CERN - PS/WG 3

FURTHER CONSIDERATIONS ABOUT THE RADIATION SHIELDING FOR 30 GeV PROTONS.

I. Introduction.

The calculations in this report are carried out along the same lines as those in the previous one (PS/WG1). It is attempted to take into consideration more details which may affect the absorption of the radiation. Whereas in the first report all calculations were made in such a way as to give a safe estimate, the results obtained in this one are not supposed to contain any appreciable safety factors unless it is stated otherwise.

As it is no longer planned to let a considerable fraction of the beam out into the open air or to leave part of the trench, which contains the accelerator tube, uncovered, the action of the beam in air is not considered this time.

II. Medical Tolerance Data.

The recent recommendations of the British, Canadian and U.S. delegates for the Internation Commission on Radiation Protection contain a figure of 0,3 rem/40hrs. week as a tolerance dose. To convert these figures into fluxes of particles values for the r.b.e. (relative biological efficiency) and the energy deposition in tissue per unit flux are needed.

1r corresponds to an energy of 90 erg deposited per g of tissue.

For fast particles the r.b.e. is unity. The energy loss is 2 MeV/g cm^{-2}. Thus a flux of 60 fast particles cm^{-2} sec.$^{-1}$ gives the tolerance dose.

For neutrons the recommendations give an r.b.e. value of 10. ("fast neutrons"). Figures for the tolerance flux of neutrons are also included in the recommendations. They are based on calculations by Mitchell (1), Tait (2) and Snyder (unpublished) which are in substantial agreement with our own estimates in the previous report.

Some of these figures are:

Neutron-Energy MeV	Tolerance Flux cm^{-2} sec^{-1}
10-3	30
2	40
1	60
Thermal	2000

For the processes to be considered, the neutrons of 10-3 MeV are the most important ones, thus the tolerance flux of 30 neutrons cm^{-2} sec^{-1} is the relevant figure for our consideration.

Safety Factor.

It was emphasised by Mitchell that these figures do not contain any safety factor. They are just limits, above which damages have to be expected. He recommends a safety factor of at least 5. This safety factor has to cover the following risks:

1. Some experiments indicate r.b.e. values for late effects induced by neutron irradiation as high as 30.

2. Very little is known about the genetic effects of chronic irradiation. It seems quite possible that doses of the order of the tolerance dose produce a significant rate of mutations. Lack of information about the spontaneous mutations makes conclusions difficult.

In this connection it was stressed by Mitchell that biological experiments on the machine ought to be provided for.

3. If the machine is run in shifts some people might be tempted to work considerably longer than 40 hours.

4. Nuclear workers are liable to receive extra radiation in the course of their work (or with the dentist !) on top of the chronic dose received near the machine.

In view of these points it seems advisable to choose the safety factor as high as 10. This increase in safety costs an extra 0,5 m of concrete.

III. Machine Data.

An energy of 30 GeV and a maximum available intensity of 10^{+9} protons per second were again used as a basis for the calculations. The effect of small changes in these values is discussed in section X.

IV. Summary of the Method.

Interaction of 30 GeV protons with matter is known only from cosmic ray experiences. The most detailed knowledge available about the processes of nuclear disintegrations induced by such protons and part of their secondaries is derived from observations in photographic emulsions exposed to the cosmic radiation at high altitudes. The results needed are summarised in section V. From this data we are able to predict approximately the flux of different types of secondary particles behind a moderate thickness x_o of shield the transition layer in which at most two successive nuclear interaction processes have to be considered (section VI). As we are interested in the flux of particles leaving the shield, the next problem is then to find the attenuation of this flux in the rest of the shield for the different types of radiation produced. In practice only the neutrons will be of interest. Here again data known from cosmic rays are used. From measurements in balloons and aircrafts it is known that the intensity of the fast neutron component of cosmic rays increases in the topmost layer of the atmosphere (till about 100 g/cm^{-2}) then decreases. From about 250 g/cm^2 downwards the attenuation can be described by an exponential law with a mean free path of about 170 g/cm^2. The same attenuation is found underground up to about 15 m water equivalent.

If we now assume; that the attenuation is similar for cosmic rays in air and for the radiation found behind the transition layer in our problem, we have only got to choose x_o large enough to correspond to a point in the region of exponential absorption, which is possible. Then the known flux of neutrons out of the transition layer is attenuated according to the known exponential law. The assumptions made here are discussed in section VII.

