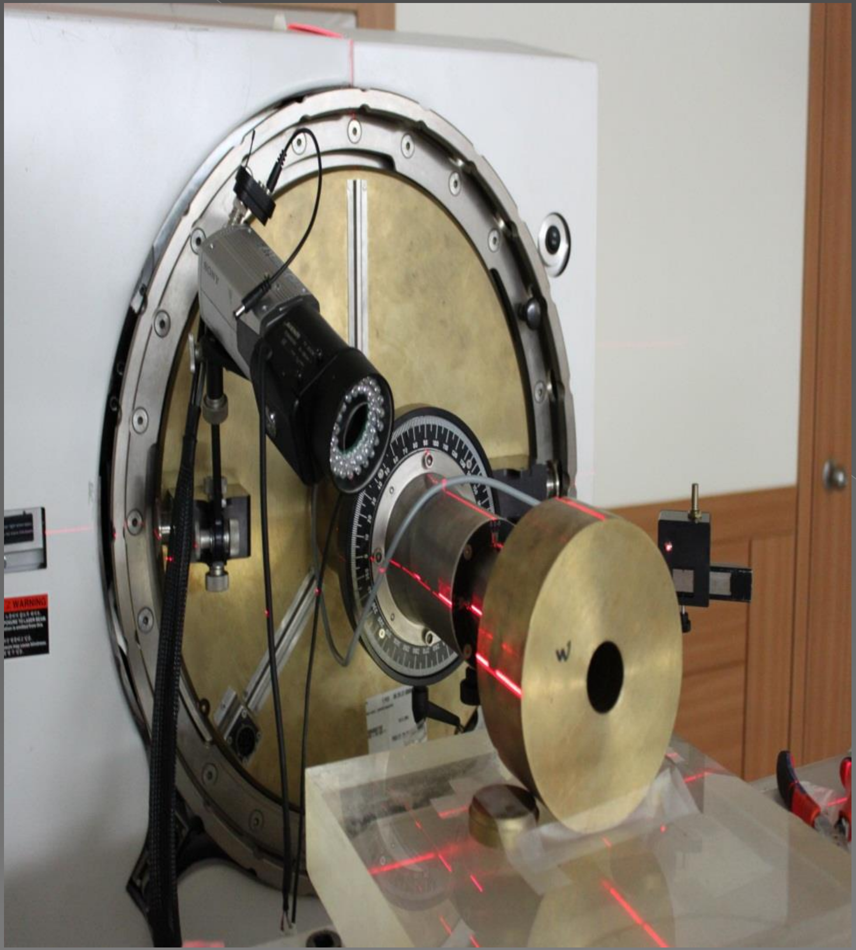
- **Solid state nuclear track detectors** →
- Emulsion
- Solid Scintillation
- Liquid scintillation
- Gamma spectrometry
- Beta monitoring
- Electrometer or electroscope
- Ionization chambers
- Surface barrier detectors
- Thermoluninescent phosphors
- Electret
- collection

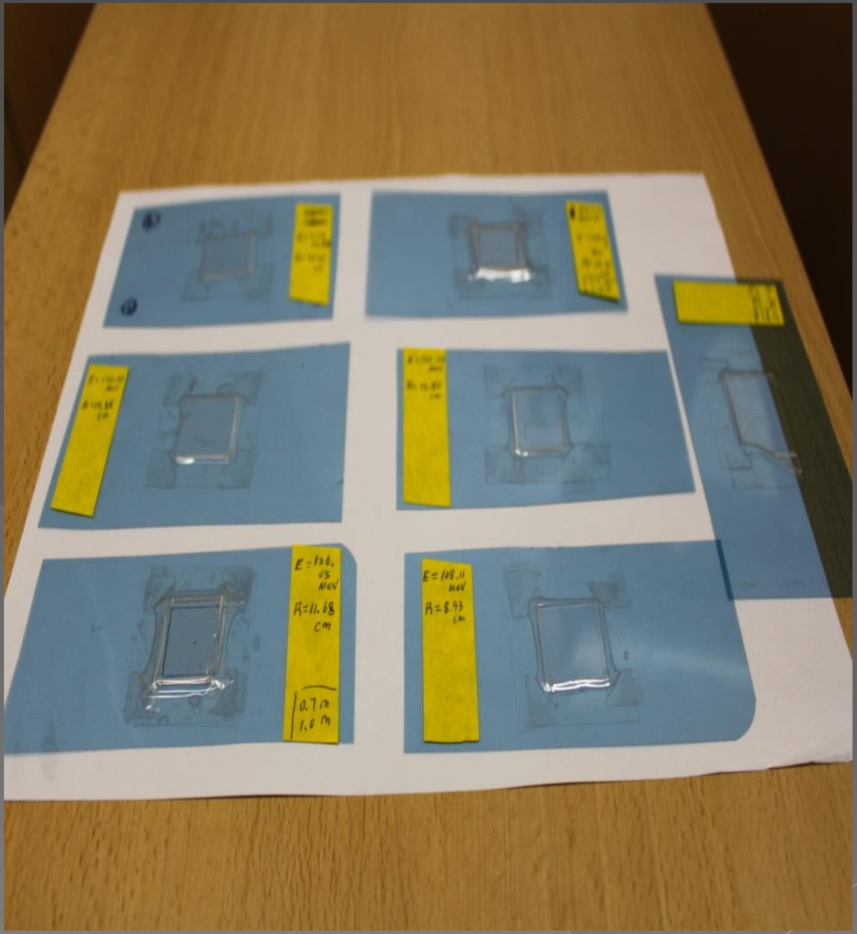
Advantages of Using Solid State Nuclear track Detectors (SSNTDs)

- Most of SSNTDs are insensitive to beta or gamma radiations.
- SSNTDs are insensitive to light, environmental temperature and humidity.
- SSNTDs are suitable for short / long term and low/high dose measurements.
- SSNTDs do not require power supply to operate.

When energy levels are sufficiently high, secondary particles with high LET are produced through nuclear interactions.

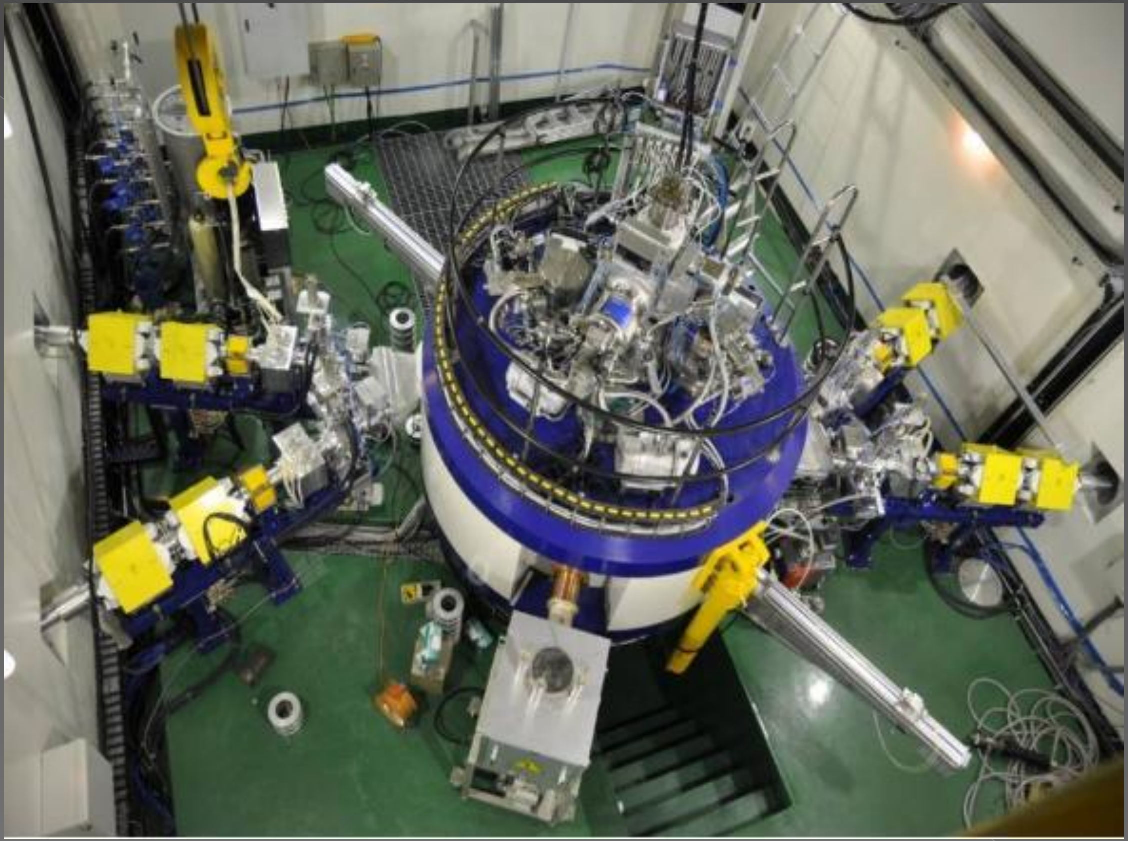
Track detectors (CR-39, $C_{12}O_7H_{18}$)





track detectors etched with a chemical etched poly allyl diglycol carbonate (commercially known as CR-39) was employed to determine the dosimetric and microdosimetric characteristics

