T H E S I S

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SHIELDING CONCRETES, THE USE OF SOME ADDITIVES IN MAKING SHIELDING CONCRETE

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ABSTRACT

This research has been done in order to define the linear attenuation coefficient of barite concrete and its other physical properties.

First of all, a standard mixture is obtained and tested, then the concretes are prepared by using; retarder, waterproofing admixture, plasticizer and also colemanite; are tested. The results of concretes with additives are compared with the results of standard mixture. In the preparation of samples great attention is spent to be the amounts of slump and cement is fixed.

When ordinary sand is used instead of barite sand it is seen that compressive strength of concrete increases and linear attenuation coefficient decreases by 13 %. The effect of workability increasing admixture to the compressive strength and linear attenuation coefficient, was observed as negligible. This observation is valid also for the retarder. Waterproofing admixture increased the compressive strength and the linear attenuation coefficient by a considerable amount. It is found that the negative effect of colemanite in cement setting can be decreased by increasing the cement dosage; at the same time colemanite has not an accountable positive effeçt on gamma ray shielding but there will be an important place on neutron shielding. More detailed knowledges, graphs and the explanation of the test results will be given in their respective chapters.

ÖZET

Bu araştırma,baritli betonun linear gama ışınlarını azaltma katsayısını ve onun fiziksel özelliklerini tanımlamak için yapıldı.

İlk önce standard bir karışım elde edildi ve test edildi,sonra retarder,betonda su geçirimsizlik katkısı, işleme kolaylığı katkısı ve colemanit kullanılarak hazırlanan betonlar test edildi.Katkılı betonların neticeleri standard karışım neticesiyle mukayese edildi.Nümunelerin hazırlanmasında slump'ın ve çimento miktarının sabit kalmasına özen gösterildi.

Barit kumu yerine normal kum kullanılmasının betonun basınç mukavemetini artırdığı,linear azaltma katsayısını % 13 düşürdüğü görüldü.İşleme kolaylığı sağlayan katkının çok az miktarda her iki faktöre etkisi(basınç mukavemeti ve linear azaltma katsayısı)nin kayda değer olmadığı tesbit edildi.Aynı ifade retarder için de söylenebilir.Su geçirimsizlik katkısının yukarıdaki faktörleri önemli ölçüde yükselttiği görüldü.Colemanitin çimento prizindeki kötü etkisinin çimento dozajını arttırmakla giderilebildiği colemanitin aynı zamanda gama zırhlaması için fazla etkisi olmadığı fakat nötron zırhlamasında önemli bir yer alacağı tesbit edildi.Detaylı bilgiler,grafikler ve test neticelerinin yorumu takdim edildikleri bölümlerde verilicektir.

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INTRODUCTION

The nuclear energy industry as well as the large-scale production of penetrating radiation and radioactive materials are of great importance at the present time.Both of the normal and special types of concrete are the materials most widely used for reactor shielding.Its popularity is due to the cheapness and mechanical properties.

Some additives will be used in making shielding concrete.The influence of additives which is to increase or decrease the shear resistance of concrete and also the linear attenuation factor against the gamma rays;will be investigated and tested.

After a general introduction to shielding fundamentals and methods in the first chapter,concrete for radiation shielding and shielding materials were discussed; effects of three types of admixtures also colemanite and ordinary sand used,in making shielding concrete are observed with tests in the later chapters.

At the same time this work is hoped to be a part of projects about the selection of the most suitable domestic shielding material for Turkey;which are started or which will start,for the shielding of reactors planned to be built in our country.

Once again the author wishes to record his indeptedness and gratitude to Prof.Erol Yaltkaya who has a great share in completion of this work.

1.SHIELDING FUNDAMENTALS AND METHODS

1.1.RADIATION QUANTITIES AND UNITS

1.1.1.Introduction

All radioactive materials and radiation are potentially hazardous.They can give rise,when outside the body,to external radiation exposure of personnel,and when inside the body to the irradiation of certain organs.

Evidence and experience indicate that limited exposure to external radiation,or intake of small amount of radioactive material into the body,are associated with a negligible probability of severe somatic or genetic injuries.This has led to the concept of the maximum permisible levels of exposure for personnel working with radioactive materials or radiation sources.In addition to the exposure of radiation workers,there is also the possibility of exposure of the general public.

There are three principles which can be applied to prevent or control the exposure of personnel to radiation hazards:

a) Remove the hazard
b) Guard the hazard
c) Guard the worker

One metnod of controlling external radiation exposure is to provide shielding.Suitable radiation-absorbing material is placed between the source of radiation and the personnel exposed in order to reduce the intensity of the radiation to acceptable levels.This reduction in intensity is known as attenuation and is a result of complex interactions between the radiations and the absorbing materials.

The absorbing material used and the thickness required to attenuate the radiations to acceptable levels depend upon the type of radiation,its energy,the flux and the dimensions of the source.The amount of shielding material required may be calculated with reasonable accuracy in most instance,but only very approximately in others,and it is essential that experimental methods should be used whenever possible to evaluate the accuracy of the calculation.

Concrete,especially heavy concrete which is one of the most familiar construction material,has many properties desirable from a nuclear radiation shielding point of view.

Concrete admixtures are indispensable aids in the preparation of concrete used for the construction of atomic power stations because they make it possible to improve one or several major properties of the concrete.

1.1.2.Nuclear radiation

1.1.2.1.Types of nuclear radiation

They are listed in the table below:

Table 1.1.2-1.Some common types of radiation

Type of radiation	Symbol	Charge
Alpha particle	α	+2
Beta particle		
a) Electron	β^-, e^-	−1
b) Positron	β^+, e^+	+1
Proton	p	+1
Neutron	n	0
Electromagnetic radiations		
a) x-rays	x	0
b) Gamma rays	γ	0

In this group sub-atomic and atomic particles are also included as well as X-and gamma radiation.Since a discussion of all types of nuclear radiation is beyond the scope of this thesis,only a few common types will be discussed.

1.1.2.1.2.Alpha Particles

Alpha particles are the helium nuclei

($^{4}_{2}$He) emitted by radionuclides,mainly by heavy nuclei such as polonium,radium,thorium,uranium,etc.In alpha decay the mass of the parent nucleus is greater than the sum of the masses of the products,and this mass difference is released as the kinetic energy of the alpha particle.The alpha particles emitted by any radionuclide have generally one or two,and rarely more,discrete energies,which are characteristics of the radionuclide.

1.1.2.1.3.Beta particles

Beta particles are high-energy electrons or positrons created and emitted by certain radionuclides. Beta particles from radionuclides are emitted in a continous energy spectrum.

1.1.2.1.4.Neutrons

The neutron is an uncharged particle having a mass slightly greater than that of a proton.Neutrons are generally classified according to their energies under four broad categories,which are as follows:

a) Thermal neutrons
b) Intermediate neutrons or slow neutrons
c) Fast neutrons
d) Relativistic neutrons

1.1.2.1.5.X- and gamma rays

X- and gamma rays are electromagnetic radiation of very short wavelength.There is no difference between X- and gamma rays except in their origin.While gamma rays are emitted with discrete energies characteristic of the nuclide formed,X-ray emission is of two types,characteristic radiation(discrete energies) and bremsstrahlung (continous spectrum of energies).Characteristic X-rays are produced from transitions between energy levels of inner electrons in an atom,while gamma rays are emitted because of transitions of the nucleus from higher to lower energy states.

1.1.3.Radioactivity

All other nuclei consist of neutrons and protons.The ratio of neutrons to protons is unity for higher isotopes and increases gradually as one approaches the heavier elements at the end of the periodic table.As this ratio increases,a stage is reached where the nuclide is no longer stable.The heaviest stable nuclide is $^{209}_{83}$Bi. Nuclides heavier than this are unstable because they have excess energy to dissipate.Such unstable nuclides are called radionuclides and they dissipate their surplus energy by the emission of radiation.This process is called radioactivity or radioactive decay.The more frequent modes of decay of radionuclides are alpha,beta and gamma decays.

Radioactivity can be of two types:

(1) Natural radioactivity

(2) Artificial radioactivity

The second one is the radioactivity induced in some elements by bombarding them with neutrons,charged particles or photons.Most radionuclides currently in use are artificially produced.

The number of atoms of a radioactive substance disintegrating per unit time,dN/dt,which is referred to as the activity of the substance,is proportional to the total number,N,of radioactive atoms present at time t;the constant of proportionality being λ.

Thus $$-\frac{dN}{dt}=\lambda N \qquad (1)$$

Integrating this equation,one has

$$N=N_0e^{-\lambda t} \qquad (2)$$

where N_0 is the initial number of radioactive atoms present, as already stated,the number of radiactive atoms at time t.

Rewriting eq.(1) one has

$$-\frac{dN}{dt}=\lambda N=\lambda N_0e^{-\lambda t} \qquad (3)$$

equation (3) indicates that the number of radioactive atoms present as well as the disintegration rate(activity) decrease exponentially with time.

The time taken for half of the radioactive atoms originally present to decay is called the half-life of the radionuclide.

Substituting $N=N_0/2$ and $t=t_{1/2}$ in eq.(2),one has

$$N_0/2=N_0 e^{-\lambda t_{1/2}} \quad \text{or}$$

$$\lambda t_{1/2}=\ln 2=0.693 \quad \text{or}$$

$$t_{1/2}=0.693/\lambda$$

The half-life is characteristic of any particular radioisotope, [1]

1.1.4.Interaction of radiation with matter

1.1.4.1.Directly ionizing radiations

Directly ionizing radiations include all charged particles such as alpha particles and heavier ions and beta particles.All charged particle radiations lose energy by interaction with the orbital electrons or nuclei of atoms in the materials they traverse.There are two main processes involving the orbital electrons:

a) Atomic or molecular excitation

b) Ionization,which involves the ejection of an orbital electron,resulting in the creation of an ion pair.

1.1.4.1.1.Alpha particles

Alpha particles emitted from radionuclides have well defined and characteristic energies.As they are doubly charged and move relatively slowly.They are densely ionizing and hence,in spite of their high energies,their penetrating power or range is extremely limited.Their range in air is only a few centimeters.Thus,shielding against this type of radiation presents no problem.

1.1.4.1.2.Beta particles

Beta particles lose energy mainly through ionization.Another process by which beta particles lose energy is by the production of bremsstrahlung(braking radiation).Beta particles are much lighter than other charged particles.Their velocity for a given energy is much higher and their specific ionization(number of ion pairs per unit length) much smaller.

For a given energy,beta particles have a much greater range than alpha particles.In addition, because of their small mass,beta particles undergo frequent scattering with little loss of energy,and thus follow tortous parts.This can cause a process analogous to reflection from surfaces.

1.1.4.2.Indirectly ionizing radiations

Indirectly ionizing radiations include some types of electromagnetic radiations and neutrons.These radiations interact with scatter by giving rise to secondary radiation which is ionizing.

1.1.4.2.1.X- and gamma rays

Electromagnetic radiation is classified according to its origin,independently of its energy.Characteristic X-rays are emitted in atomic transitions of bound electrons between the various electronic shells in the atom.Annihilation radiation is produced by the interaction of positrons and electrons,whereby the masses of two particles are completely converted into energy in accordance with Einstein's mass-energy relationship.

There are a number of ways in which electromagnetic radiation may interact with matter.There are three important processes in the interaction of X- and gamma rays with matter due to interaction modes and their possible effects.These are the photoelectric effect,the compton effect and pair production.

1.1.4.2.1.1.Photoelectric effect

The most important energy loss mechanism for low-energy photons in the range of hundreds of electron volts is the photoelectric effect.In this process the low energy photon interacts with a bound electron in one of the various shells of the atom and disappears by the transfer of its entire energy to the electron,which is then ejected from the atom as a photoelectron.The kinetic energy T of the electron is given by

$$T = h\nu - \Phi$$

where $h\nu$ is the photon energy and Φ the binding energy of the electron.Thus,for the photoelectric effect to occur,the photon energy must be greater than the binding energy. [1].

1.1.4.2.1.2.Compton effect

The compton effect can occur with a free or loosely bound electron.In this process,the incident photon undergoes an elastic collision with a free or loosely bound electron and shares its energy and momentum with the electron,which is then accelerated and the photon is deflected with lower energy.

The compton effect depends on the number of electrons present in the material which the photons traverse.This process is the dominant absorbtion process for intermediate energy gamma rays.

1.1.4.2.1.3.Pair production

At photon energies exceeding 1.02 MeV,the photon may interact either with the coulomp field of the nucleus or,less frequently,with that of an electron to produce a positron-electron pair.This process can be regarded as the inverse of the annihilation process. [1]

1.1.4.3.Neutrons

Although neutrons generally occur bound in nuclei,it is possible to obtain them in the free state.Such free neutrons can interact in various ways with nuclei.The neutron nuclei reactions of present interest fall mainly into three generally categories,namely,scattering,capture and fission.In scattering reaction,the compound nucleus rapidly expels a neutron with a lower kinetic energy than the absorbed neutron.The excess energy is in the form of internal energy,so that the nucleus is in excited state.The phenomenon is referred to as inelastic scattering.On the other hand,if the extra energy which the nucleus has required is solely kinetic in nature,a form of elastic scattering has occured.The term "scattering" is used to describe these reactions because the direction of motion of the neutron remaining after the interaction with a nucleus is generally different from that of prior to the interaction.