V. Interaction and absorption processes.

Though the 30 GeV protons and their secondaries will undergo elastic and unelastic scattering, with or without charge exchange etc., it is assumed here, that the nuclear collisions giving rise to stars in photographic emulsions are the processes which are chiefly responsible for the degeneration of energy and for an energy flux in direction greatly different from the direction of the primaries. The first assumption at least is supported by the fact, that it seems possible to draw a consistent picture of mosmic ray intensities throughout the atmosphere on this basis.

We based ourselves on the paper by CAMERINI, LOCK and PERKINS (3, p.1). From this paper we use the following data:

A fig 1
B fig 4
C fig 10
D tab 3
E fig 11
F fig 16
G fig 17

Protons of 30 GeV lose their energy mostly by nuclear collisions. The collision mean free path L will be of the order of 150 g/cm^2. The exact value is not important for these considerations. The following particles are created:

1. π-mesons (1/3 neutral and 2/3 charged). They appear mostly as "thin" tracks in the emulsion corresponding to an ionisation $\leq$ 1.4 x the minimum value or an energy $\geq$ 80 MeV.

The distribution in multiplicity for various energies is given by A. All multiplicities below the maximum one have about equal probability. B gives the mean multiplicity as a function of energy. It rises from 0,1 at 500 MeV to 4 at 10,000 MeV with decreasing slope. In material of low atomic weight the multiplicity might be somewhat lower.

C gives a differential energy spectrum for the mesons. It can be represented by a power law with exponent -1.4 below 1.1 GeV, -2.5 above this value. The mean energy is 10^9 eV per meson according to D; this value does not depend strongly on the primary energy.

The angular distribution (laboratory system) is given in E. If x is the ratio of flux per angular interval according to distribution E compared to the same for an isotropic distribution, we get

0 - 30°	30 - 60°	60 - 120°	120 - 180°
8.7	1.35	0.34	0.21

2. Protons.

These appear in the emulsions as "black" tracks ($\geqslant$ 6.8 minimum ionization; $\geqslant$ 30 MeV) and "grey" tracks (30 to 500 MeV). Also about 1/4 of the "thin" tracks represent protons (>500 MeV) Their multiplicity is 2 to 4 times that of the grey tracks. The multiplicity distribution for grey and black tracks is given in B. The differential energy spectrum according to C falls off with an exponent -1.4; the mean energy is about 10^8 eV according to F independent of star energy. The angular distributions G for grey tracks show less collimation than E; above 100 MeV 3/4 of the protons are emitted into the forward hemisphere. The black tracks are emitted almost isotropically.

3. Neutrons.

For these we take the same multiplicities and distributions as for protons.

Absorption processes.

1. Charged π-mesons

These can produce the same nuclear reactions as the primary protons do. The mean free path is the same. On the other hand they can decay into μ-mesons. The mean free path for decay is determined by the mean life (2.5×10^{-8} sec), the velocity of light and the time dilation, which is proportional to the energy in terms of the rest energy. (140 MeV).

2. Neutral π-mesons

These will decay with very short mean life into two photons, which start an electron-photon cascade. This is absorbed in the first 2 m of shield. Photo neutron production can be disregarded.

3. Protons

The grey protons may produce stars as the primaries did. Also they lose energy by ionization. The black protons are quickly stopped by ionization.

4. Neutrons

These can produce stars as well. Below 30 MeV their energy loss will be by elastic and unelastic collisions only. This attenuation is discussed in section VII. Finally they reach thermal energies and are captured. The diffusion length of thermal neutrons is comparable to the slowing down length of the fast ones. So the flux of thermal neutrons out of the shield will be of the order of the fast neutron flux. As the tolerance flux is much higher for the thermal neutrons we can disregard them.

5. μ-mesons

These lose their energy by ionization only. From Halpern and Hall's curves (4), we take an ionization loss of 2.0 MeV g^{-1}c We assume, that it is constant over the whole path. Then the range distribution is given the energy spectrum.

VI. The initial flux.

The data of the previous section were used to find the number of particles created by 30 GeV protons in 2 interactions. First distribution B, extrapolated to 30 GeV, was applied. After the first collision we expect in average 8 thin tracks, 8 grey tracks, and 18 black tracks, which means 6 charged mesons, 3 neutral mesons, 2 "thin", 8 "grey" and 18 "black" protons and the corresponding neutrons.