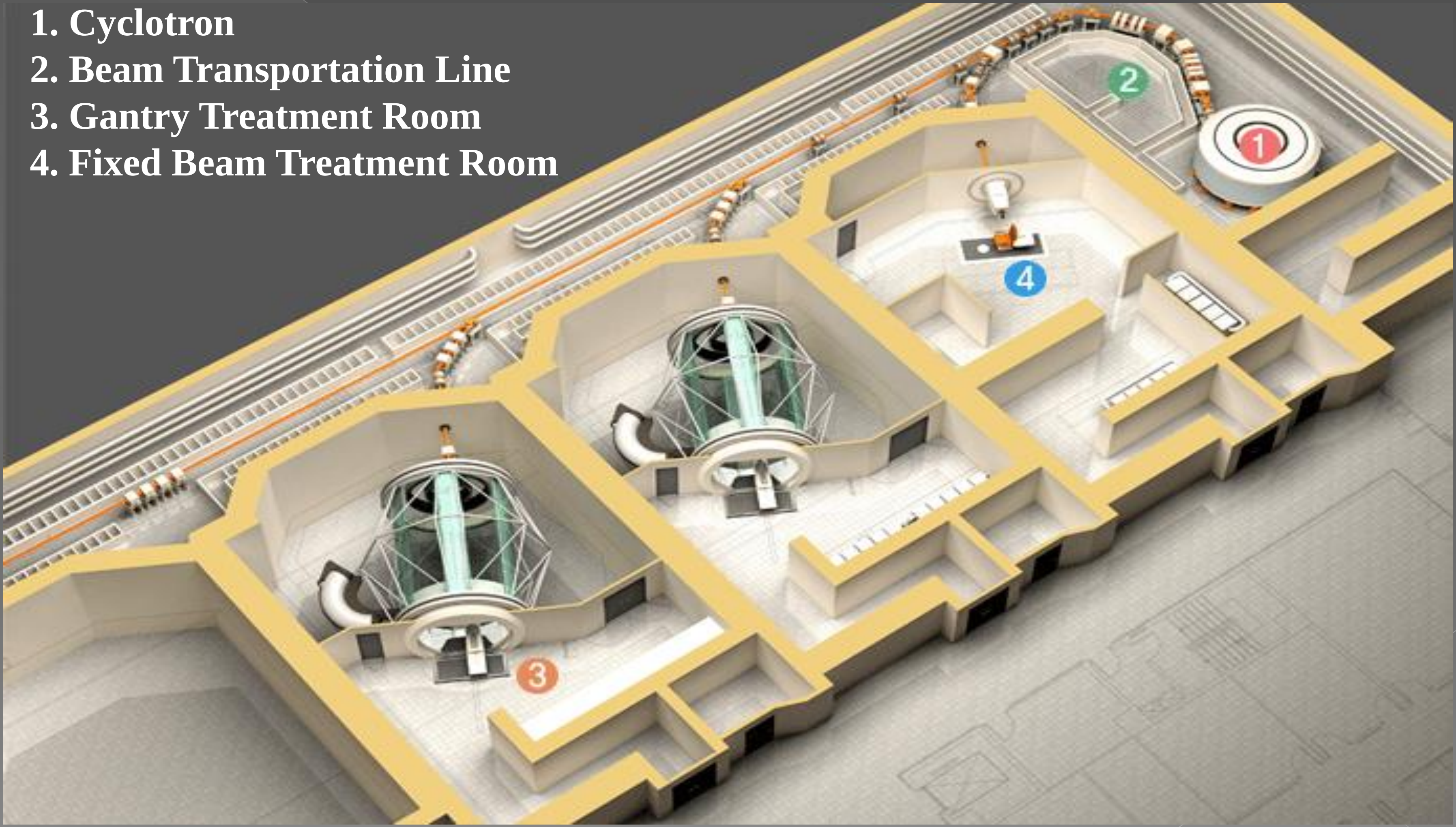
Irradiation at KIRAMS-30 Cyclotron at Jeongup



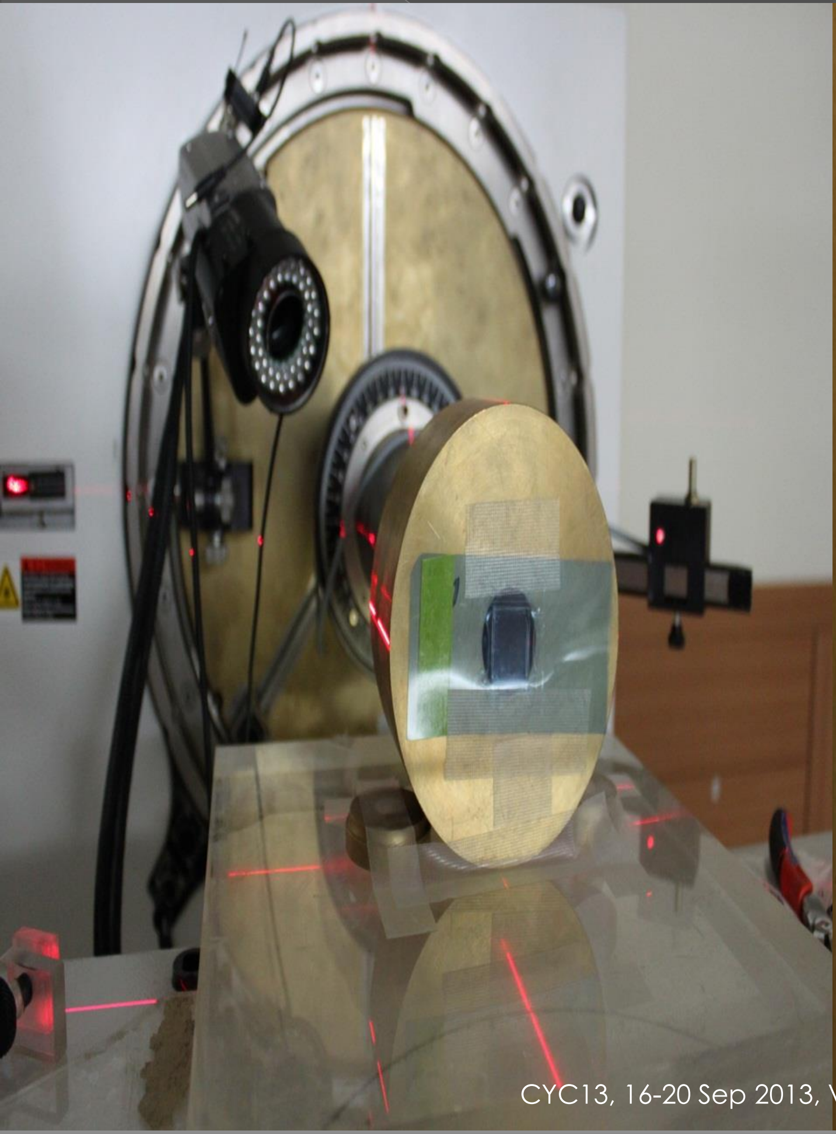
General Specifications	
Type of Accelerated Ions	Negative Hydrogen
Extraction method	Stripper carbon foil
Beam Energy(proton)	15 ~ 30 MeV
Beam Current(proton)	Guaranteed 300 uA
No. of Beam lines	4
Dual beam	available