1.1.5.Radiation units and associated concepts

1.1.5.1.The roentgen(R)

The roentgen(R),as first defined in 1928, was applicable to X-rays only.In 1937,however,it was redefined as follows,sa as to include gamma rays:

"The roentgen shall be the quantity of X- or gmma radiation such that the associated corpuscular emmission per 0.001293 g of air produces,in air,ions carrying 1 esu of quantity of electricity of either sign."

The roentgen,which is the unit of exposure, is not a radiation unit in the strict sense of the term.[1].

The energy absorbed per gram of air per roentgen is thus 0.113/0.00129 = 88 ergs.The energy equivalents of the roentgen in a number of energy units are summarized in table 1.1.5.1-1.

Table 1.1.5.1-1 Equivalents of one roentgen of X- or gamma radiation

1 esu of ion pairs produced per cm^3 of air
2.08×10^9 ion pairs produced per cm^3 of air
1.61×10^{12} ion pairs produced per gram of air
7.1×10^4 MeV absorbed per cm^3 of air
5.5×10^7 MeV absorbed per gram of air
88 ergs absorbed per gram of air

Thus the term radiation dose means one quantity only,i.e. the amount of energy absorbed. [1]

The dose rate is frequently used as a measure of the radiation intensity or flux in a certain region.However,this is justifiable only for gamma rays of a specified energy.The radiation intensity is the rate at which the energy flows past a unit area at a given location,but the dosage rate in roentgens per unit time is a measure of the rate at which energy is absorbed in air at that point.

It will be seen that if at a certain location there is a flux of ϕ_γ photons/(cm^2)(sec) of energy E_γ MeV per photon,the rate of energy absorbtion is $\phi_\gamma E_\gamma \mu_e$ MeV/(cm^2)(sec where μ_e is the energy absorbtion coefficient of the medium for the specified gamma radiation. [2]

Values of μ_e as a function of photon energy are plotted in Fig.1.1.5.2-1.

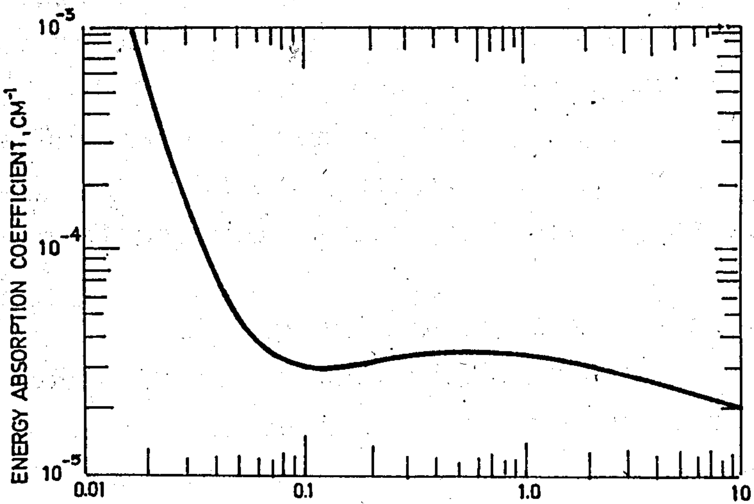


Fig.1.1.5.2-1 Variation of energy absorption coefficient of air with gamma-ray energy

1.1.5.3.The rem,H(dose equivalent)

From the biological point of view,evidence has accumulated that the effects of the various types of ionizing radiations are not the same.One can assume that radiation can bring about a change in a system only by virtue of the energy actually absorbed.

The term RBE(relative biological effectiveness) is used to specify the variation in the degrees of effectiveness of different types of radiation and is defined as follows:

$$\mathrm{RBE}=\frac{\text{Dose of 250kV X-rays to produce a certain biological effect}}{\text{Dose of given radiation to produce the samebiologicaleffect}}$$

The biological effect of a particular type of radiationdepends therefore not only on the absorbed dose but also on the RBE of the radiation.To take these factors into account,a new unit,the "rem" (roentgen equivalent man) was defined as that dose of any ionizing radiation which is biologically equivalent to the dose of one rad of X- or gamma radiation.Rem is here taken as the unit of RBE dose.

One thus has the relationship:

$$\text{RBE dose in rems} = \text{Dose in rads} \times \text{RBE} \qquad (1.1.5.3\text{-}1)$$

The dose equivalent,H, as defined by ICRU(The International Commission on Radiological Units and Measurements)

The special unit of the dose equivalent is rem. It should be noted that the quantity H may be used when its value is in the region of the maximum permissible dose equivalent and not for high level accidental exposures.In the case of radiation dose delivered by particles havin the range of L_∞ values (L is the linear energy transfer),the dose equivalent may be taken as

$$H = D\overline{Q}N \qquad (1.1.5.3\text{-}2)$$

where

$$\overline{Q} = \frac{1}{D}\int_0^\infty Q D_{L_\infty}\, dL_\infty \qquad (1.1.5.3\text{-}3)$$

where D is the absorbed dose,Q is the quality factor and N is the product of any modifying factors such as distribution factors.[,] .

The relation between Q and LET recommended for radiation protection is given in table 1.1.5.3-1 .

Table 1.1.5.3-1 Q - L_∞ Relationship

L_∞ in water keV/μm	Q
3.5 or less	1
7	2
23	5
53	10
175	20

1.1.5.4.The curie

The curie was originally defined as the disintegration rate from one gram of radium.Later on it was defined as the amount of radon in equilibrium with one gram of radium.Still later,in 1930,it was defined as the amount of any decay product of radium that is in equilibrium with one gram of radium.The term curie is now used for all radionuclides and is defined as the activity of that amount of a substance which undergoes $3.7x10^{10}$ disintegrations per second.

As a result,to summarize the ICRU recommandations specify the use of units to be restricted as follows:

Rad - Solely for absorbed dose
Roentgen - Solely for exposure
Curie - Solely for activity
Rem - For dose equivalent [1]

According to safety series No 47,some above factors were changed to a new one.The below table hab been prepared by E.R.A. Beck for use by the division of the publications of the IAEA.These factors are listed in table 1.1.5.4-1 .

Table 1.1.5.4-1 .Factors for converting some of the more common units to international system of units(Sl)equivalent

Column 1 Multiply data given in:	Column 2	Column 3 by:	Column 4 to obtain data in:
Radiation units			
▶ becquerel	1 Bq	(has dimensions of s^{-1}	
disintegration per second (=dis/s)	1 s^{-1}	=1.00X10	Bq*
▷ Curie	1 Ci	$=3.70X10^{10}$	Bq*
▷ roentgen	1 R	$=2.58X10^{-4}$	C/kg*
▶ gray	1 Gy	=1.00X10	J/kg*
▷ rad	1 rad	$=1.00X10^{-2}$	Gy*
Sievert (radiation protection only)	1 Sv	=1.00X10	J/kg*
rem (radiation protection only)	1 rem	$=1.00X10^{-2}$	J/kg*

NOTES:

(1)▶indicates sl derived units and those accepted for use with sl

(2)▷indicates additional with accepted for use with sl for a limited time

(3) sl base units are the metre (m), kilogram (kg), second (s), ampere (A), kelvin (K),..

(4) The corret abbreviation for the unit in column 1 is given in column 2

(5)* indicates conversion factors given exactly

1.1.6.Maximum Permissible levels of radiation

Man has been continously exposed to natural sources of radiation,namely cosmic rays and naturally ocuring radionuclides. The average dose due to background radiation is estimated to be about 100 mrem/yr, although these are places where the background dose may be 10-30 times higher than this average value. The solution to this problem is therefore to limit radiation doses to those which would unvolve risks which are not entirely unacceptable to the individual radiation worker and to the population at large. With this consideration in view the International Commission on Radiological Protection (ICRP) has defined the maximum permissible dose for an individual as that dose accumulated over a long perod of time or resulting from single exposure which in the light of present knowledge carries a negligible probability of occurence of severe somatic or genetic injuries.

Soon after discovery of X-rays and radioactivity it was recognized that exposure to intense beams of radiation could result in a variety of injuries to the human body.

The tolerance dose was defined as that dose which a person could occupationally receive continously or at repeated intervals without suffering from changes in the blood or damage to the skin or the reproductive organs.It was also estimated that if the total dose per month did not exceed one-hundredth of the of the dose required to cause skin erythema,no injury would result in the long run.The unit roentgen had come into use at about that time,and an exposure rate of 10^{-5} R/s was recognized as a tolerance level. In terms of the roentgen,the skin erythema dose was estimated to be 600 R,and corresponding daily tolerance dose was 200 mR.

In 1936,the value of the tolerance dose was reduced to 100 mR/d on the basis of two important factors.One was that a dose of 200 mR with backscatter corresponded to a free air dose of 100 mR for the quality of radiation then encountered.The other was that more and more energetic X-rays were being produced and used and it was recognized that a greater percentage of the surface dose was reaching the deep-seated critical organs.[1].

It is to be noted that the commission decided to exclude from the proposed values contributions from medical procedures and from natural background radiation.This was necessary because these contributions vary considerably from country to country.However,the commission recommended that these contributions should be considered separately and that contributions from medical procedures should be limited to a minimum value consistent with medical requirements.The maximum permissible annual doses are listed in table below.

Table 1.1.6-1. Maximum permissible annual dose equivalents for partial-body irradiation

Organ	Category of individuals	
	Adults irridated in the course of their work [rem]	Members of public [rem]
Gonads,red bone marrow and in the case of uniform irridation,the whole body	5	0.5
Skin,thyroid,bone	30	3
Hands,forearms, feet,ankles	75	7.5
All other organs	15	1.5

In our country,for the values of MPD Radyasyon sağlığı tüzük ve yönetmeliği is valid.

1.2.ABSORBTION OF x-AND GAMMA RAYS BY CONCRETE

1.2.1.Production and characteristics of X-rays

X-rays were discovered by Roentgen,a German physicist,in 1895.Three months after this discovery, X-rays were used in Vienna hospital in connection with surgical operations.X-rays result as secondary effects in several types of atomic and nuclear processes,but the sources used in medicine and industry consist of heavy metallic "targets" being struck by fast moving electrons.The entire process takes place in vacuum.The electrons are " boiled off" a hot flament,as in a radio tube,and given a high velocity by one of several methods.In the usual X-ray tube the acceleration is produced by application of a high voltage between the target and the electron source.Two other types of sources which are now being built commercially are the betatron and the electron synchrotron.In both,a magnetic field causes the electrons to travel in circular orbits.

As the electrons are suddenly stopped or slowed down in the target a portion of their energy is radiated as electromagnetic waves.A beam of X-rays is not, however,a continous wave;it is composed of a host of small packets called quanta or photon.

In the usual process,an X-ray photon is produced by collision of a single electron with an atom of the target and,therefore,it can not have more energy than the electron which produced it.The electron's initial energy, that is the energy just before entering the target,is determined by the accelerating voltage across the X-ray tube, but the probability of the electron being brougth to rest by a single encounter with an atom is low.[2] As a result, photons of a wide range of energies are produced by electrons whose initial energies may all have been the same.

The maximum energy of any photon is strictly limited by the tube voltage.For that reason it is customary to speak of 150 kilovolt X-rays or 1 million-volt X-rays and by such terms is meant X-rays produced by a tube,the maximum applied voltage of which is the number given.In a particular opeeration the highest energy X-rays produced will have an energy(MeV) which is numerically equal to the peak tube voltage (MV), but in general the photons will have lower energies which are distributed over a wide range of values.W might speak, therfore,of an effective Mv for an electron accelerator,but the current practice is to designate the operating level by indicating the energy attained by the X-ray producing electrons in MeV.The unit of X-ray dosage is called a roentgen as defined before.

1.2.2.Sources and characteristics of gamma rays

Although X-rays,bremsstrahlung,and annihilation radiation are not strictly gamma rays,since they do not arise from nuclear transitions.They are essentially identical with gamma rays in their fundamental nature.As far as their interaction with matter is concerned,the only differences that may arise are the result of the higher energies, in general,of the gamma radiations.

There are several ways in which gamma rays interact with an absorbing material;three,namely,the photoelectric effect,the compton effect and pair production are important.These effect was shortly defined in sec.1.1.5.2 .

As pointed out in the preciding section, the number of photons produced per disintegration and the energies of these photons both depend on the type of radioactive source.Two 1-curie sources of different types will not then,in general,produce the same dose rate at a given distance.However,the dose rates at equal distances from two sources of the same type will be directly proportional to the curie ratings of the two sources.The proportionality constant is called the emission constant and may be defined as the number of roentgens per hour,measured at 1 m,per curie as defined in sec.1 .