To get the number of particles they produce, we need their distribution in energy. But the only energy spectrum available is C, which is derived not from 30 GeV stars, but from all the stars investigated. Thus it will be influenced by the energy spectrum of primary cosmic rays. (cf. section VIII). Now the mean energy of star particles does not depend strongly on star energy; more energetic particles give more pronged stars rather more energetic star particles. Therefore it seems permissible to use C, thus assuming that its shape will be more dependent on the mechanism of break-up in the nucleus than on the primary spectrum. As low energy stars are more numerous in cosmic rays than high energy ones, 30 GeV being very rare already, the effect of this simplification will be, that we use a spectrum which falls off too quickly towards higher energies. We will correct for that later.

The procedure is then to choose several intervals of energy and to multiply the number of secondary star producers by the probability of being in each particular interval. For particles in each interval the probability of losing most of their energy by ionization is calculated, for mesons also the probability of decay. The remaining particles actually produce stars. These stars contain different types of particles again, in multiplicities derived from B. Finally summing up the numbers of particles out of all energy intervals one gets the total number of particles produced after 2 interactions. They are given in table 1.

Now we choose $x_o = 2L$, so we are interested in the flux of neutrons after two interaction lengths. Not all the neutrons listed in the last column of table 1 contribute to this flux. Some interactions will take place at greater thicknesses only, while others give rise to neutrons along the path 2L, but these are emitted in a backward direction or have been slowed down before reaching the depth 2L. The number actually contributing to the flux was calculated, assuming all the grey neutrons to be emitted into forward directions and having an attenuation length L, the black ones to be emitted isotropically and with a mean free path of L/2. Using the values of table 1, the formula obtained yields a number of 7 fast neutrons contributing to the flux. We increase this number to 15 to allow for the energy spectrum, as a flatter shape of this spectrum would correspond to more weight at higher multiplicities

VII. The attenuation.

The attenuation measurements of neutrons in the atmosphere give relative values of flux (or density) of neutrons at various altitudes. The decrease in intensity towards greater depth is not only determined by the slowing down of those neutrons found at a greater altitude (The slowing down lengths are known to be smaller than the attenuation lengths found). It is given mostly by the attenuation of the comparatively few energetic particles which produce new neutrons near the level, where the measurement is made.

Various points to be considered, in which the attenuation of the radiation from the machine in dense material can be expected to be different from the attenuation of cosmic rays in air.

1. The distribution in energy.

The cosmic ray primaries fall upon the atmosphere with an integral energy spectrum which can be represented by $\frac{1}{(1+E)^{\gamma}}$ (E in Ge

where γ probably varies from -1.1 to -1.7 in the range 0.1 to 100 GeV. (3, p.323). This spectrum has a lower energy cut-off between 0,4 and 14 GeV according to geomagnetic latitude. This is to be compared with a monochromatic beam of 30 GeV particles.

Simpson (5) finds, that the attenuation length varies from 212 to 157 g cm^{-2} between latitudes corresponding to the cut-off values of 14 and 0.4 GeV. This shows in the first place, that the attenuation length is a function of primary energy. Furthermore it indicates that the latitude-sensitive part of the spectrum, thus particles certainly below 30 GeV, contribute to that component of cosmic radiation which creates neutrons throughout the atmosphere. From Simpson's figures (his table X) we would find an attenuation length of about 190 g cm^{-2} for 30 GeV particles. Simpson's values found at high latitudes agree well with those of other workers for various similar nuclear components. (3, p.355, table 10), his low latitude figures are somewhat higher. It is perhaps reasonable to assume 175 g cm^{-2} here as an attenuation length.

2. Atomic number of the absorber.

The reaction cross-sections involved in the attenuation of the nuclear components are expected to vary with atomic weight. A roughly as the geometrical ones, viz. as $A^{2/3}$. The number of nuclei per unit mass is proportional to A^{-1}. Thus in comparing equal masses of absorbers of different A, one has to expect a dependence on $A^{-1/3}$. This is a rather slow variation, which will not introduce an appreciable difference in mass-absorption between air, earth and concrete.

3. The angular distribution.

The cosmic ray primaries fall isotropically on the atmosphere. In the case of the machine we will have a beam. First the Gross-transformation (6) has to be applied. This gives the

A more rigorous treatment yields an expression for the number of μ-mesons at a depth x in the shield, of which the leading terms are of the form:

$$N\, e^{-x/L}\, (R/L)^{\gamma} \int_{R/L}^{x/L} e^{y}/y^{\gamma}\, dy.$$

where

L attenuation length of particles producing μ-mesons (via

N probability of μ-production per interaction

R minimum range of μ-mesons (assumed 100 g cm^{-2})

γ exponent of integral range-spectrum for μ-mesons.