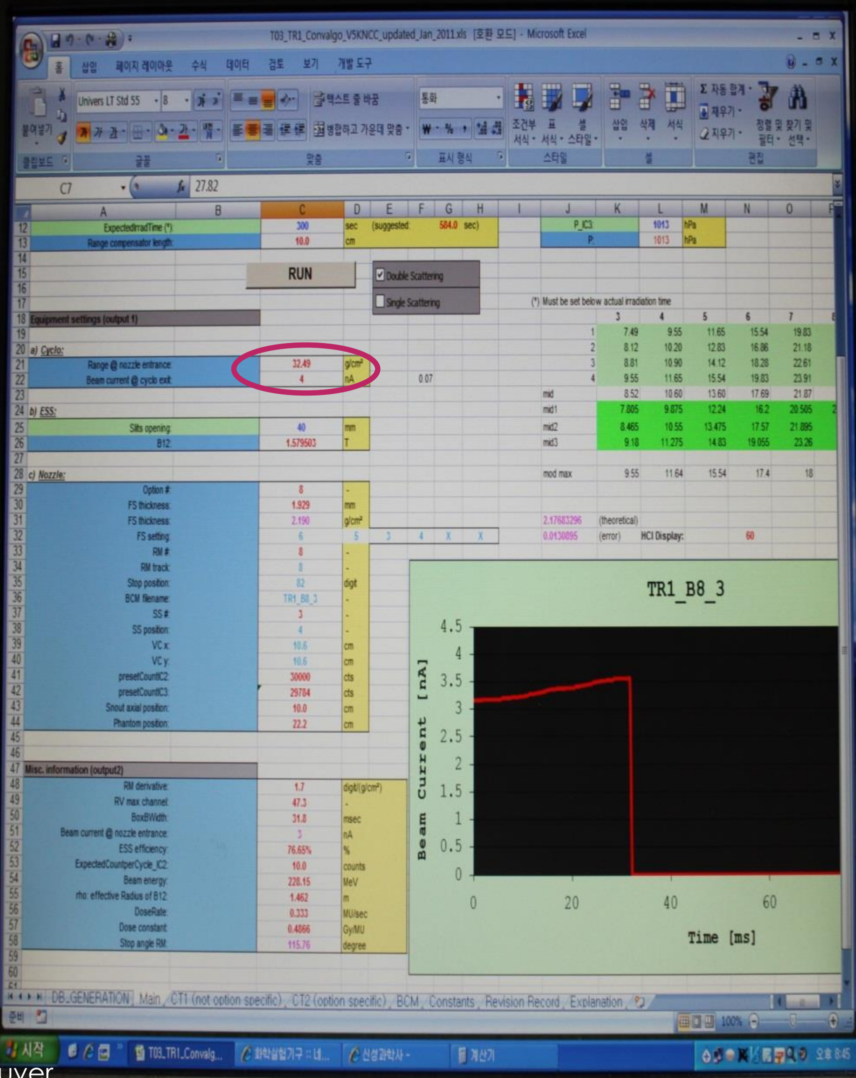
Irradiation at the national cancer center in South Korea (E_p: 70-250 MeV)

1. Cyclotron
2. Beam Transportation Line
3. Gantry Treatment Room
4. Fixed Beam Treatment Room



Track detectors





T03_TR1_Convalgo_V5KNCC_updated_Jan_2011.xls [호환 모드] - Microsoft Excel

C7 27.82

ExpectedIrradTime (*):	300	sec	(suggested: 584.0 sec)
Range compensator length:	10.0	cm	

☑ Double Scattering

☐ Single Scattering

Equipment settings (output 1)

a) Cyclo:

Range @ nozzle entrance:	32.49	g/cm²	
Beam current @ cyclo exit:	4	nA	0.07

b) ESS:

Slits opening:	40	mm
B12:	1.579503	T

c) Nozzle:

Option #:	8	-					
FS thickness:	1.929	mm					
FS thickness:	2.190	g/cm²					
FS setting:	6	5	3	4	X	X	
RM #:	8	-					
RM track:	8	-					
Stop position:	82	digit					
BCM filename:	TR1_B8_3	-					
SS #:	3	-					
SS position:	4	-					
VC x:	10.6	cm					
VC y:	10.6	cm					
presetCountIC2:	30000	cts					
presetCountIC3:	29784	cts					
Snout axial position:	10.0	cm					
Phantom position:	22.2	cm					

Misc. information (output2)

RM derivative:	1.7	digit/(g/cm²)
RV max channel:	47.3	-
BoxBWidth:	31.8	msec
Beam current @ nozzle entrance:	3	nA
ESS efficiency:	76.65%	%
ExpectedCountperCycle_IC2:	10.0	counts
Beam energy:	228.15	MeV
rho: effective Radius of B12:	1.462	m
DoseRate:	0.333	MU/sec
Dose constant:	0.4866	Gy/MU
Stop angle RM:	115.76	degree

P_IC3:	1013	hPa
P:	1013	hPa

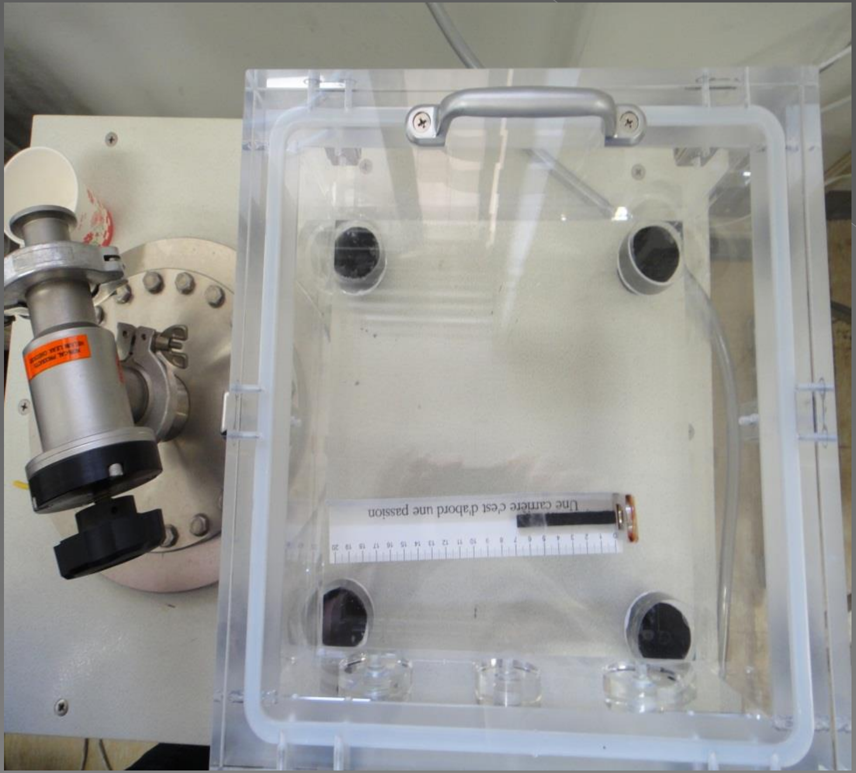
(*) Must be set below actual irradiation time

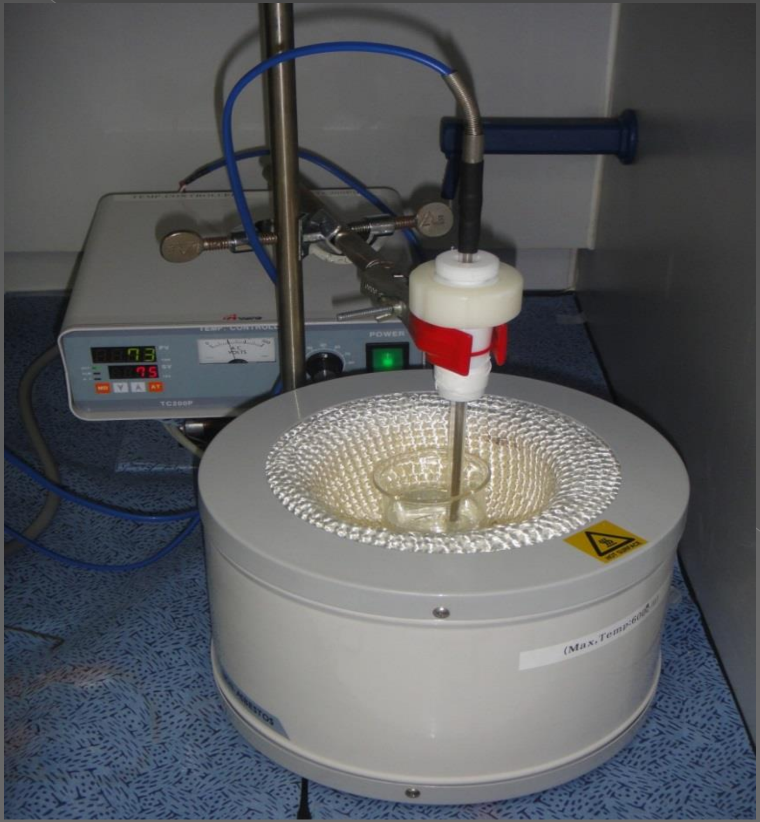
	3	4	5	6	7
1	7.49	9.55	11.65	15.54	19.83
2	8.12	10.20	12.83	16.86	21.18
3	8.81	10.90	14.12	18.28	22.61
4	9.55	11.65	15.54	19.83	23.91
mid	8.52	10.60	13.60	17.69	21.87
mid1	7.805	9.875	12.24	16.2	20.505
mid2	8.465	10.55	13.475	17.57	21.895
mid3	9.18	11.275	14.83	19.055	23.26
mod max	9.55	11.64	15.54	17.4	18