1.2.3.Attenuation of X-rays and gamma rays

1.2.3.1.General

Attenuation of a beam of photons in matter can take place in a number of fashions.Most of the attenuation is produced by photoelectriç absorbtion,compton scattering and absorbtion,and electron pair production.The contribution of each of these processes to the total attenuation depends upon the photon energy and the kind of atoms making up the absorber and is almost completely independent of latter's chemical combinations.

The weights of the atoms,in turn,are roughly proportional to the number of electrons in cm,and in the X-ray region for which concrete is most advantageous as a shielding medium.The barrier's effectiveness is determined largely by the total number of electrons.

1.2.3.2.Photoelectric absorbtion

The effectiveness of an absorber in attenuating a beam of X-rays by the photoelectric process depeds upon the relation between the energies of the X-ray photons and the energies required to eject the various electrons. The probability of absorbtion through removal of a given electron is greatest for a photon whose energy is approximately equal to the binding energy of that electron.If the photon energy is less than the binding energy,no interaction can take place,while the probability of interaction rapidly decreases with an increase of photon energy over binding energy.For the lighter atoms,such as found in ordinary concrete,the binding energy of the electrons varies from a minimum of a few ev for outer electrons to about 4 kev.These values are so far below the energy of the X-rays for which protection is required that the photoelectric effect plays a minor part in the attenuation of X-rays by concrete or by other materials composed of light atoms.

1.2.3.3.Compton scattering and absorbtion

The compton effect results from elstic collisions between photon and electron.In this process the individual X-ray photon gives a portion of its energy to the electron and has its direction changed.Both effects are of importance.The loss of energy is a true absorbtion and is designated by the term compton absorbtion.The change in direction suffered by the photon is designated compton scattering.

The number of photons are determined,approximately,by the total number of electrons in the path of the X-rays.It was stated above that the number of electrons in various types of atoms is roughly proportional to the latter's weights.

1.2.3.4.Seccndary effects

The actual attenuation process in a protective barrier is much more complicated than outlined in the brief discussion above.Electron ejected from an atom by photoelectric process are replaced by other electrons and in most cases another X-ray photon is produced.The positive electron resulting from pair production soon looses its kinetic energy by collision and finally combines with a negative electron.Both electrons disappear and their mass shows up as two oppositely directed 0.51 Mev photons called annihilation radiation.Other secondary photons may be produced by high energy electrons,which themselves are secondary effects.These and other processes take place in the absorbing barrier.

1.3.SHIELDING FOR X-RAYS AND GAMMA RAYS

1.3.1General principles

The attenuation of X- and gamma rays in an absorbing material is the result of a combination of the photoelectric effect,the compton effect and pair production, and is a complex process.These three types of interaction have been described in sec.1.2.The photoelectric effect is the predominant type of interaction at low energies, the compton effect at medium energies and pair production at very high energies. Because of the increasing cross sections for interaction in materials for this type of shielding are lead and iron.

In the medium energy range (0.5-0.75Mev), the density of the material is more important than the atomic number, but in the higher and lower energy ranges, materials of higher atomic number are more effective.

The scattering of X- and gamma rays in passing through the absorbing material involves two geometrical conditions which must be considered in shielding calculations; narrow beam and broad beam.

1.3.1.1. Narrow beam conditions

Here one considers a narrow beam collimated beam of gamma radiation which might be obtained from a small source such as is used in gamma radiography, but is usually produced only for experimental purposes. Photon scattering in the shielding material placed in the collimated beam are removed from the emergent beam (Fig.1.3.1-1).

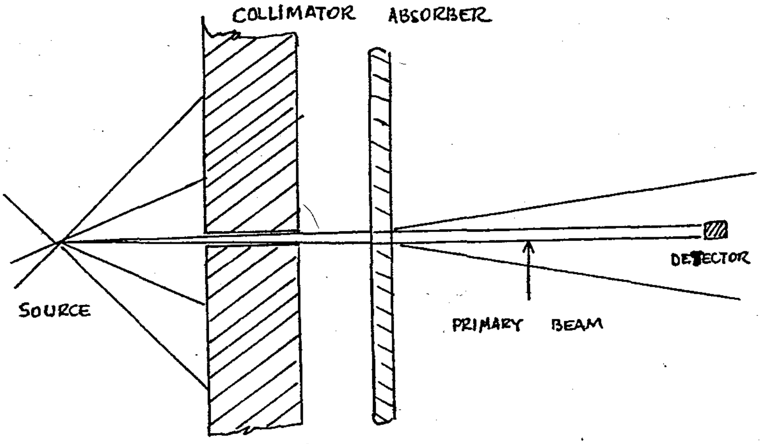


FIG.1.3.1-1. Narrow-beam conditions

The total attenuation is then an exponential process expressed by

$$I = I_0 e^{-\mu x} \qquad (1.3.1.1-1)$$

where

I is the intensity(flux) of the radiation beam emerging from the shielding material, in photons/cm^2.s

I_0 is the intensity(flux) of the beam incident on the shielding material

μ is the linear absorbtion coefficient for the shielding material referred to a thickness of 1 cm

x is the thickness of the shielding material, in cm,

It can be shown that the half-value thickness of a material is related to its linear absorbtion coefficient by the relation

$$HVT = \frac{0.693}{\mu} \qquad (1.3.1.1\text{-}2)$$

similarly

$$TVT = \frac{2.303}{\mu} \qquad (1.3.1.1\text{-}3)$$

The linear absorbtion coefficient varies with (a) the energy of the photon, (b) the atomic number of the material in question, and (c) the density of the material. The term of mass absorbtion coefficient, which is equal to the linear absorbtion coefficient divided by the density, is also often used.Fig.1.3.1-2

In Fig. 1.3.1-2 below the mass absorbtion coefficients for lead and for concrete (photoelectric, compton, pair production and total) are shown as a function of the photon energy. Data for the curves are taken from ACI compilation No.1 [2].

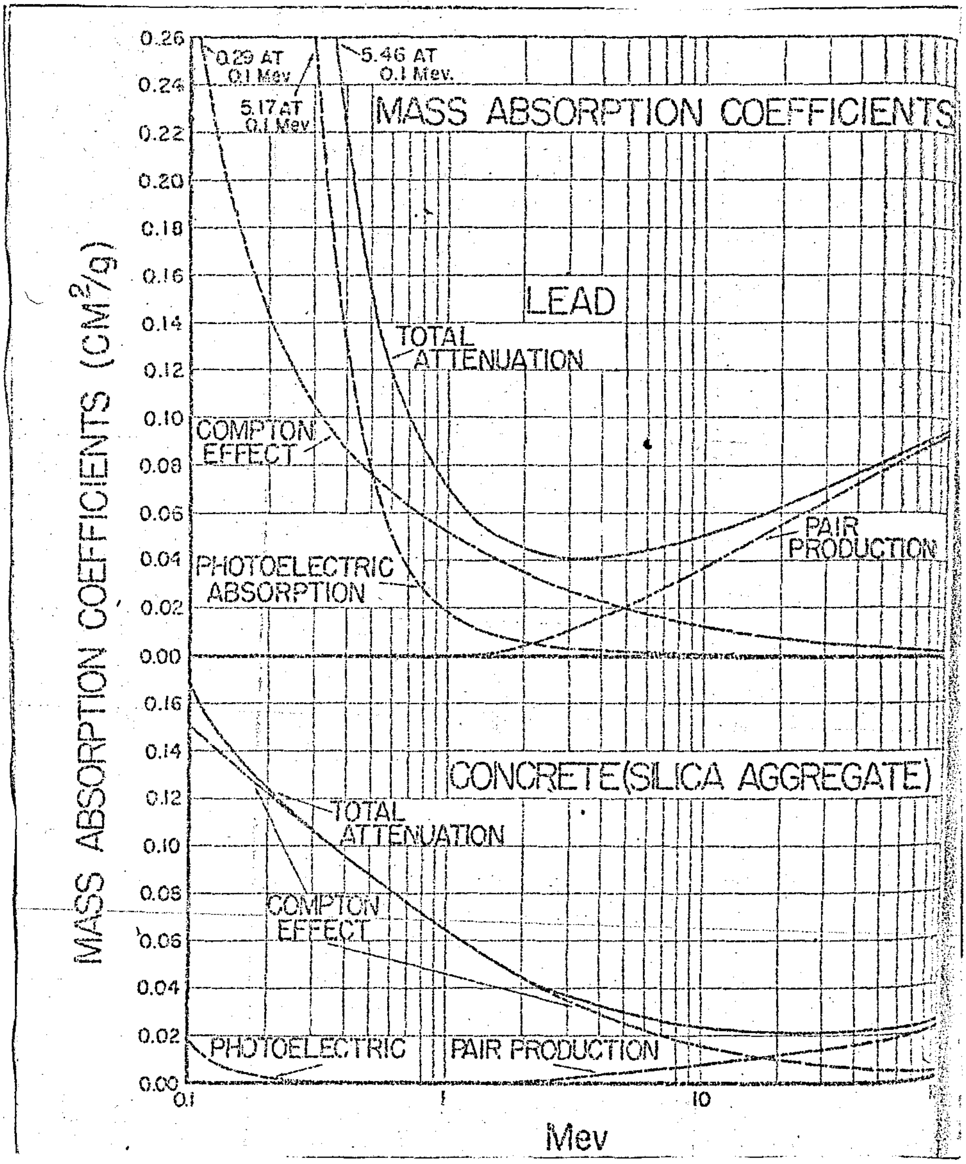


Fig. 1.3.1-2 .Calculated narrow-beam mass absorp-
coefficients for lead and concrete
as a function of X-ray energy

1.3.1.2.Broad beam conditions

This is the more frequently encountered conditions in radiation shielding problems.When broad paralel beams or divergent beams of radiation pass through attenuating material,some scattered radiation re-enters the emergent beam.(Fig 1.3.1.2-1)

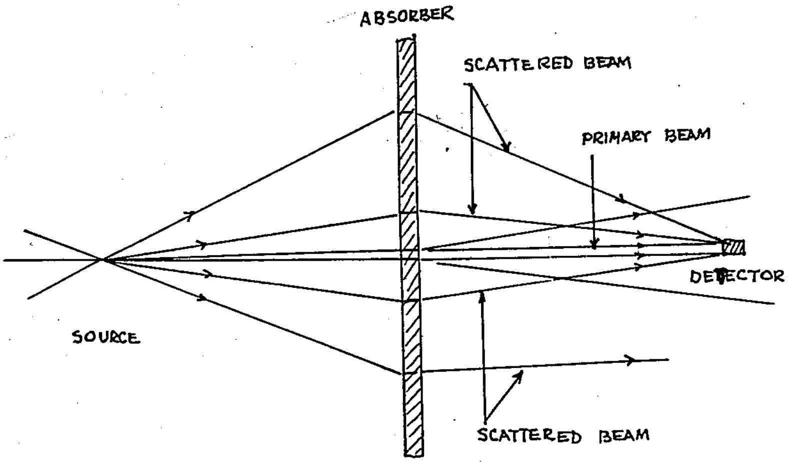


Fig.1.3.1.2-1.Broad Beam Conditions

Thus the attenuation no longer follows an exponential process,as it is reduced by an amount known as the " build-up factor" for any particular source-shield arrangement.

The calculations involved in the assessment of the thickness of shielding required for broad beam conditions are complicated.

Protection of occupied areas adjacent to X-and gamma ray installations may be achieved by shields or walls which absorb radiation.As the cost of such shielding can prove to be an important consideration.

The protective barriers can be of two types.The primary protective barrier which is a barrier sufficient to attenuate the useful beam to the permissible levels and the secondary protective barrier which is a barrier sufficient to attenuate the scattered and leakage radiation to the permissible levels.