Numerical evaluation shows, that owing to the low value of N as compared with the multiplicity of neutron production and the lower biological efficiency of μ-mesons, the μ-mesons can still be disregarded in designing the shield.

VIII. Absorption in Concrete and Earth and Geometrical Considerations.

In heavy concrete (density 4) the interaction length of 150 g cm^{-2} is 0.37 m, the attenuation length of 220 g cm^{-2} 0.55m, giving an attenuation to 0.16 intensity in 1 m.
The density of dry earth was assumed to be 1.5 g cm^{-3}. The interaction length then becomes 1 m, the attenuation length 1.5 m, giving an attenuation per m to 0.5 intensity.

To get the density of particles leaving the shield it is necessary to make an assumption about the angular distribution of the particles producing them. This will be based on the distributions E and G for thin and grey tracks. Both show increasing collimation with increasing energy. The following assumption is proposed: Half the intensity is emitted isotropically, the other half is uniformly distributed over a cone of 30° half opening in the forward direction. This assumption underrates somewhat the collimation in E, and seems to exaggerate it greatly for G. Allowing however for contributions from the strongly collimated primaries and for the fact, that the most energetic and therefore best collimated particles will contribute most to the intensity behind great thicknesses of shield, it is perhaps a reasonable approximation. The position of the ~~apex of~~ the 30°-cone is not very critical, it is assumed to be at the end of the transition layer, viz. at 1 m of concrete or 2 m of earth. The corresponding solid angle is $2\pi(1-\cos 30^\circ) = 0.82$. First the case of the beam of 10^9 protons/sec striking a wall at right angles is treated for concrete. 1 m is needed as transition layer. Then we have a flux of 15 neutrons per primary proton, of which 7.5 are attributed to the collimated part of the beam. This is attenuated in each following m to 0.16 intensity and distributed over an area of $0.82\ X^2$, where x is the distance from the end of the transition layer. Thus:

$$7.5 \cdot 10^9 \frac{(0.16)^x}{0.82\ x^2}$$ gives the density of particles and

this has to be made equal to the tolerance flux of 3 cm^{-2} sec^{-1} or $3 \cdot 10^4$ m^{-2} sec^{-1}. The calculations are carried in table 2. The total thickness found is 6.2 m.

The corresponding quantity for earth is 13.2 m (table 3).

Next this consideration is applied to beams, which include an angle $< 90^\circ$ with the wall. Up to $= 60^\circ$ the same density as in the previous case will be found, in some points at least behind the wall, owing to the assumption of uniform distribution over the 30°-cone. If gets smaller than 60°, the thickness of shield required decreases by a factor $\cos(60^\circ - \ )$, giving 5.4 m of concrete for $= 30^\circ$.

For angles of this order, however, the contribution of the isotropical part becomes important. To find this contribution, again the density is calculated from an expression as above, only with a solid angle 4π instead of 0.82. This contribution will, under the assumptions made, be independent of the angle of incidence of the beam. A total thickness of concrete of 5 m is found in this way. (Perhaps we ought to take a somewhat stronger attenuation because in the sideward direction the less energetic particles contribute preferentially. An attenuation length of 170 g cm^{-2} would give about 4.5 m).

For angles of incidence of 30° and less, both contributions will be of the same order. Therefore it seems advisable to keep the thickness of concrete at 5.4 m, thereby covering all the possible - and probable - directions of incidence between 0° (glancing incidence) and 30°.

The corresponding considerations for earth yield a figure of 11 m.

So far it has always been assumed, that the full beam strikes the wall over an area small compared with that area, over which the neutrons are distributed when leaving the shield. On the basis of the above considerations it can be attempted, however, to estimate the densities for the case, where the full beam strike an object in the tube (target) or near it (magnet). If this object is several 100 g cm^2 thick in the direction of the beam, similar processes will take place in it as in the transition layer of the shield. From a target yield point of view this has to be investigated in greater detail in a later report. For the shielding problem the object can be considered just as part of the transition layer of the shield, separated from the rest of the shield by a certain length of path in air, which makes the angular spread more effective.