2.17683296 (theoretical)

0.0130895 (error) HCI Display: 60

Before etching for checking the exact etching condition one corner was irradiated with ^{252}Cf and other corner was irradiated by ^{241}Am

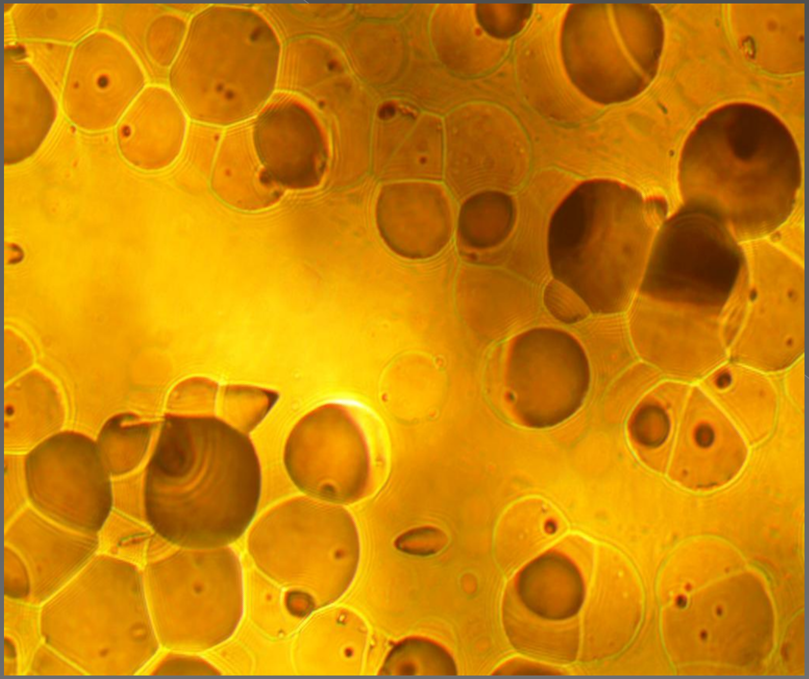




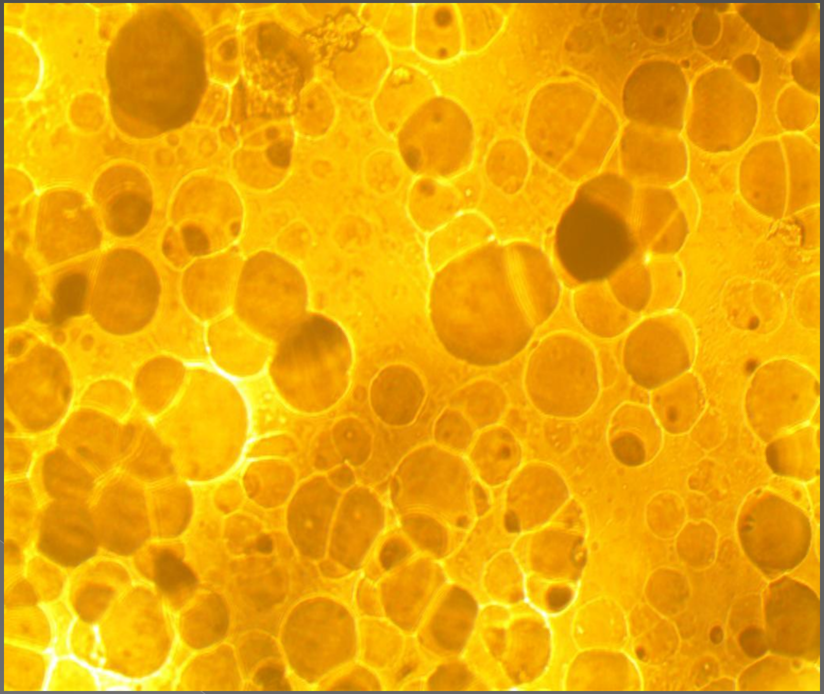
- After irradiation, each part of the CR-39 detectors was etched at 6NaOH at at 70℃
- The etching time 15 h and removal thickness was 20µm

- Magnification of 1000 pixels,
- Field-of-view area :4.71 × 10^{-4} cm^2.

- 72 MeV

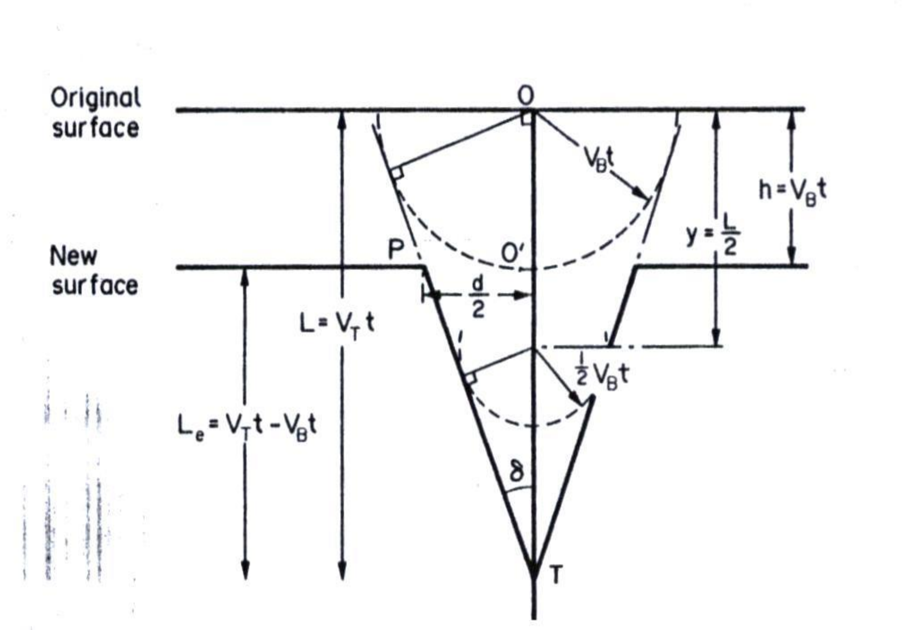


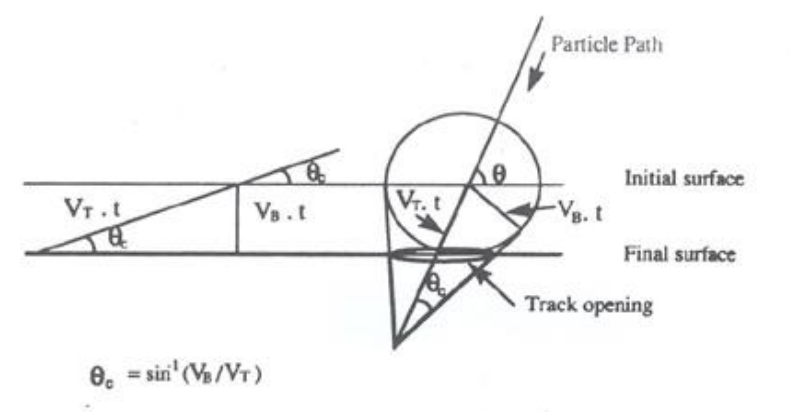
- 150 MeV



The typical etched tracks of secondary particles registered by CR-39 detector for different proton energies of 72 and 150 and MeV.