1.3.1.3.Reduction of intensity

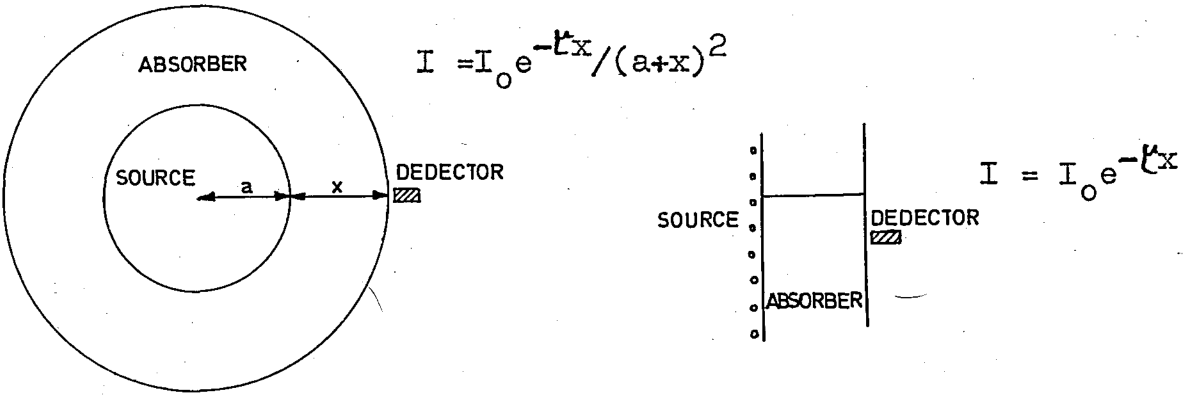
Consideration of attenuation of radiation will be limited to gamma rays and neutrons.Both of these are attenuated exponentially by an absorber.Two general formulas describe this attenuation;when the radiation is considered as a point source, the geometry is said to be spherical; when it is considered as a plane source on one side of a wall, and its intensity measured on the other side, the geometry is said to be plane. The relations of these two geometries are shown in Fig.1.3.1.3-1. The usual forms of the absorbtion law for these geometries are

spherical $$I = I_o \left(\frac{1}{a + x} \right)^2 e^{-\mu x} \qquad (1.3.1.3\text{-}1)$$

plane $$I = I_o e^{-\mu x} \qquad (1.3.1.3\text{-}2)$$

where

I = intensity of radiation at point x (Fig.1.3.1.3-1)
I_o = intensity of source
μ = absorbtion coefficient of absorber material
x = thickness of absorber
a = distance from source to start of absorbing material



SPHERICAL GEOMETRY PLANE GEOMETRY

Fig.1.3.1.3-1 Geometry types used for absorbtion measurement

The factor $1/(a+x)^2$ in Eq.(1.3.1.3-1) is the reduction in intensity due to the inverse-square relation with distance, similar to that for light or gravity.For larger distances from the sources and for relatively thin absorbers,Eq.(1.3.1.3- may be used,with resulting simplicity.Intensity may be measured in r per hr,mrem per hr,neutron flux,or similar units. The term $e^{-\mu x}$ gives the exponential reduction in intensity due to the presence of absorbing material of thickness x.The factor μ is the absorbtion coefficient of the absorber and is given in terms of reciprocal length.The larger the value of μ, the greater the intensity reduction for a given thickness. The absorbtion coefficient μ equals $N\sigma$,where N is the number of atoms per cucm and σ is a quantity known as the total crosssection of the absorber,and is given in terms of sqcm. For comparative purposes, mass absorption coefficients μ/ρ (sqcm per g),obtained by dividing the linear absorbtion coefficient μ by the density of the absorber,are often used.

1.3.1.4.Half thickness

When there is just enough thickness of absorber to reduce the intensity by a factor of 1/2,this thickness is known as the half-thickness and is given in inches or centimeters.It is determined from

$$1/2 = e^{-\mu T1/2} \qquad (1.3.1.4-1)$$

or

$$T_{1/2} = 0.693/\mu \qquad (1.3.1.4-2)$$

where $T_{1/2}$ is the half-thickness and μ is the absorbtion coefficient.This value varies with the type and energies of the radiation;as well as with the material of the absorber. A similar factor known as the relaxation length is sometimes used in place of the half-thickness;it is equal to $1/\mu$.

The number of half-thicknesses required for a shield may be computed from the equation

$$N = 3.322 \log R \qquad (1.3.1.4-2)$$

where N is the required number of half-thickness, and R is the reduction (attenuation) factor, which is needed to attenuate the radiation to desired level.

1.3.1.5. Source strength

In the case of gamma ray emitters, their strength is often described in terms of curies. Assuming a point source, the dose rate may be found from the equation [8]

$$I_o = 7CE/a^2 \qquad (1.3.1.5-1)$$

where I_o = intensity in r per hr at one ft from the source
C = the number of curies of the isotope
E = energy of emitted gamma rays in Mev/disintegration
a = distance from the source to the inside of the shield, ft

The energy of the gamma rays may be obtained from tables for various isotopes. [7]

2.CONCRETE FOR RADIATION SHIELDING

2.1.Introduction

The primary factor involved in radiation shielding is the reduction of the intensity of the radiation to the desired level.Secondary to this are economic and mechanic factors which are valid to a considerable extent.

Accomplishment of the reduction in radiation intensity is relatively simple.Almost any material will serve for shielding purposes if sufficient thickness is used.However the use of materials requiring excessive thicknesses may be precluded on an economic basis;other materials requiring only moderate thicknesses may not be prectical for economic or mechanic reasons.Thus although water is a good neutron shield,it requires excessive thickness for shielding accompanying gamma radiation,and water tanks are relatively fragile and subject to leakage.At the other extreme,lead shields are very effective against gamma radiation,but lack mechanical strength for large,permanent shielding structures. Both of these materials are relatively infrequently chosen for permanent shielding installations of considerable magnitude because they are uneconomical and not completely suitable mechanically.

Fortunately,concrete is an excellent shielding material for large,permanent shields.It possesses good compromise thickness requirements for both neutron and gamma ray attenuation, sufficient mechanical strength,low maintenance and reasonable cost.Ordinary concrete in sufficient thickness will provide satisfactory shielding;heavy concrete made from special aggregates with a generally higher unit cost,is often preferable due to smaller thickness requirements.Certain mechanical problems and requirements,such as homogeneity,are common to both types.Assuming that these requirements are met,the space requirements and other economic factors will yield a decision as to the type of concrete to be chosen.

2.2.Types of concrete

Ordinary portland concrete is usually made with local products and therefore varies from batch to batch in its exact make-up and from location to location in its typical composition.Variation of size of the aggregate and the sand particles as well as the mix proportions will produce variations in density,appearance and strength properties.Use of special aggregates,sand,cements or additives to the mix water as described in the following sections may enhance the nuclear characteristics of the concrete.Placement methods and procedures to be followed are important in insuring reliable shield performance over the projected life of concrete.

2.3.Use of aggregate

Aggregates are used in concrete to give strength to it.Usually they are graded as coarse and fine.The fine aggregate weigth is about 40% of the total aggregate weigth. Coarse aggregate may range from 2 to 5 cm across the largest dimension.In nuclear applications use of high-density aggregates such as various ores of iron and scrap metal, increase density of the concrete,an important consideration for shields.Certain aggregates may increase the fixed water content in the concrete,another property desirable from a nuclear viewpoint.

In other words,the water content of hardened concrete is an exceedingly important parameter by which to estimate the effectiveness of concrete shields in attenuating neutrons,as can be seen clearly from Fig.2.3-1

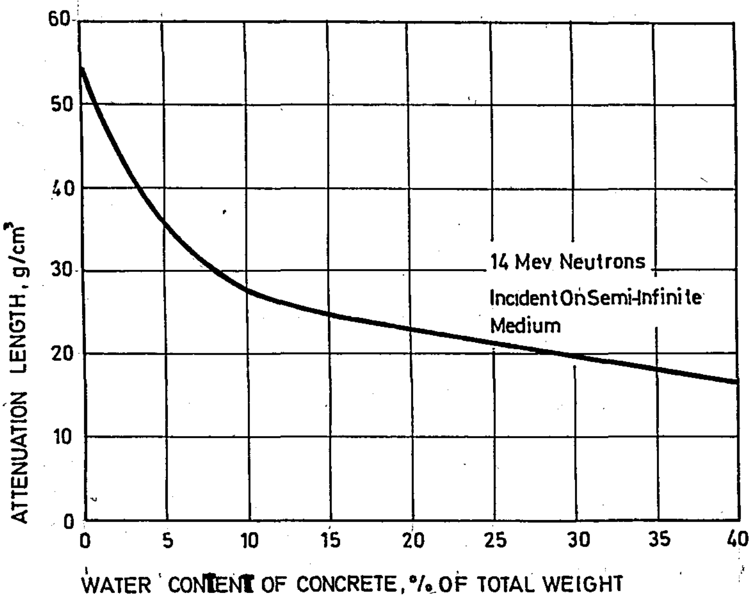


Fig.2.3-1.Effect of water content upon attenuation length of neutrons

This figure indicates the relationship between the neutron attenuation("relexetion") length in mass thickness units and the variable content of a concrete of otherwise standard composition,as derived from calculations of Spielberg and Duncer[5].According to this diagram a reduction of water content from 15 to 5 % by weigth of the concrete results in an increase of the attenuation length by a factor of about1.7[5]

2.4.An estimate of concrete mix proportions

The relationships to estimate the water content of concrete are based upon the assumption that at least the cement content and the water cement ratio of the particular concrete are known.In some instances,this information may not be available.Then both values can be estimated from the following relationships if at least the design strength of the concrete is known.

The amount of mixing water W_0 is primarily a function of the required workability and the maximum aggregate size of the fresh concrete.[6]It can be approximated by the following relationship

$$W_o = a_1 - b_1 \log S_a \tag{2.4-1}$$

where W_o= mixing water (kg/m^3),S_a= maximum aggregate size of concrete(cm),and a_1 ,b_1 = coefficients given in table 2.4.-1 for various consistencies of fresh concrete.[6].

Table 2.4-1.Coefficients a_1 and b_1 for eq.2.4-1

Consistency	No air entrainment		Air entrianment	
	a_1	b_1	a_1	b_1
Stiff	208	83	188	88
Plastic	230	93	206	90
Fluid	234	97	218	93

The consistency of a concrete mix may be chosen according to the type of a structure as shown in table 2.4-2.

Table 2.4-2. Consistency of fresh concrete

Type of structure	Consistency
Reinforced foundation walls and footings	Plastic
Unreinforced walls and footings	Stiff to plastic
Reinforced slabs,beams and walls	Plastic to fluid
Building columns	Plastic to fluid
Pavements	Stiff
Other slabs on the ground	Plastic
Mass concrete	Stiff

The maximum aggregate size depends on the dimension of the concrete section and the pnesence and spacing of reinforcement.The following limits are normally used in USA.

For reinforced concrete it shall not exceed one-fifth of the smallest dimension of the concrete member nor shall it be larger than the three-fourths of the minimum clear spacing between reinforcing bars.For plain concrete it shall not exceed one-third of the minimum dimension of the structure.But consideration also has to be given to the available materials. In normal building construction the maximum aggregate size usually does not exceed 3.0 to 4.0 cm even if the dimension of the crosssection would permit this.

The water cement ratio and the cement content of concrete are governed by strength and durability requirements. The relationships between strength and water cement ratio can be approximated by the following expression:

$$\frac{W_o}{C} = \frac{a_2}{f_c' + c_2} - b_2 \qquad (2.4\text{-}2)$$

if f_c'= compressive strength of concrete after 28 days(kg/cm^2) and a_2, b_2, c_2 = coeffƒcients depending on type of cement and entrainment as given in table 2.4-3 .

Table 2.4-3.Coefficients a_2 and b_2 for eq 2.4-2 .

Type of cement	No air entrainment			Air entrainment		
	a_2	b_2	c_2	a_2	b_2	c_2
Type I	500	0.34	225	1220	0.79	660
Type III	570	0.37	250	1000	0.61	560

Normally Type III cement is used in comparatively thin concrete sections when a high concrete strength is required after a few days.Air entrainment generally is used when the concrete member is exposed to freezing and thawing.Then,the water cement ratio normally does not exceed a value of 0.60

and may be less than computed from eq.(2.4-2).

2.5.Calculation of shield thickness

The type and intensity of the radiation can usually be obtained from the data of reference [7], the identification and amount of the isotope to be shielded being given. For pieces of the apparatus, the data will normally be provided by the designers or users.

From the data of table 2.5-1, the source intensity in r per hr for the gamma emitters can be computed using Eq.(1.3.2.3-1) or for a neutron source Eq.(2.5-1).

$$I = 8.57 \times 10^{+5}\ KM/a^2 \qquad (2.5\text{-}1)$$

where I =Neutron flux,n per sqcmsec

K =a constant depending on the type and strength of the source (see Table 2.5-1)

M =number of milicuries of active isotope

a =distance from the source,ft

Table 2.5-1 gives values of energy and neutron emission for some commonly used isotopes and neutron sources.

Table 2.5-1 .List of commonly used gamma and neutron emitters

Isotope	Energy of radiation,Mev	Remarks
C^{14}	-	Beta radiation only
Na^{24}	1.38,2,76	-
Co^{60}	1.17,1.33	-
Ir^{192}	1.2 max	-

The number of half-thicknesses required for a shield may be computed from the equation 2.5-2 .

$$N = 3.322 \log R \qquad (2.5\text{-}2)$$

where N is the required numbed of half-thickness and R is the reduçtion (attenuation) factor, which is that needed to attenuate the radiation to the desired level.

The number of half thicknesses can be found from Eq.(2.5-2) and Eq.(1.3.1.5-1) .