This way of looking at the target does not, of course, take account of those scattering processes, which deviate the protons just enough to make them miss the next bending section, thus giving rise to a beam in a tangential direction. This beam might be much better collimated than in our 30°-cone. Thus the present estimate gives rather a limiting case of maximum spread, or minimum shield required.

For the machine in question, the average distance between tube and shield is about 3 m. For the 30°-cone round the $\vartheta = 30^\circ$-beam, which will be considered again as determining the thickness of the shield, this means a minimum airpath of 3.5 m. Taking account of this extra airpath a thickness of shield of 4.8 m is found. This is not greatly different from the 5.4 m found above; the actual value needed in practical cases is expected to lie between these limits. In earth the effect of the air path is even less, because the path in earth is very long anyway.

IX. Sources of Error.

As has been pointed out, the lack of information about the behaviour of 30 GeV protons limits the accuracy of the whole estimate. First it results in an uncertainty in the initial number of neutrons. A change in this number by a factor of 2 makes a change of about 0,5 m of concrete (1,5 m of earth). Second the value of the attenuation length is not better known than to a 10% accuracy. This again results in a 0,5 m (1 m) uncertainty in the thickness of shield. Third the angular distribution introduces an error which is estimated to be of the same order of magnitude as the previous ones by considering 20° and 40°-cones instead of the 30° one.

There is no reason why all three of these errors should be in the same direction, but it does not seem possible to estimate the shield more accurately than to ± 1 m of concrete or ± 2 m of earth.

X. Small changes in Machine Parameters.

A rough estimate of the effect of changes in machine parameters can be made along the same lines, provided that they do not result in changes in shield thickness much greater than the limits of error given above. A variation in beam intensity (or in tolerance flux) by a factor of 2 means a change in thickness of shield of 0.5 m (1.5 m).

A change in energy has more complicated influences. It changes the initial number of particles and the attenuation length. Working this out for a reduction in energy to 10 GeV, we find a reduction in shield by 1 m of concrete or 2.5 m of earth.

XI. Comparison with the Brookhaven Machine.

It is interesting to apply our considerations to an existing machine. The machine in Brookhaven has been run at 2.2 GeV and with a beam intensity of $0.8 \cdot 10^9$ protons/sec. There is a heavy concrete shield of 2.7 m thickness at a distance of 2.6 m from the tube. A Cu target of about 50 g cm^{-2} is used.

Making a rough calculation along the lines given in this report (X does not hold because of the big difference in energy), a neutron flux behind the shield is found of $1.7 \cdot 10^6$ $m^{-2} sec^{-1}$ for the case of the full beam striking the wall, or $2.7 \cdot 10^5$ for the case of a very thick target. These values ought to be correct to within a factor 3 or 4 according to section IX.

A few preliminary values of radiation doses measured outside the shield are available from letters and reports by Cowan (7), Handloser (8) and Riddiford (9). According to these there is a radiation level between 2 and 10 times tolerance dose behind the shield. They use an r.b.e. = 5 and no safety factor. If their ionization chamber looks sufficiently similar to tissue for the neutrons, this would correspond to a tolerance flux of 60 $cm^{-2}sec^{-1}$ or $6 \cdot 10^5 cm^{-2}sec^{-1}$. The statement then means, that the flux is between 1.2 and $6 \cdot 10^6 m^{-2}sec^{-1}$. These figures are near to our full beam values. One could conclude from this comparison, that our estimate tends to give too low flux values or too little shield. Now there are indications, that a considerable fraction is scattered over the shield. Also the smaller machine dimensions tend to make any density value higher. Therefore it is better to wait for more detailed information before trying to incorporate these results in our estimate.

XII. Practical Conclusions.

1. The circular trench.

The trench containing the accelerator tube will be buried over its whole extent. It will be covered by a concrete roof and at least 1 m of earth. This makes the shielding problem very easy. All one has to do is to fence off an area on top of the tunnel, which contains all the points which are separated from the accelerator tube by less than 11 m of earth (minus the thickness of concrete counted twice). This area will be unaccessible during operation; its extent depends of course on the depth in which the tunnel lies in each particular point and on the way the earth dug out of the trench is disposed of. Special attention has to be given to the entrances, extra banks may be necessary here depending on the particular situation at each entrance.