V_T :Track Etching Velocity
V_B : Bulk Etching Velocity



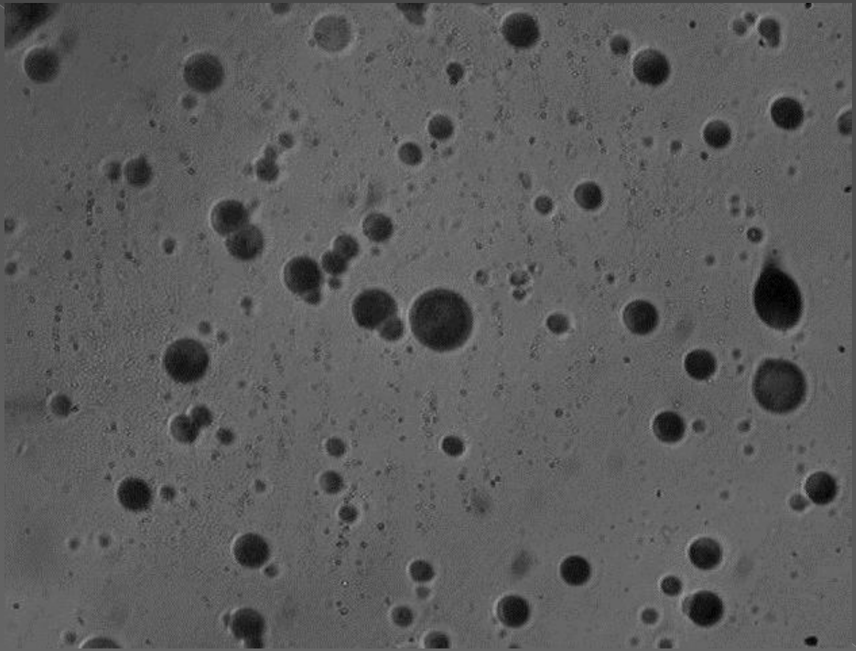


$$D = d = 2V_Bt\sqrt{\frac{V_T - V_B}{V_T + V_B}}$$

$$V_T \text{ Sin } \theta > V_B$$

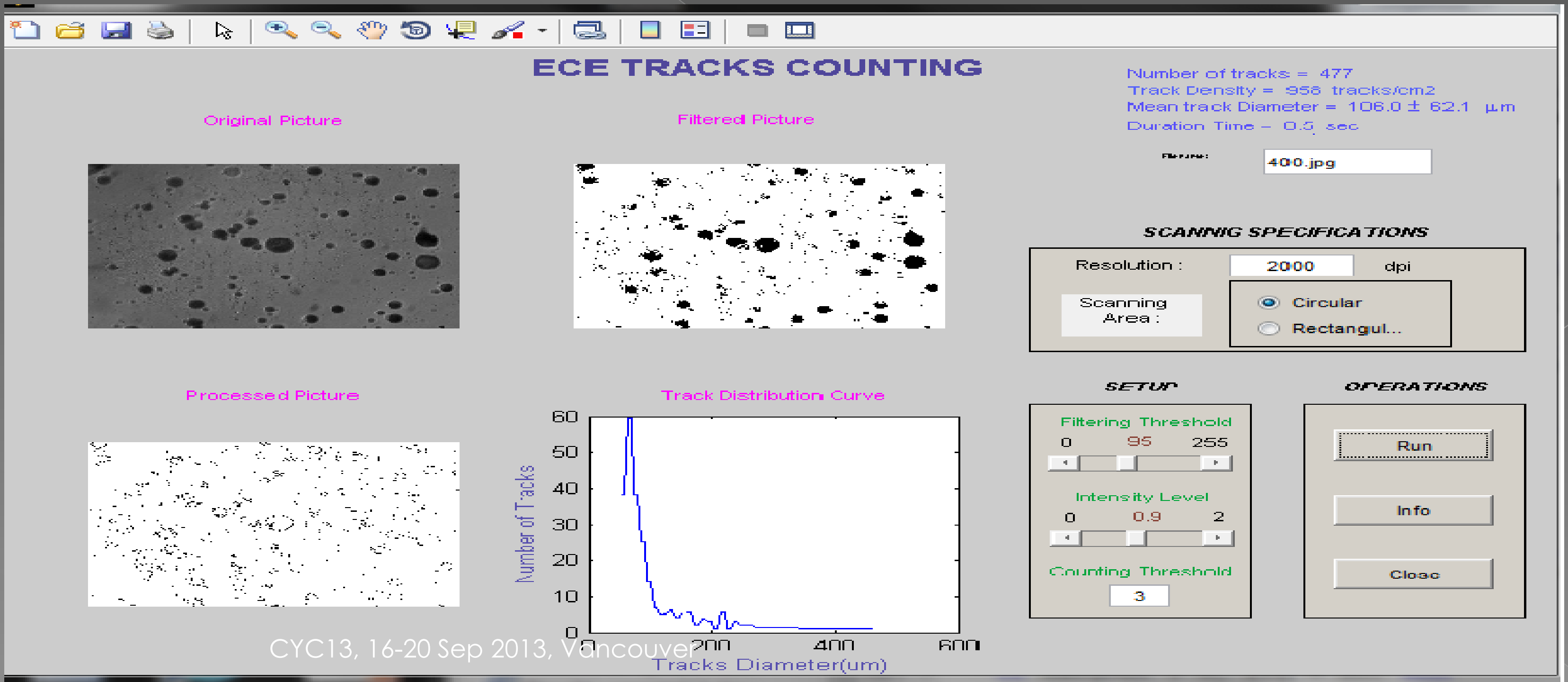
$$\theta_C = \text{Arc Sin } V_B/V_T$$

$$D = \frac{2V_Bt\sqrt{(V_T^2 - V_B^2)}}{V_T \sin\theta + V_B} \qquad d = 2V_Bt\sqrt{\frac{V\sin\theta - 1}{V\sin\theta + 1}}$$



Our customized computer program called track counting system which provide typical result shown at blow

Ghergherehchi, et al, Radiation Measurements 50 (2013)



ECE TRACKS COUNTING

Number of tracks = 477
Track Density = 958 tracks/cm2
Mean track Diameter = 106.0 ± 62.1 µm
Duration Time = 0.5 sec

400.jpg

SCANNIG SPECIFICATIONS

Resolution : 2000 dpi

Scanning Area : ● Circular ○ Rectangul...

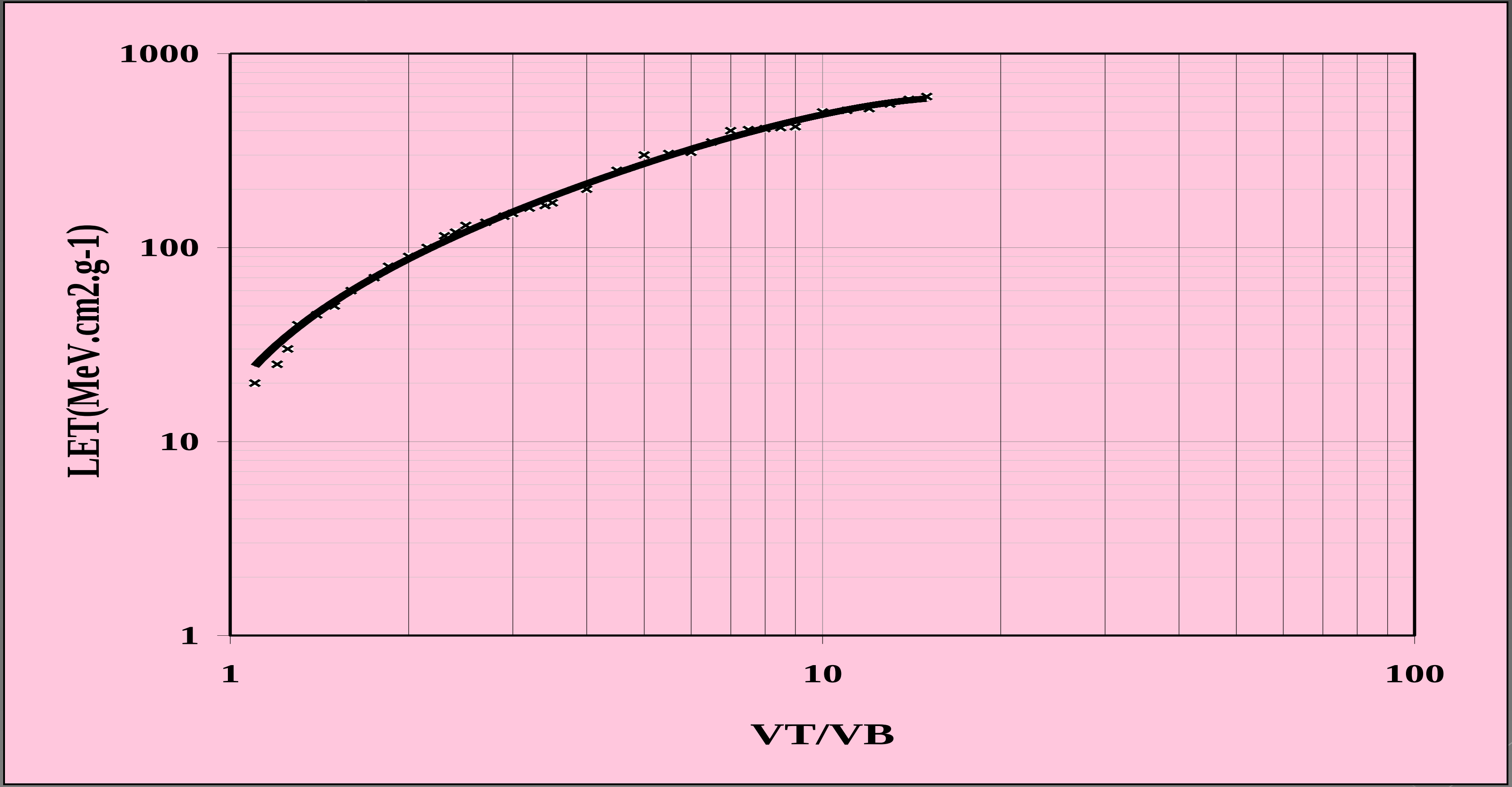
SETUP

Filtering Threshold: 0 95 255

Intensity Level: 0 0.9 2

Counting Threshold: 3

LET spectrometer based on chemically etched



This calibration curve from irradiations of ^{12}C to ^{56}Fe ions, with LET values in water ranging from 7.9 to 700 keV/µm (Spurny,radiat.Meas.2005)