As an example of this method of calculation, assume that it is desired to design a concrete shield for a 1000-curie source of Co^{60}, such as used in high-powered radiography. An internal diameter of the spherical (for simplicity) shield of 2 ft is specified to provide space for manipulating the source. Fig.2.5-1 is a diagram of the set-up. [9]

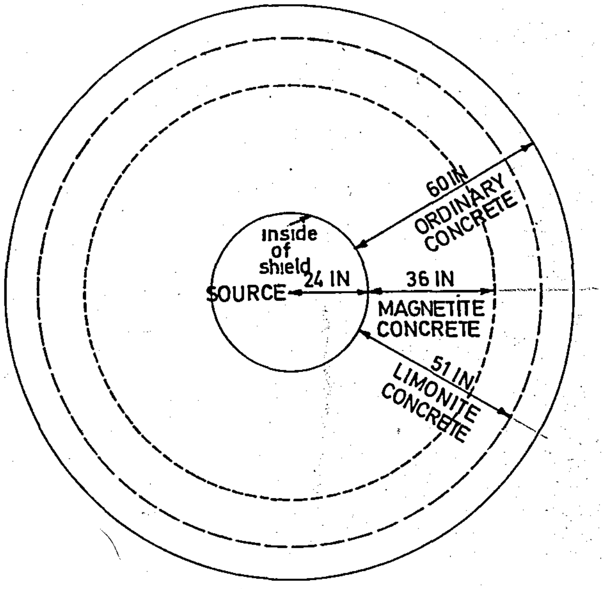


Fig.2.5-1. Comparison of spherical shielding composed of various types of concrete required for shielding a 1000-curie Co^{60} source

From Table 2.5-1 or reference[7] it is determined that Co^{60} emits two major gamma rays of 1.33 and 1.17 Mev (the low-energy gamma ray and the beta emission can be neglected). Then from Eq.(1.3.1.5-1) the source energy is found to be

$$I_o = 7x1000x(1.33+1.17)/2^2 = 4375 \text{ r per hr}$$

at the inside surface of the shield. The gamma rays are cascaded and so are added. With a tolerance level of 6.25 mr per hr, the required reduction factor is

$$\mathcal{R} = 4375/0.00625 = 7x10^5$$

Then from Eq. 2.5-2, the required number of half thicknesses is

$$N = 3.322 \text{ Log } 7x10^5 = 19.42$$

This is almost an equal number of half thicknesses for an attenuation of 10^6.

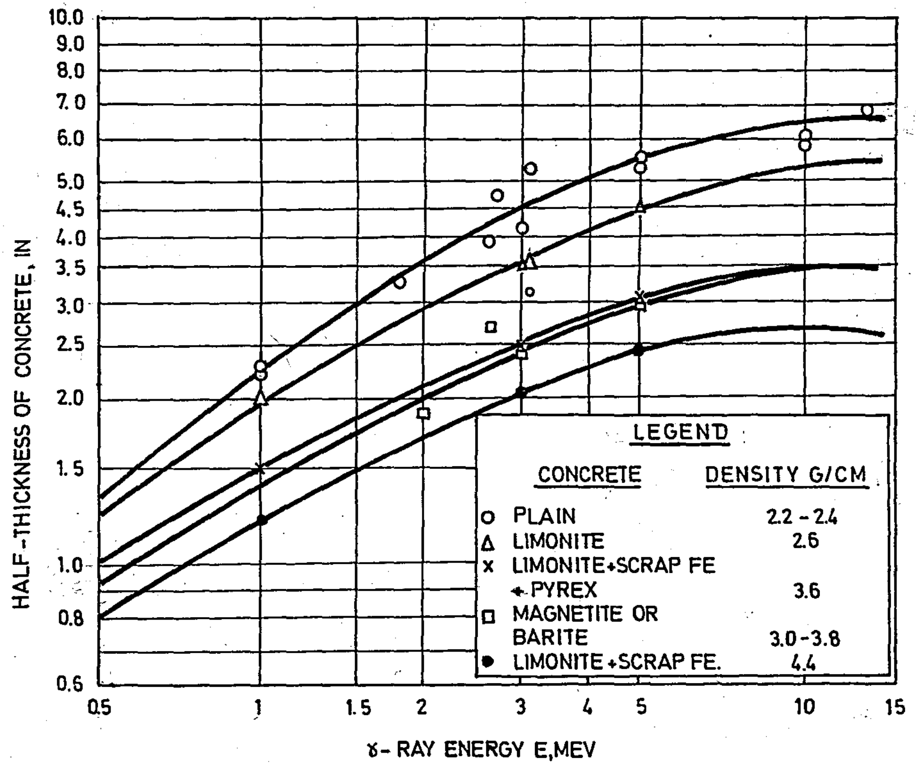


Fig. 2.5-2 Half-thickness values for ordinary and heavy concrete for varying gamma ray energies

The maximum energy-gamma ray being 1.33 Mev, the half thicknesses obtained from Fig. 2.5-2 are :

Type of Concrete	Half-thickness, in	Total thickness, in
Plain	2.82	54.76
Limonite	2.38	46.22
Barite	1.65	32.04

If we add two half-thicknesses as a factor of safety, then the approximate required thickness becomes 60 in. for plain concrete, 51 in. for limonite concrete and 36 in. for barite concrete.

2.6. Economic factors

Ordinary concrete will in general be the cheapest material to use; where space is not limited and when strength is important, ordinary concrete will fill the bill more adequately than special concretes.

Special concretes should be used where space is a limiting factor and money is not; in general, the gain in shielding reduction is off set by the cost of the special concrete, especially in areas for away from the source of good agregate and whenever auxiliary strength members must be used for support of the shield; one of the items whech runs up the cost of special concrete is the unfamiliarity of the contractor with special shield concretes.

Foundation problems for heavy concrete shields may add to the expense, even though the building costs may be less. These and other structural factors require much more attention, before a decision as to the type of concrete to use for shielding can be made.

3.SHIELDING MATERİALS

3.1.Nuclear applications of concrete

Ordinary concrete is an inexpensive,easily handled material where nuclear properties are good enough, taken in conjunction with its excellent structural properties,to make it desirable as a shielding material.Concrete made with portland cement,local sands and crushed rock and mixed in the field is quite variable from one mix to another in composition and in some properties;no two batches are ever exactly the same.This variableness lies within tolerable limits,however;and its abundance,low cost and ease of procurement and handling make-up for lack of high nuclear performance.Concrete is therefore attractive as both shield and structural material in lan-based power plants and other stationary facilities,where size is not a handicap.Nuclear performance of concretec may be enhanced by using special aggregatєs,adding heavy metals to the mix or boron additives to the mix water.

3.2.Requirements for concrete for shielding use

Concretes for shielding must fulfill the following requirements:

(1) The possibility of prolonged use as a shielding material without deterioration of their properties;

(2) Resistance to the action of elevated temperatures without dangerous loss of strength;

(3) Long-term resistance to radiation;

(4) The material must not crack,warp or expand under the action of temperature and radiation;

(5) Low heat conductivity;

(6) Low cost; and

(7) Convenience in placement and operation.

The above requirements give the specific properties of normal and special concretes called for under operational conditions of concrete shields. [10]

3.3.Importance and control of water in concrete

Water is the most desirable ingredient in concrete from a nuclear point of view,because water contains a large proportion of hydrogen and is,therefore a good neutron moderator and attenuator.Hydrogen is a very effective moderator of neutrons,making them more easily available for capture.A beam of neutrons passing through concrete containing normal amount of hydrogen(0.5 wt.%) will therefore be quickly reduced in intensity(or attenuated to much smaller values).

3.4.Desirable physical and mechanical properties

There are several properties of interest which one must consider in the use of concretes for shielding.They are:(1) density;(2) compressive strength;(3) thermal conductivity;(4) hydrogen content; and (5) dehydration with temperature.These are discussed below briefly.

3.4.1.Density

The density of a concrete plays a great role in its nuclear performance,because density is a measure of the atomic concentration of the constituent elements.The overall density of concretes varies from a low level of 1.3 g/cm^3 for certain earth aggregate concretes to oevr 4.8 g/cm^3 for certain steel loaded,iron ore aggregate concretes.High density is a desirable property for stopping both gamma rays and neutrons.The greater the density the greater the number of nuclear interactions,and the more effective the material becomes in its ability to absorb radiation.The density may be increased by use of heavier aggregates.

3.4.2.Compressive strength

Compressive strength is of importance since most concrete shields are also structural members and preservation of shield integrity over its expected lifetime is a necessity.Ordinary concrete made with common aggregates u using well-known mixing and placement methods gives the best all-around strength characteristics.Proper use of aggregates can enhance the strength of concrete.For neutron shielding, where a high water content is desirable,strength may hav to be sacrificed somewhat to obtain the desired water content. A good quality portland concrete has a 90-day compressive strength of 245 to 455 kg/cm^2.Iron-ore aggregate concretes have compressive strengths of 385 to 455 kg/cm^2 if conventionnal placement is used.[10]Barite concretes have strengths ranging from 245 to 350 kg/cm^2.

3.4.3.Thermal conductivity

The termal conductivity of ordinary concrete varies between 0.0008 to 0.004 cal/s-cm-°C,depending on the mix.In general,heavy aggregates added to concretes increase their conductivity.Barytes concrete has a conductivity of around 0.004 cal/s-cm-°C.Iron-ore-aggregate concretes have conductivities ranging from 0.005 to 0.012 cal/s-cm-°C.High density concrete made with steel shot may have a conductivity as high as 0.037 cal/s-cm-°C.[10]

3.4.4.Hydrogen content

Hydrogen occurs in concrete mainly in the form of fixed water and small amounts of organic impurities.The main shielding effectiveness of concrete for neutrons is due to the water content of concrete.The concrete should be protected against loss of water by cooling or other means.

3.5.Use of special concretes

Concrete is a very versatile material and its properties can be changed within limits almost at will to suit special needs.These needs usually fall into one or more of the following three categories:(1) Higher neutron-attenuating performance;(2) Higher gamma ray attenuating performance; (3) Higher temperature pergormance.However,it must be emphasized that this better performance is usually obtained at the expense of higher construction costs and less reliability.because most contractors are not familiar with the use of heavy concretes and do not know the best mixing ano pouring methods.Also water retention may be more difficult in these special concretes,compressive strength usually goes down,and uniformity of the pour is harder to achieve,except by the use of special and expensive method.[10]

Use of high density aggregates,such as various iron ores,barium ores,lead ores etc.may boost the density to as high as 4.0 g/cm^3.The density can be raised to nearly 4.8 g/cm^3 by using ferroboron or ferrophosphorus as the aggregate.If steel punchings are used a density over 5.6 g/cm^3 may be achieved.

Where the thermal-neutron attenuation properties are desired to be increased to the maximum attainable,or where the supression of hand capture gamma rays is desired concrete may be loaded with boron-combining materials.Boronation can take the form of (1) a boron-bearing aggregate such as colemanite;(2) use of pyrex glass ground to a sand as a part of the sand;(3) use of boric acid,borohydrides or complex borates dissolved in the mix water;or (4) use of boron in cementing agent.[10] The presence of boron retards the setting process; care has to be taken not to use too much.One percent boron is adequate for most all uses.The effects of colemanite on the concrete will be discussed in the later chapter.

3.6.The technology of concrete

This section deals with guide-lines to follow in the handling and use of concretes for shielding,the selection and handling of aggregates and other ingradients in the concrete and the estimation of final properties of the concrete from known parameters of the ingredients.

Mixing formulas for concretes call for the addition of various coarse and fine aggregates,whose uses and selection are described in the appendix .Aggregates can be put through a series of sieves.Two main categories are recognized,coarse aggregates and fine aggregates.According to the American Society for Testingand Materials (ASTM)[11], coarse aggregate is the portion of the aggregate which is retained on a U.S.No.4 size sieve,having an opening of 4.76 mm.Fine aggregate is defined as part of the aggregate passing through No.4 sieve and predominantly retained on a No. 200 sieve having an opening of 0.074 mm.Most mechanical engineering and general handbooks list standard sieve sizes.

In most instance the best binder for shielding concretes is portland cement,which must meet the requirements of certain standards.The cement used should be subjected to complete chemical analysis.

Normal aggregates for concrete must meet the requirements of set standards.Appart from the generally-accepted characteristics of aggregates,full chemical analysis is to be carried out and the specific gravity must be determined in the vibrato-compacted state,together with the appearent density.Aggregates should be clean and should be fractioned.The use of scrap iron or other metal waste aggregates covered with fat or oil is not permitted.

The strength of aggregates and their water absorbtion should lie with in the limits laid down in the table 3.6-1 . [10],

During the transport and storage of aggregates precautions should be taken to prevent separation into the individual fractions.

More detail about this section will be given in the later sections.

Table 3.6-1 Standard strength and water absorbtion values of aggregates

Type of concrete	Compressive Strength (kg/cm^2)	Water absorbtion (wt %)
Magnetite	2000	1-2
Limonite	350	9-10
Barytes	400	1-2
Serpentine	400-650	0.5
Scrap iron	2000	-

3.7.Construction Standards for concrete shields

There are a few general rules which must be followed for all shields.The following standards are a summary of them and should be applied to insure high performance concrete for the shield.[10]

(1) Density should be uniform throughout the shield and within 5% of desing density.No large voids,areas or bubbles should exist.

(2) Neutron shields:Fixed water content of the cured shield should be not less than 5 wt% for ordinary concrete.For heavy concretes the minimum fixed water f_H is defined by

$$f_H = \frac{11.5}{\rho} \% ,$$

where ρ is the concrete density in g/cm^3.

(3) Compressive strength (ordinary concrete) should be not less than 350 kg/cm^2 for ordinary concrete, or as recommended for special concretes.