2. The target area.

The tube must be separated from areas which are supposed to be accessible during operation by walls of heavy concrete of <u>5.5 m.</u> Whether one of the target areas has to be accessible for the set-up of later experiments while the beam is let into the other one, is a question of organisation. It will certainly increase the efficiency of the machine if it is so.

As the accelerator tube is considerably below ground level, the target area will be so as well. So the outer walls of the target house have not to be reinforced in the accelerator plane.

The roof of the target area and of the tube tunnel in the target house ought to be thick enough to stop most of the highest energy particles, which means a thickness of about 300 g cm^{-2} of concrete. Even then the area on top of this roof, especially on top of the tube, will not be accessible during operation. The consequences of such a restriction are better analyzed in the course of discussion on special building proposals.

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XIV. Acknowledgements.

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A.Citron
W.Gentner

CIRCULATION LIST No. I

Table 1

Particles produced by 1 30 GeV proton after 2 interactions.

Produced particles \ Generating particles	primaries	thin		grey		mesons	total
		p	n	p	n	π	
π-mesons	(6)	0.45	0.48	–	–	1.4	2
μ-mesons	–	–	–	–	–	0.17 ⓐ	0.17 ⓐ
thin neutrons	(2)	0.15	0.16	–	–	0.4	0.7
grey neutrons	(8)	2.2	2.7	0.75	2.2	6.6	14
black neutrons	18	7.4	9.4	5.4	25.4	22	90

ⓐ in earth; in concrete 0.07.

The numbers in brackets refer to particles which make further nuclear collisions of which the products are listed in the table. Numbers of produced protons are considered equal to the number of corresponding neutrons given in the table.

Neutral π-mesons are produced with half the multiplicity of the charged ones given in the table.

Table 2

Attenuation and spread of neutrons in concrete.

1 Total thickness
2 Thickness from transition layer
3 Attenuation factor
4 Numbers of neutrons
5 Area of 30^o-cone
6 Density of collimated beam
7 Area of total sphere
8 Density of isotropic part

1	2	3	4	5	6	7	8
m	m			m^2	m^{-2}	m^2	m^{-2}
1	0	1	$7.5 \cdot 10^9$	-	-	-	-
2	1	$1.62 \cdot 10^{-1}$	$1.2 \cdot 10^9$	0.82	$1.5 \cdot 10^9$	12.6	$9.5 \cdot 10^7$
3	2	$2.62 \cdot 10^{-2}$	$2.0 \cdot 10^8$	3.3	$6.1 \cdot 10^7$	50	$4.0 \cdot 10^6$
4	3	$4.25 \cdot 10^{-3}$	$3.2 \cdot 10^7$	7.4	$4.3 \cdot 10^6$	110	$2.9 \cdot 10^5$
5	4	$6.88 \cdot 10^{-4}$	$5.0 \cdot 10^6$	13.1	$3.8 \cdot 10^5$	200	$2.5 \cdot 10^4$
6	5	1.11	$8.5 \cdot 10^5$	20.5	$4.1 \cdot 10^4$	320	$2.6 \cdot 10^3$
7	6	$1.80 \cdot 10^{-5}$	1.4	29.5	$4.7 \cdot 10^3$		

Table 3

Attenuation and spread of neutrons in earth.

1 Total thickness
2 Thickness from transition layer
3 Attenuation factor
4 Numbers of neutrons
5 Area of 30^{o}-cone
6 Density of collimated beam

1 m	2 m	3	4	5 m^{2}	6 m^{-2}
2	0	1	$7.5\ 10^{9}$	–	–
3	1	0.50	3.8	0.82	$4.6\ 10^{9}$
4	2	0.25	1.9	3.3	$5.8\ 10^{8}$
5	3	0.12	$9.5\ 10^{8}$	7.4	1.3
6	4	$6.8\ 10^{-2}$	4.7	13.1	$3.6\ 10^{7}$
7	5	3.4	x/ 2.3	20.5	1.1
8	6	1.7	1.2	29.5	$4.1\ 10^{6}$
9	7	$8.4\ 10^{-3}$	$6.0\ 10^{7}$	40	1.5
10	8	4.2	3.0	52	$5.8\ 10^{5}$
11	9	2.1	1.5	66	2.3
12	10	1.0	$7.5\ 10^{6}$	82	$9.1\ 10^{4}$
13	11	$5.0\ 10^{-4}$	3.7	99	3.7
14	12	2.5	1.9	118	1.6

x/ difficult to decide whether 3.3 or 2.3 in original manuscript.