Integral Dosimetry and Microdosimetry Characteristics

Dose characteristics and clinical radiobiological effectiveness for the particles having LET values higher than 10 keV/μm can be obtained from the LET spectra by the following

$$D_W = \frac{1}{A}\left(\frac{S(E)}{\rho}\right)_W \frac{Q}{e} 1.062 \times 10^{-10}, \qquad (Gy)$$

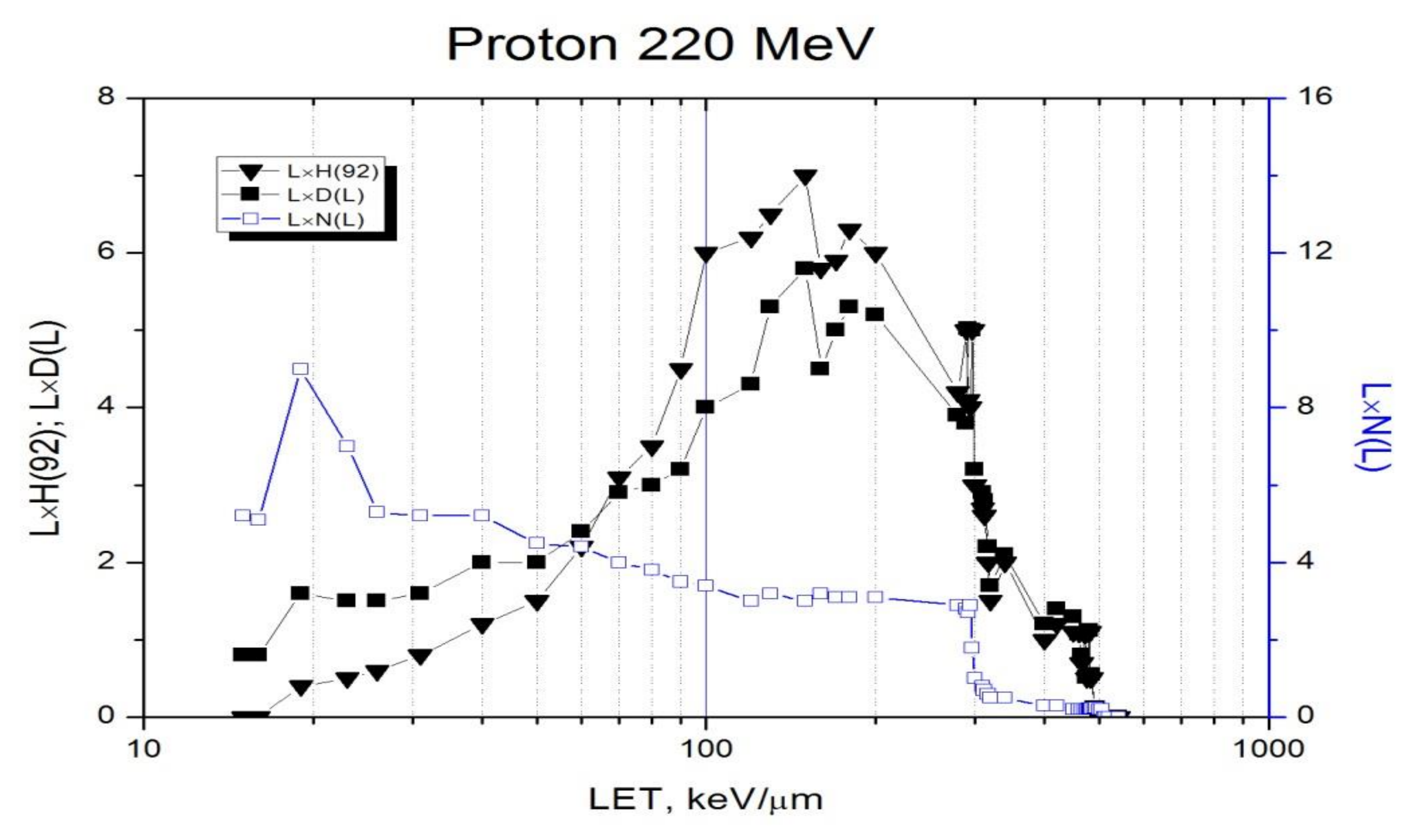
$$D_{LET} = \int \left(\frac{dN}{dL}\right) L \, dL$$

$$H_{LET} = \int \left(\frac{dN}{dL}\right) L Q(L) \, dL$$

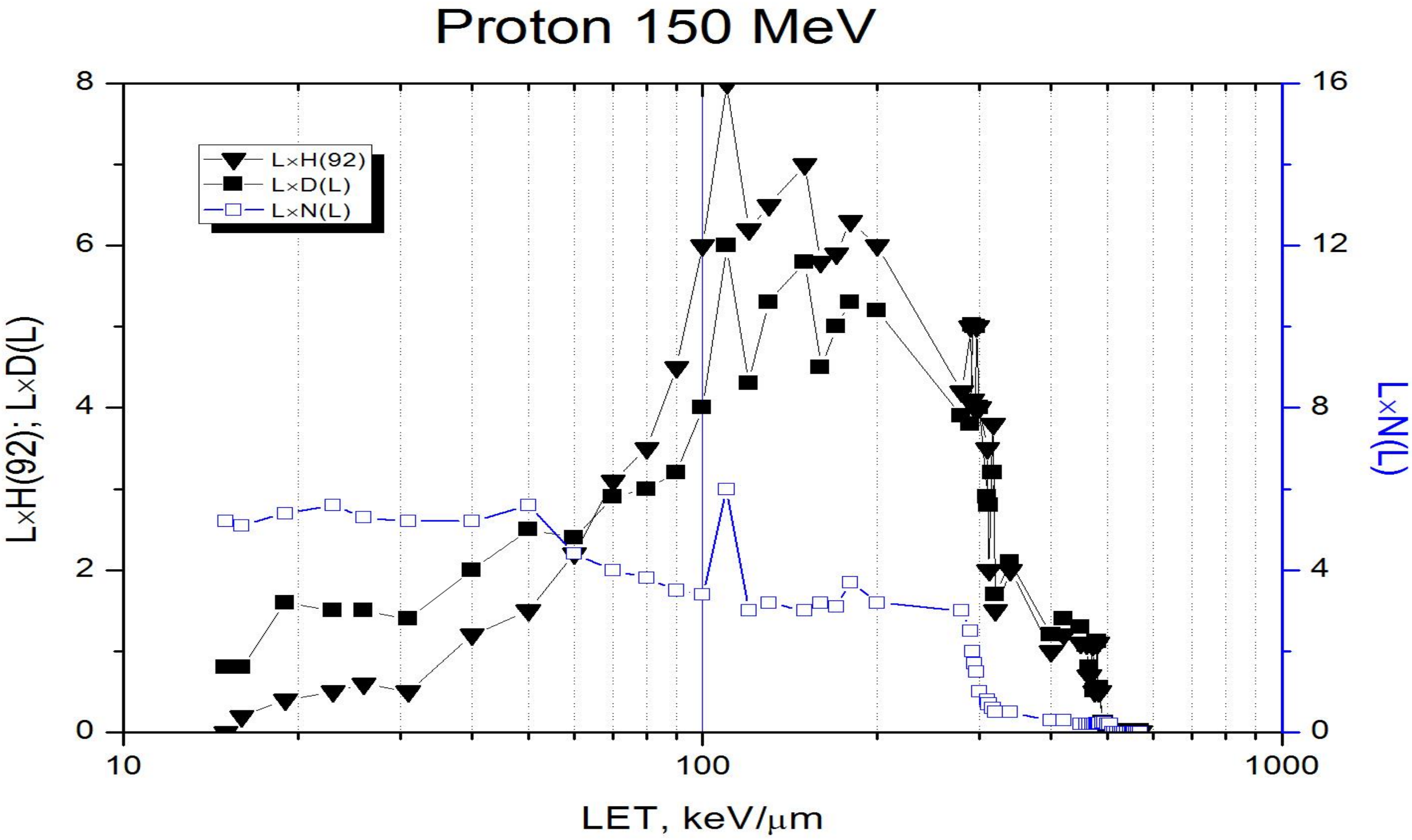
$$R_{LET} = \int \left(\frac{dN}{dL}\right) L r(L) \, dL$$

RBE=1 + $(R_{LET}–D_{LET})/D_{point}$.