(4) Ambient temerature during pouring should be between 10 to 32 °C,for best results.

(5) For poured shields,monalithic poors are to be used,whenever possible.If the mass of the shield is too great for one pour,joints between pours are to be stepped or broken.Fresh layers must be bonded to hardened layers

by moistening and roughening the hardened layer or through the use of neat cement.

(6) Moist curing of all concrete shields should be allowed to proceed for 28 days to develop the necessary strength and fixed water content

(7) Shields also used for structural purposes are to be reinforced with steel reinforcing bars.

(8)Concrete placed or poured around objects or penetrations must be tightly packed around the object to insure that no streaming gaps or voids exist in these areas.

3.7.1.Ordinary concrete shields

Ordinary concrete is a fairly easy material of construction to work with,and excellent results can be obtained with just a little care and effort.The characteristics of good sand,cement and aggregate are left.But to attain the best end,carefull attention must be given to the selection of cement,aggregate and water in accordance with preceding principals and to the following considerations:

(1) The mix must be workable so that it can be placed and finished without undue labor.

(2) Since cement is the most costly ingredient in the mix,the proportion used should be as small as is consistent with attainment of desired properties.

(3) The strength and the degree of watertightness of mixes,having like constituent materials,density and workability,increase with the cement content.

(4) With the cement content,materials and workbility all constant,the strength and degree of watertightness increase with density of the mix.

(5) For usual methods of placement,the strength and degree of watertightness of well-cured concrete and mortar are greatest when the mix is plastic(has a slump of approximately two inches).Drier mixes,although frequently as strong are likely to be porous unless compacted by pneumatic rammers or electrically driven vibrators.Increasing the water content beyond that required for plasticity cau-

ses the strength to decrease rapidly.

(6) In proportioning concrete or mortar which is to be subjected to freezing temperatures, a minimum amount of water and quick-setting cement should be used. [10].

(7) The principal shemes used in scientific proportioning of mixes are based upon relationships between properties and ratio of cement to water in the mix.

The most accurate method of measuring proportions of ingredients is to weigh the required quantities of each material. See app I .

Probably the most used method of proportioning is that based upon arbitrary selection. In specifying proportions for mortars it is common practice to call for 1:2, 1:3, or 1:4 parts of cement to parts of fine aggregate, depending upon the quality of mortar demanded. In proportioning concrete by this method, the engineer, guided by experience and a knowledge of the requirements for the structure, assumes a mortar of given proportions and selects a proportion of stone such that the voids in the stone, as measured at the job, will be 15 to 25 % less than the volume of the mortar. Such methods or proportioning may give very fair results when used by a man experinced in judging aggregate, but in the hands of persons inexperienced in their use a poor mix or waste of cement is likely to result.

To facilitate the use of Water-cement ratio method, the slumps, sand ratios and moisture contents suggested by the Portland Cement Association in Design and Control of Concrete Mixtures are tabulated in Table 3.7.1-1

Table 3.7.1-1.Useful data for designing concrete mixes

Recommended slumps for concrete

Type of structure	Slump (in) Minimum	Maximum
Massive section,pavements and floors laid on ground	1	4
Heavy slabs,beams or walls	3	6
Thin walls and columns ordinary slabs or beams	4	8

Approximate amounts of free water in aggregates

	wt%
Very wet sand	6-8
Wet sand	4
Moist sand	2
Moist gravel or crushed stone	1.5

Approximate water-absorbtion of air dry aggregates

	wt%
Ordinary sand	0.5-1.0
Gravel and crushed limestone	0.5-1.5
Trap rock and granite	0.3-0.5
Porous sandstone	

On important work moisture determinations should be run several times a day.When moisture content determinations are not made,the approximate values in table 3.7.1-1 may be assumed.

Experience has shown that different concrete structures require different types of mixes because of various pouring,setting,load conditions or use of structure; no one type of concrete is sufficient for every use or placement conditionsConcrete for use as biological shielding has different performance requirements from that to be used in a road pavement or a dam,for instance.

For neutron shielding the water content of a concrete should be high,while the strength of the concrete may not be too important.Therefore,a 1:2:4 or even higher cement: sand:gravel ratio with a high water cement ratio is desirable.

The concrete engineer can be guided in this selection of the proper mix by the use of tables 3.7.1-1. The table taken from [12] ,lists the aggregate proportions and water-cement ratios desirable for concrete in various types of structures.

Table 3.7.1-2. A guide to water-cement ratios and aggregate proportions for various ordinary concrete structures

	Desired compressive strength at 28 days (lb-in^{-2})(b)	Water-cement ratio by wt	Proportins by volume (a)
Concrete for			
High early strength in pavements;strong columns,beams and slabs;or structures very severly exposed	5500	0.40	1:1:2 to 1:1$\frac{1}{2}$:3
Walls,dams,piers, pavements and other structures requiring high strength or watertightness;or for structures severly exposed	4500	0.50	1:1$\frac{1}{2}$:2$\frac{1}{2}$ to 1:2:3$\frac{1}{2}$

Walls,dams,piers,reservoir linings exposed to weather in northern climate.Watertigth structures,pipes, tanks sewers,pavements and thin members exposed to frost action	3800	0.55	1:1$\frac{1}{2}$:3 to 1:2$\frac{1}{2}$:4
Walls,dams,piers,reservoir linings exposed to wheather in southern climate.Basement walls or thin structural parts subjected to moderate exposure	3000	0.60	1:2:3 to 1:2$\frac{1}{2}$:4
Enclosed structural members piers,retaining walls,foundations and footings protected from alternate wetting and drying and from sever weather	2200	0.65	1:2$\frac{1}{4}$:3$\frac{1}{2}$ to 1:3:5
Mass concrete requiring little strength and well protected	1800	0.75	1:2$\frac{1}{2}$:4$\frac{1}{2}$ to 1:3$\frac{1}{2}$:6

a) Proportions of cement:sand:gravel

b)To convert these values to kg/cm^2,multiply by 0.0703

3.7.2.Serpentine concretes

Concrete made with the mineral aggregate serpentine,a mineral of asbestos,in place of trap rock or ordinary stone,is usable at temperatures up to 428 °C.Table 3.7.2-1 presents a typical chemical analysis of serpentine aggregate.The water of crystallization present in the mineral serpentine ($3MgO.2SiO_2.2H_2O$) is retained up to about 510°C. [10]

Table 3.7.2-1 Chemical analysis of serpentine rock

Compound	Composition (wt%)
MgO	40.0
SiO_2	39.3
* H_2O	12.2
FeO	3.8
Fe_2O_3	2.1
Al_2O_3	1.5
CaO	0.61
NiO	0.39
Cr_2O_3	0.35
K_2O	0.18
Na_2O	0.10
TiO_2	0.05
+ Cl	0.01-0.1

* Water content varies slightly.This value represents a minimum.
+ As $MgCl_2$ or NaCl

Two properties of serpentine concrete which make it very desirable for use in neutron shields under certain conditions are (1) the high fixed water content;

and (2) the ability to withstand high temperature as described above.

The density of serpentine concrete(2.1 g/cm^3) is slightly less than that of ordinary concrete(2.3 g/cm^3), but the increased hydrogen concret of serpentine is enough that its neutron attenuation properties are equal about those of ordinary concrete.The gamma ray attenuation propertiesof serpentine concrete are somewhat inferior to those of ordinary concrete.[10]

Serpentine concrete can be made with either portland or lumnite cement.The use of lumnite cement is not recommended for large shield volumes.

Because of the large affinity of serpentine aggregate for water,the handling and mixing problems are different from ordinary stone aggregates.The mixing proportions can not be varied as easily as with ordinary concrete and once a good mixing formula is found.Table 3.7.2-2 presents the mixing proportions for a comparatively high-strength serpentine concrete used in the biological shield if the Fermi plant (here after called the design mixture),and Table 3.7.2-3 lists the sieve analysis of the aggregate that was used to produce this concrete.(

Table 3.7.2-2 Typical analysis of serpentine concrete (14)

Material	**Amount required for 1 cuyd*		Dry material	
	wt(lb)	Vol(cuft)	Vol %	wt %
Serpentine	2032	12.51	51.5	54.5
Sand	956	5.83	23.9	25.8
Cement	525 *	2.68	11.1	14.2
Water	373	5.98	13.5	5.5
Plastiment	1.39 +			

* 5.5 bags cement

\+ 4 oz per cement

Table 3.7.2-3 .Sieve analysis of fine and coarse serpentine aggregate or concrete mixture shown in Table 3.7.2-2 and properties of the aggregate(14)

Screen or sieve size	Percent passing through sieve	
	Fine aggregate	Coarse aggregate
No.100 sieve	1.92	
No. 50 sieve	12.68	
No. 30 sieve	47.74	
No. 16 sieve	84.01	
No. 8 sieve	97.50	
No. 4 sieve	100.00	2.72
1/8 in screen		15.02
1/2 in screen		24.91
3/4 in screen		41.91
1 in screen		72.75
1$\frac{1}{2}$ in screen		100.00
Specific gravity	2.604	2.60
Fineness modulus (%)	2.56	
Organic material	Les than standard	

The physical and mechanical properties of serpentine rock and concrete are listed in Table 3,7,2-4 .

Table 3.7.2-4.Physical properties of serpentine rock and serpentine concrete. [10]

Property	Serpentine Rock	Serpentine Concrete
Density(g/cm^3)		2.06-2.2
Lump	2.60-2.65	
Loose material	1.3 -1.6	
Dry,rodded	2.08	
Thermal conductivity (cal/sec-cm-^{0}C)	0.012 at 70^{o}C	~ 0.024
Coefficient of expansion(per^{o}F)	15.10^{-6}	$\sim 18.10^{-6}$
Water content (wt%)	13.5	
Wet		16.8**
Compressive strength(kg/cm^2)	13	135~ 162

Concrete composition given in table 3.7.2-2.
This value nicludes the water taken up by the cement plus the water content of the serpentine aggregate.

3.8.The desirability and use of heavy concrete

Heavy concrétes make use of heavy-ore aggregates or metal in place of,or in combination with,trap rock to enhance the nuclear properties,especially the gamma ray attenuation properties.The density of conventional concrete is often found to be insufficient for a particular shielding application.

For example,types of concrete possesing extremely high density have had to be developed in order to achieve both maximum effective absorption of gamma radiation and secondary radiation due to neutron capture by the shield.The most commonly used types of concrete are those based on barite($\rho \cong 3.5$ g/cm^3),magnetite ($\rho=3.4$ to 4.0 g/cm^3) and limonite($\rho=3.1$ g/cm^3).They satisfy economic and technical requirement in most cases since their cost is fairly reasonable,they are resistant to environmental influences and they are easy to use in the hands of experienced cotractors. [10]

Sometimes concrete of greater density is preferred in order that the shield thickness may be reduced.

When it is a question of attenuating gamma radiation,the heaviest possible shielding structures are generally called for.A wide range of heavy concrete,with densities from 3.50 to 5.50 g/cm^3 may be obtained by using steel scrap,which is available at fairly low ccst,together with barite or magnetite.

Extremely dense concrete ($\rho=6.35$ g/cm^3)may be obtained by using steel foundry tailings instead of barite or magnetite.

A new range of special heavy concrete has been obtained using scrap together with limonite($2Fe_2O_3.9H_2O$) containing 10 to 12 % water and a binding agent based upon aluminous cement.By combining elements such as colemanite ($2CaO.3B_2O_3.5H_2O$) and pandermite ($5CaO.6B_2O_3.9H_2O$),which are rich in boron and water,with scrap iron one can obtain very heavy iron-boron concrete (ρ=5.3 g/cm^3) particularly suited to shielding against gamma and neutron radiation.

Among the heavy concretes described below are ferrophosphorus concrete,limonite and magnetite concretes, ilmenite concrete,magnesium oxychloride and iron concretes, iron portland concrete and barytes concrete.

3.8.1.Ferrophosphorus concrete

Ferrophosphorus concrete is a heavy concrete made using iron phosphide ores(mixtures of FeP,Fe_2P,etc) as the aggregate,producing a concrete with a density of about 4.8 g/cm^3.

Physical and mechanical properties are given in table 3.8.1-1. [15]

Table 3.8.1-1.Physical properties of ferrophosphorus concrete

Property	Value of description
Density (g/cm^3)	4.8
Compressive strength(kg/cm^2)	337
Age 60 days	337
Age 4 months	275

3.8.2.Iron ore concretes
(Hematite,Goethite,Limonite,Magnetite)

Various iron ores are properly used in making heavy concretes.Hematite,Fe_2O_3,a red-black ore with cherry red streaks,is a pure oxide of iron found mainly in Urals, Swizerland and Brazil.240.000.000 tons of hematite reserve is present in our countary.[16]

Goetheit, with a composition listed variously as $FeO.(OH)$ or as $Fe_2O_3.H_2O$ (they are equivalent) is distributed commonly throughout the world. Limonite often called impure goetheit, is very abundant throughout the world and is in reality a mixture of goetheit and hematite, with or without small amount of jarosite. Pure hematite ore used as the aggregate in concrete will yield a concrete density close to that of magnetite concrete. Pure goetheit as the aggregate in concrete will yield a concrete density slight greater than that of limonite. Magnetite ore will in general yield the heaviest iron ore concrete.