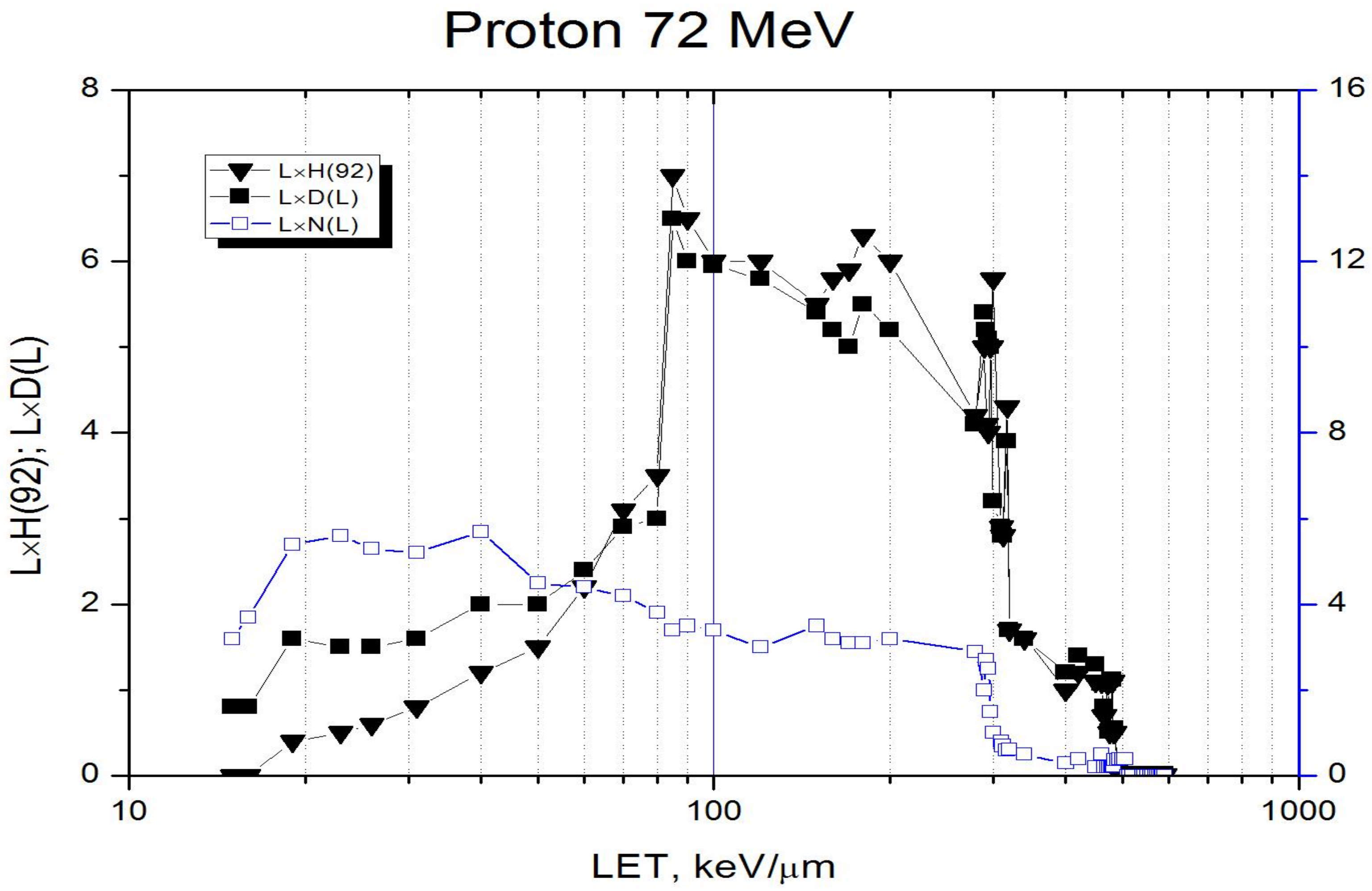
where dN/dL is the number of tracks in an LET interval, L is the value of the LET and Q (L) is the quality factor corresponding to the value of Land r (L) is the biological weighted function.



Event number LN(L), dose LD(L), and dose equivalent LH92(L) distributions in terms of LET for Ep = 220 MeV.



Event number LN(L), dose LD(L), and dose equivalent LH92(L) distributions in terms of LET for Ep = 150 MeV.



Event number LN(L), dose LD(L), and dose equivalent LH92(L) distributions in terms of LET for Ep = 72 MeV.

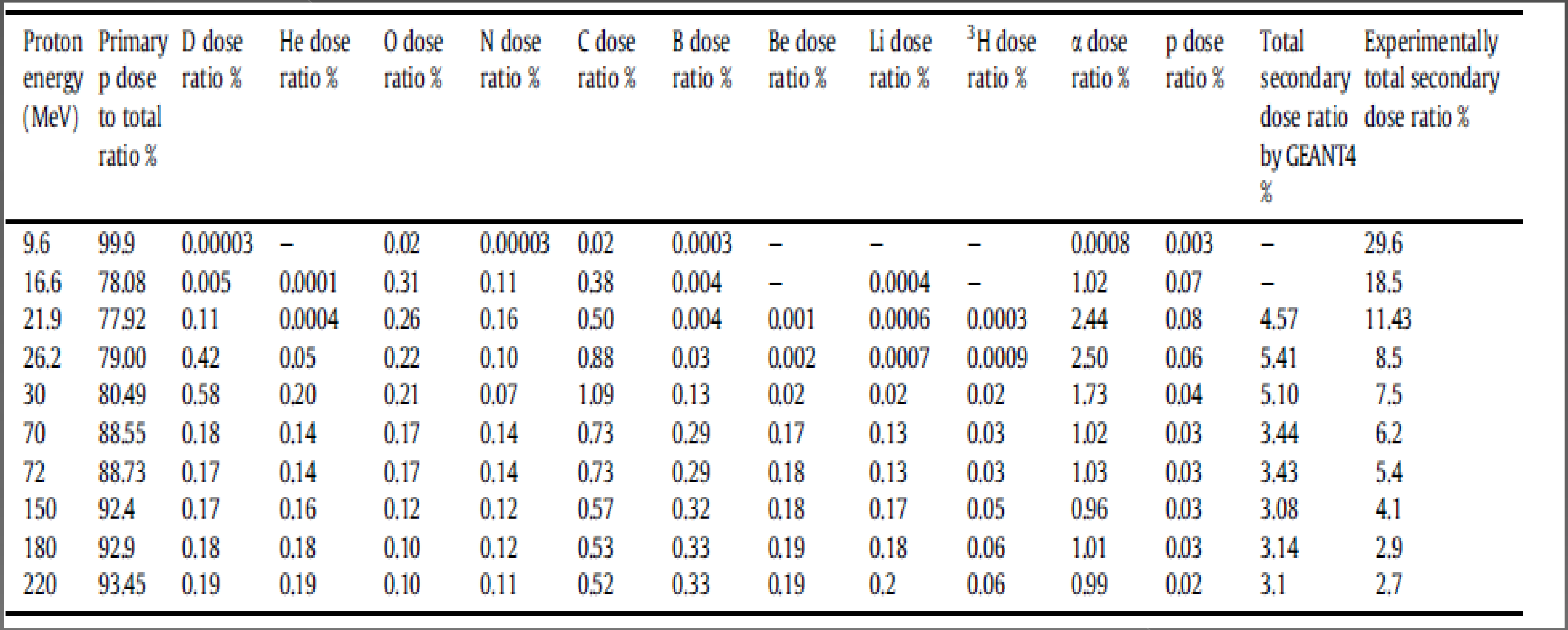
Dose ratio of the secondary to primary particles for a 1 - Gy entrance dose for different proton energies.