Concrete made with goetheite and hematite will, except for density variations, as pointed out above, handle like limonite and will have properties very close to limonite concrete. [10]

3.8.3. Limonite and Magnetite concretes.

Iron ore concretes are popular because of the ready availability and low cost of the iron ores limonite, magnetite, hematite and goethetite. These are all oxides of iron. Limonite and goetheite ($Fe_2O_3H_2O$) have the added attraction of fixed water of hydration in the mineral. In some applications, however, it is necessary to attenuate neutrons as well as gamma radiations. To slow down fast neutrons, the concrete should also contain light material, such as hydrogen. Since maximum density is incompatible with maximum hydrogen content, a compromise between density and hydrogen content must be made to obtain the proper composition for attenuating both gamma radiations and fast neutrons.

The chemical compositions and mixing recipes of limonite and magnetite concretes with and without added steel in the mix are given in table 3.8.3-1. Typical physical and mechanical properties are listed in table 3.8.3-2. [10]

Table 3.8.3-1.A comparison of the compositions of several limonite-magnetite concretes

Material	Composition (wt%)			
	Conventional placement		Prepacked concretes	
	Type C	Type D	Type A	Type B
Coarse aggregate				
steel punchings	-	-	54.6	
limonite	-	21.1	23.4	31.1
magnetite	58.0	33.2	-	40.6
Fine aggregates				
limonite	20.7	-	9.8	12.6
magnetite	4.0	29.2	-	-
portland cement	11.2	11.2	7.7	9.9
plastiment	0.1	-	0.1	0.1
Water*	6.0	5.3	0.58	0.58
w/c ratio*	0.54	0.47	0.58	0.58

* Initial values

Table 3.8.3-2.Physical and mechanical properties of limonite and magnetite high-density concrete

Property	Value		
	Age(d)	Limonite-iron	Limonite-magnetite
Density(g/cm^3)			
wet		4.27	3.44
hardened		4.3-4.5	3.58
Void volume(%)		-	1.3
Compressive strength(kg/cm^3)	7	337	276
	28	392	390
	90	-	460

The table above shows us that the properties of concretes made from different limonite and magnetite reserves will be slightly different from each other because of their different chemical compositions.

3.8.4.Barytes(Barite) concrete

Barytes concrete is made using barite ore, $BaSO_4$,as the heavy aggregate.With this aggregate concrete densities of around 3.58 g/cm^3 are obtainable.The main difficulty with this concrete is the procurement of the ore. Barytes concrete prepared by standard methods,has been used extensively in the construction of very high-activity cells and protective walls around accelerators and in biological shields for reactors.Since it has high density to begin with and its cost is relatively low,it has become a fairly extensively used shielding material.The behavior of barytes aggregates in concrete is similar to that of ordinary aggregates in standard concrete and no special problems have been encountered regarding the selection and proportioning of the ingredients of the concrete.[9] If a concrete of higher density is desired in certain cases,the barytes can be combined with everdenser aggregates,such as scrap and cast iron turnings, so that a wider range of heavy aoncretes is available.[10]

Lastly,for the purpose of effective shielding against neutrons,concrete based on barytes can be improved by the incorporation of aggregates containing water of crystallization,such as limonite or boron or in the form of calcium borate.

The physical properties are listed in table 3.8.4-1. [10]

Table 3.8.4-1.Physical and mechanical properties of barytes and barytes-limonite concretes

Property	Value	
	Barytes concrete	Barytes-Limonite concrete
Density(g/cm^3)	3.5	3.25
Specific heat ($gcal/g/^{\circ}C$)	-	~ 0.15
Compressive strength (kg/cm^2)		
age 7 days		264
age 28 days	253	
age112 days	295	
Shear strength (kg/cm^2)	60	56

More detailed explanations will be given about barytes concrete in the later sections,since the main subject of the thesis is barytes conçrete.

3.8.5.Special concretes based on barytes

It is definitely established that in the case of high gamma ray energies the efficiency of shielding is proportional to its concentration of high-density materials.This accounts for the interest developed to increase the density of the concrete based on barytes by using cast iron turnings or scrap in granular form.

Similarly,in view of the considerable role played by hydrogen in biological shielding,it has proved necessary to increase the hydrogen content of barite concrete by the incorporation of materials containing hydrated water. (e.g. limonite) without decreasing the density of the concrete.

3.8.5.1.Barytes concretes with the addition of scrap and cast iron

Metallic scrap from the processing industry is used as coarse aggregates to increase the density of concretes.For satisfactory homogeneity of the concrete, the percentage by weigth of scrap to be combined with the barite must not be less than 20% for a type of metallic aggregate whose limiting dimensions are between 10 mm and 35 mm.This specfications carries with it the implication that concretes of density higher than 4 g/cm^3,will be obtained by replacing the coarse barite aggregates by scrap. For desities of less than 4 g/cm^3,the barite sand is to be replaced by cast iron in granular form.Fig. 3.8.5.1-1 shows how the density of concrete varies as the barytes aggregate is replaced by iron scrap. [10]

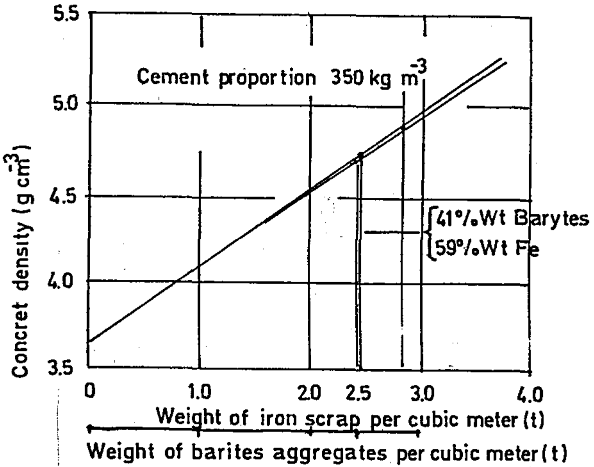


Fig.3.8.5.1-1 Density of heavy concrete made with barytes aggregate and scrap iron as a function of the amount of each ingredient

Table 3.8.5.1-1 summarizes the proportions of the various ingredients for the properties of several compositions of barite concrete with added minerals of iron.

Table 3.8.5.1-1. Composition and properties of barites concretes with other mineral and iron additives

Composition of property	Concrete Type				
	Barytes iron	Barytes iron	Barytes limonit	Barytes Colemanit	Barytes Pandermi
Density (g/cm^3)	4.5	4.9	3.36	3.3	3.33
Compositions(kg/m^3)					
Barytes sand, 0-2 mm	-	580	-	1070	280
Barytes sand, 0-3 mm	500	-	-	-	-
Barytes fine gravel, 2-7 mm		1100	-	-	700
Barytes fine gravel, 3-7 mm	700	-	-	-	-
Barytes gravel, 7-15 mm	780	-	1000	-	750
Barytes coarse gravel, 15-30 mm	-	-	960	1550	900
Scrap iron, 10-15 mm	2100	1000	-	-	-
Scrap iron, 15-30 mm	-	1800	-	-	-
Limonite sand, 0-2 mm	-	-	500	-	-
Limonite fine gravel, 2-5 mm	-	-	500	-	-
Colemanite sand, 0.5-2.5 mm	-	-	-	55	-
Pandermite, 0.5-2.5 mm					220
Cement	350	350	350	425	300
Water	120	110	130	185	180
Plasticizer(l/m^3)		1.75			
Compressive strength,					*
at 9 days	-	-	-	168	
at 28 days	515	350		309	

*Values are not reported

3.8.6.Iron-portland(scrap-based) very heavy concrete

Iron-portland concrete(also called scrap-based concrete) is concrete in which the aggregate is iron(steel) punchings and iron shot,used in combination with or without trap rock.Punchings are often combined with other heavy aggregates such as magnetite,barytes or limonite and sometimes with iron and steel tailings.Punchings other iron and steel waste occur during transformation processes such as production of nuts,iron fittings,gusset plates and iron work.The mainssources of steel waste are nut and bolt manufactures and factories in which punchings and tailings are likely to occur during production.

Densities as high as 6.0 g/cm^3 are attainable. Physical properties are summarized in Table 3.8.6-1 . [10]

Table 3.8.6-1. Densities and compressive strengths of several concretes developed for shielding use [17]

Concrete	Density g/cm^3	Compressive Strength kg/cm^2
Iron-portland	5.8-6.0	257 (age 32 days) 372 (age 91 days)
Colemanite-barytes	3.1-3.2	175 (after 6-day cure)
Boron frits-barytes	3.1	
Luminite-colemanite-barytes	3.1	246 (after 6-day cure)
Luminite-portland-colemanite-barytes	3.1	210 (after 6-day cure)

The most reliable method for investigating the grain size of scrap and iron-shot concrete is to ensure in advance a high density of metallic skeleton.This method is good only for a first approximation.For example,Fieselheiser [18] has found that the best density was obtained on the basis of 50% scrap and 50% shot.

For concretes like these, the optimum mixing formula and conventionally placed, as developed at SACLAY in France[10] is shown in Table 3.8.6.-2.

Table 3.8.6-2 .Compositions and desities of some iron-scrap-based concretes.

Ingredient or property	Saclay [10] Optimum composition	Feiselheiser [18]
Placement method	Conventional	Conventional
Aggregate composition, kg		-
Steel scrap, sizes 6-15mm	880	-
Steel scrap, sizes 15-30mm	2720	2820
Steel scrap, mixed total	3600	-
Steel shot No.100+	275	
Steel shot No. 50+	400	
Steel shot No. 40+	300	
Steel shot No. 16+	325	
Steel shot No. 12+	475	
Steel shot No. 0+	475	2820
Steel shot, mixed total	2250	
Mortar composition (kg)		
Portland cement	350	385
Plasticizer	1.75	122
Water	100	
w/c	0.28	0.32
Concrete wet density, g/cm^3	6.30	6.14

* amounts given for 1 m^3 of concrete

+ value included in the total

Metallic aggregates which are recovered from processing industrial wastes with their properties are shown in Fig.3.8.6-1

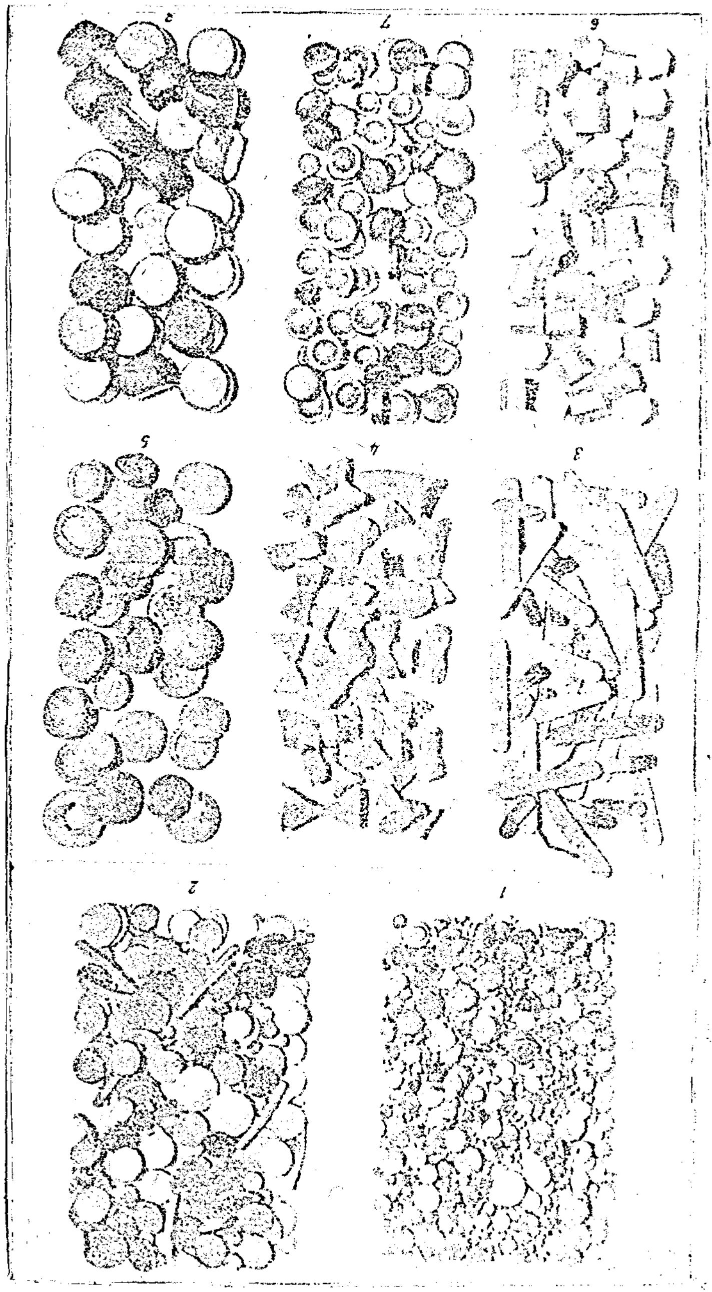


Fig.3.8.6-1. Metallic aggregates used in making heavy concrete

1 Fine scrap(dia = 6-12 mm),Densities(gcm^{-3}):bulk=3.55; compacted=4.40;lump=7.7.Void volume=43%.

2 Small punchings(dia = 4-20 mm),Densities(gcm^{-3}):bulk=3.49; compacted=4.31;lump=7.66.Void volume=44%.

3 Dexion angle punchings(thickness=2mm;width=10mm;lengths= 10,14 and 52mm),Densities(gcm^{-3}):bulk=3.27;compacted=4.04; lump=7.36.Void volume=46%.