E_P (MeV)	Dose ratio of the secondary to primary particles for 1 - Gy entrance dose at each detector	Dose ratio of the secondary to primary particles for 1 - Gy entrance dose at 220 MeV
220	2.7	2.7
150	3.4	4.3
72	5.4	7.4

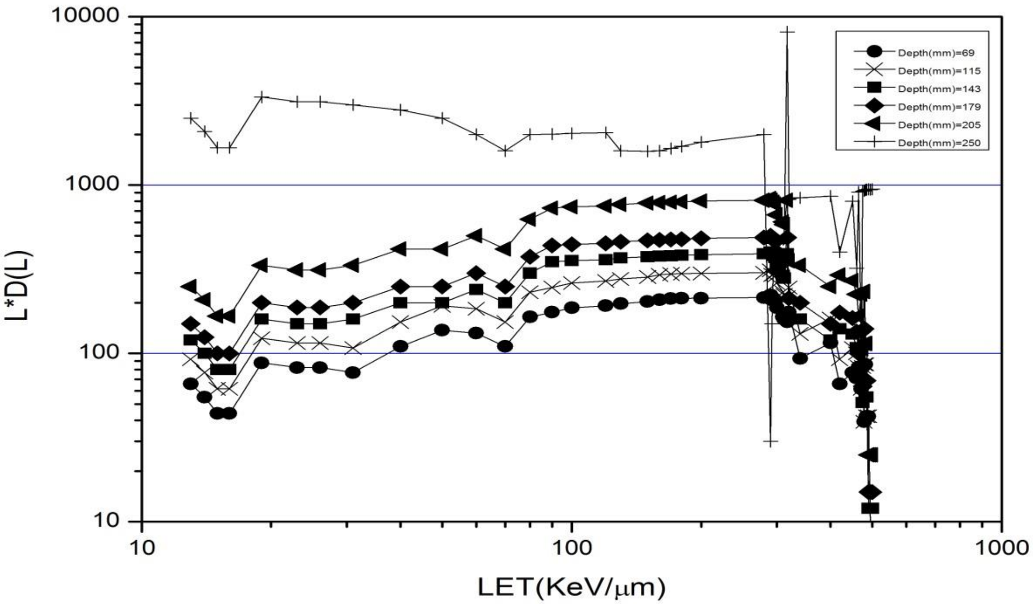
Absorbed dose D and dose equivalent H for different proton energies ranging from 9.6 to 220 MeV along with the prediction of the total cross-sections for the constitutive CR-39 material obtained using the Alice code

Energy (MeV)	**Total cross section (mb) for ${}^{1}P+{}^{16}O$**	**Total cross section (mb) for ${}^{1}P+{}^{12}C$**	**Absorbed dose**	**Dose equivalent**	**The dose ratio of secondary to primary particles**
9.6	708.1	574.0	296	4270	29.6% (Ghergherehchi,2011, JKPS)
16.6	559.4	523.6	185	2421	18.5%
21.9	537.5	436.5	114	1741	11.43%
26.2	505.7	404.8	85	1402	8.5%
30.0	470.3	384.7	75	1311	7.5%
70	317.7	254.5	84.7	731	6.2%(spurny 2001)
72	313.5	251.4	74.2	607	5.4%
130	238.7	189.1	49.3	400	4.3% (spurny 2001)
150	223.7	176.7	43.7	337	4.1%
180	205.1	162.0	28.7	292	2.9%
220	187.6	124.2	27.1	256	2.7%

The calculated various secondary particles dose by GEANT4 in CR-39 and the comparison of calculated total secondary dose ratio with experimentally obtained values in this work. (Ghergherehchi 2012,Radiation Mesurment)



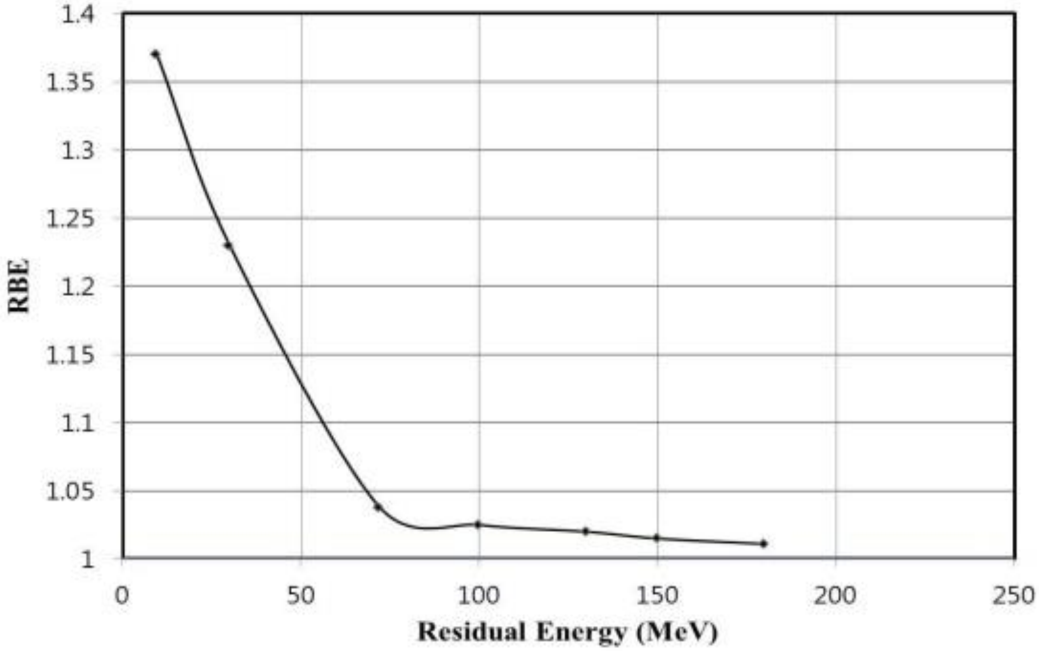
Proton energy (MeV)	Primary p dose to total ratio %	D dose ratio %	He dose ratio %	O dose ratio %	N dose ratio %	C dose ratio %	B dose ratio %	Be dose ratio %	Li dose ratio %	^{3}H dose ratio %	α dose ratio %	p dose ratio %	Total secondary dose ratio by GEANT4 %	Experimentally total secondary dose ratio %
9.6	99.9	0.00003	–	0.02	0.00003	0.02	0.0003	–	–	–	0.0008	0.003	–	29.6
16.6	78.08	0.005	0.0001	0.31	0.11	0.38	0.004	–	0.0004	–	1.02	0.07	–	18.5
21.9	77.92	0.11	0.0004	0.26	0.16	0.50	0.004	0.001	0.0006	0.0003	2.44	0.08	4.57	11.43
26.2	79.00	0.42	0.05	0.22	0.10	0.88	0.03	0.002	0.0007	0.0009	2.50	0.06	5.41	8.5
30	80.49	0.58	0.20	0.21	0.07	1.09	0.13	0.02	0.02	0.02	1.73	0.04	5.10	7.5
70	88.55	0.18	0.14	0.17	0.14	0.73	0.29	0.17	0.13	0.03	1.02	0.03	3.44	6.2
72	88.73	0.17	0.14	0.17	0.14	0.73	0.29	0.18	0.13	0.03	1.03	0.03	3.43	5.4
150	92.4	0.17	0.16	0.12	0.12	0.57	0.32	0.18	0.17	0.05	0.96	0.03	3.08	4.1
180	92.9	0.18	0.18	0.10	0.12	0.53	0.33	0.19	0.18	0.06	1.01	0.03	3.14	2.9
220	93.45	0.19	0.19	0.10	0.11	0.52	0.33	0.19	0.2	0.06	0.99	0.02	3.1	2.7



The distributions absorbed doses for various depths in CR-39 as L*D(L) for a primary proton energy of 220 MeV

RBE values at various residual proton energies

- **Nanodosimetry with high energy proton**
- **Correlation between this result of l*D(L),L*H92(L) with prediction of the Alice code**



REB calculation based on the microdosimetry method for 220MeV proton beams.

Depth in CR-39(mm)	69	115	143	179	205	250
E_{mean} (MeV)	180	150	130	100	72	Bragg
D_{point} (mGy)	225	179	147	98	75.3	3.1
D_{LET}(mGy)	3.4	4.1	5.5	6.8	7.4	2.7
D_{LET}/D_{point} %	1.51	2.29	3.74	7.09	9.8	87.09
R_{LET}(mGy)	6.052	6.84	8.52	9.25	10.28	3.86
RBE	1.011	1.015	0.020	1.025	1.038	1.37