4 Punchings from nut manufacture(thickness=15mm;width=20mm; length=35mm).Densities(gcm^{-3}):bulk=2.57;compacted=3.37; lump=7.54.Void volume=55%.

5 Stamp works punchings(dia = 25 mm;thickness = 7 mm).Densities(gcm^{-3}):bulk=3.41;compacted=3.87;lump=7.30.Void volume=47%.

6 Pieces from hexagonal billets(width=14mm;height=15mm), Densities(gcm^{-3}):bulk=4.19;compacted=4.88;lump=7.80. Void volume=37.5%.

7 Small stamp works punchings(dia=25mm;thickness=6mm),Densities(gcm^{-3}):bulk=3.4;compacted=3.9;lump=7.35.Void volume=47%.

8 Large punchings(dia=25mm;thickness=15mm),Densities(gcm^{-3}): bulk=4.23;compacted=4.91;lump=7.67.Void volume=36%.

3.8.7.Ilmenite concrete

Ilmenite concrete has been used in some reactor shields,mainly Canadian.[10] Ilmenite is an iron titanium ore,with the composition $FeO.TiO_2$.It is usually 12 to 15 % lighter than other iron ores,and thus the attainable concrete density is less.These type of concretes are an excellent gamma ray shield.However the ore is widely available in many areas of the world and is expensive.Its density is of the order of 3.5 g/cm^3.

3.8.8.Borated concretes

Boron may be added to ordinary and high density concretes in a variety of ways to enhance the thermal neutron attenuating properties of the concrete and to supress secondary gamma-ray generation.Other elements,such as iron, will capture thermal neutrons.A number of heavy concretes have been made and tested using boron containing ores or other additives in the aggregate.Colemanite($Ca_2B_6O_4.5H_2O$)is an ore of calcium and boron(containing about 18% boron) which may be used in conjunction with iron ores or barytes as the aggregate.Calcium borate is similar to colemanite and consists of up to 50 % B_2O_3.It is widely used,particularly in U.S.A.

Descriptions of several concretes made using colemanite as the aggregate or in the cement and boron frits in the cement,are given in Table 3.8.8-1,and their densities and compressive strengths are given in Table 3.8.8-2 .[17]

Table 3.8.8-1.Description of several borated concretes developed for shielding use.

Material	Description
Colemanite-Barytes	Boron in colemanite($2CaO.3B_2O_3.5H_2O$) acts as gamma supressor,but high solubility of colemanite retards initial set of portland cement;this concrete has higher density(3.1 g/cm^3) than ordinary concrete,high water content(6 to 8%),and 1% boron content
Boron frits-Barytes	Boron in boron frits acts as gamma supresor,and boron frit is less soluble than colemanite;thus,detrimental effect on initial set of portland cement is not so great;this concrete has higher density(3.1 g/cm^3) than ordinary concrete,medium water conten (5%) and 1% boron content.

Lumnite-Colemanite-Barytes	As an alternate to using portland cement in barytes-colemanite concrete, lumnite was used and found to retard initial set of cement only slightly; this concrete has higher density (3.1 g/cm^3) than ordinary concrete,high water content(9.3%) and 1% boron content; curing methods were unsatisfactory.
Lumnite-Portland-Colemanite-barytes	Portland cement usually accelerates initial set of lumnite,but addition of colemanite counter balanced this effect; this concrete has higher density(3.1 g/cm^3)than ordinary concrete,high water content (8 to 10 %) and 1% boron content.

Table 3.8.8-2.A summary of the densities and compressive strengths of concretes containing colemanite as an aggregate

Concrete Type	Colemanite (wt %)	Density (g/cm^3)	Compressive Strength (kg/cm^2)
Barytes-colemanite^{a,b}	7.1	3.2	176
Barytes-colemanite^{c,d}	1.7	3.3	309
Lum-Colem-Barytes	6.4	3.1	237 (e)
Lum-Port-Colem-Bary	6.5	3.1	211
Colemanite-iron	5.35	5.35	1150 (f)

(a) U.S. data

(b) Colemanite added as gravel

(c) French data(SACLAY

(d) Colemanite added as a fine sand

(e) Six days compressive strength

(f) Value appears high

3.8.9.High temperature concretes

Ordinary concrete can not be used for neutron shielding at high temperatures exceeding 93°C because the water necessary for the nuclear shielding properties is lost above this temperature.However,the mineral serpentine,$3MgO.2SiO_2.2H_2O$ keeps its hydrated water to temperatures exceeding 482°C and may be used as the aggregate in concrete.Lumnite cement also is stronger than portland cement for high temperature use,see sec.3.7.2.

3.9.Design criteria

The first step in any reactor shield design is to establish the design criteria.These include the limitations imposed on radiation intensities in various parts of the reactor plant.Limitations that must be considered are:(1) allowed biological dose rates,(2) effects of nuclear heating, (3) neutron-induced activation of components or equipments, (4) radiation damage effects,(5)mechanical criteria e.g.necessary expansion,movement and structural limitations,and (6) environmental restrictions.For concrete shields,limitations 2 through6 above effet the use of concrete and the added protection which must be designed in the reactor plant to meet the set limitations.

The following design criteria are recommended for use in the design and construction of concrete shields.[19] These standards followed will adequately protect concrete against loss of water,temperature effects,radiation absorption effects and stress conditions.

Temperature limitations are given in Table 3.9-1.

Table 3.9-1.Ordinary and heavy Concrete shields

Neutron shields	
Maximum internal temperature	88°C
Maximum ambient air temperature	71°C
Gamma ray shields	
Maximum internal temperature	177°C
Maximum ambient air temperature	149°C

First of all the concrete engineer must have a knowledge of the required nuclear performance characteristics of the shield,to undertake the physical design.Secondly he must be aware of and take into account the nuclear and physical environmental conditions underwhich he is to mix and place his shield and underwhich he must operate satisfactorily for a thirty-to-forty year lifetime.Thirdly,he must pick and choose his raw materials very carefully,know their physical characteristics and how they react with each other during mixing,setting and curing.Fourthly he must consider all these factors together in this development of the final concrete proportioning,so that the end product will be the best shield possible consistent with recognized safety standards.

Poor concrete work,once done,is hard to undo. Unsatisfactory mixes can not be tolerated.If any defective concrete results,it must be replaced or repaired to bring it up to minimum standards.

4. THE ADMIXTURE EFFECT ON THE CONCRETE SHIELDING

4.1. Introduction

Concrete admixtures are indispensable aids in the preparation of concrete used for the construction of nuclear power stations because they make it possible to improve one or several major properties of the concrete.

Since individual building units of nuclear power stations require large volumes of concrete, it will be of interest to discuss concrete admixture in general.

It is not our purpose here to pass in review of all the concrete admixtures which are in use in the construction industry today.

4.2. Plasticizer

Plasticizers are admixtures which improve the workability of concrete, reduce the amount of water needed for mixing and improve the mechanical strength characteristics of concrete by reducing the water-cement ratio while maintaining the usual characteristics of the concrete mix. In addition, they improve the impermeability of concrete. Plasticizer is effective even in low concentrations. The concrete's adhesion to reinforcing steel is also improved.

Plasticizers are used primarily for structural concrete in building construction, in prestressed concrete; in prefabricated building elements requiring sound exposed surfaces of optimum resistance and long durability.

The dosage of plasticizer (Plastiment) is between 0.3% and0.5% of the cement weigth. [20]

4.3. Retarders

Retarders are concrete admixtures which, depending on dosage, ambient temperature of concrete, type of cement and water-cement ratio, will inhibit the setting of concrete by periods raniging from a few hours to a few days. The concrete will set more slowly, so that more time can be allowed for transport, unloading, casting and compaction. This is of particular importance for ready-mixed concrete, which must often be carried to the construction site over a long distance or is intended for the casting of large units, such as foundation pavements, ceilings of large halls, beams, retaining walls, etc. Such structures are generally built without joints. The concrete is cast in layers containing diminishing doses of retarder, with one layer being vibrated together with the following. By using retarder, the concrete can be re-vibrated.

The dosage of retarder is between 0.2% and2% of the cement weigth. [21]

4.4.Waterproofing agent-Plastocrete

A waterproofing agent is a normal setting admixture intended primarily for the protection of waterproof and frost-resistant concrete. Its effect is based on the reduction of the capillary volume and the interruption of the capillary flow through the introduction of micro-pores.

Plastocrete is the additive in cases where impermeability of maximum degree is required. It is especially suitable for slender, heavily reinforced concrete structures standing in water, for reservoirs, foundations, building elements exposed to weather and frost, as well as for underwater and powerplant constructions in general.

The dosage of waterproofing agent is 0.5 % of the cement weigth. [22]

5.SHIELDİNG MATERIALS IN TURKEY

5.1.Introduction

Among the various subjects related to reactor shielding the provision of shielding against the gamma rays and the detailed studies on this subject have been given in the above chapters.

If we make a comparison in different subjects of the shielding materials,concrete is the one which has the highest priority (for gamma shielding) between the others.The characteristics such as;cheaper cost;easy placing and high water content etc.are the reasons to choose concrete in shielding against nuclear radiation.Ordinary concrete can be obtained by mixing coarse aggregate,fine aggregate and cement.But heavy concrete can be obtained by using various heavy ores as aggregate materials.Heavy concretes provide sufficient efficiency for different purpose of shieldings.

Detailed information on this subject can be found in the previous chapters.

The samples of barytes concrete which are the subject of this study(thesis) have been prepared in the National Water Affairs Research Laboratories (DSI).The experiments of the samples of baryte concretes (with or without additives)against the gamma rays have been made by using narrow beam conditions which are well collimated.

Linear attenuation coefficients for barytes concrete (with or without additives) have been experimentally determined by using the Nuclear Laboratory of Ministry of Defence,Research and Development Department.Further the result of experiments have been compared with literature values.

5.2.Shielding material reserves in Turkey

As shielding materials the following are used: ordinary concrete,heavy concrete,very heavy concrete and water as described in the preceeding sections.

Turkey has great reserves of mineral ores to be used as shielding materials;e.g.magnetite 240.000.000 tons, limonite 18.113.000 tons,hematite 140.000.000 tons and baryte is also over 20.000.000 tons.The potential of boron minerals is over 600.000.000 tons.

It can obviously seen that our country isa country very rich in shielding materials.[16]

5.3.Baryte aggregate investigations

The good Turkey barytes can be obtained from mines at Antalya,Elazığ and Bandırma.Beyşehir/Konya is another source of Turkey baryte.Muş-bilir is the best source of this ore today.

According to Ref.16,some more important deposits can be listed in Turkey.

Samples of heavy aggregatesused in this research were from Beyşehir.Table 5.3-1 gives data on the barytes used in this research.

Table 5.3-1.Certificate of complete analysis of baryte ore of Beyşehir/Konya origin(1).

	wt %
Barium sulphate	97.25
Strontium sulphate	2.37
Ferric oxide	0.046
Silica	0.15
Calcium	0.006
Fluorine	0.013
Lead less than	0.002
Zinc less than	0.002
Specific gravity	4.45 g/cm^3
Conductivity	1.35x10^{-4}
Moisture dried at 105°C	Nil

(1) The values in the table are obtained from Etibank.

Table 5.3-2.Physical properties of barite aggregates.(More deatil about tests is given in app)

Aggregate size	Specific gravity g/cm^3	Absorbtion (%)	Sodium sulphate			Organic color	Los Angeles Abrasion	
			Grading (%)	Actual loss (%)	Weighted loss(%)		Loss at 100 rev	Loss at 500 rev
No.4 to 3/8 in	4.15	0.4	41.3	2.1	1.0		25.1	74.9
3/8into 1/2 in	4.13	0.4	20.3	6.9	1.3			
1/2into 3/4 in	4.14	0.4	38.4	9.5	3.6			
			Total		5.9			
Sand F.M. 2.71	4.02	1.4			13.8	Clear		

Table 5.3-2.Physical properties of barite aggregates
(More detail will be given about tests in App.)

Sand grading percent:

Pan	No.100	No.50	No.30	No.16	No.8
	6.0	8.1	14.3	26.7	20

Coarse aggregate grading percent:

No.4-3/8 in	No.3/8-3/4 in
40	60

Sand percent:50

The results of physical properties tests of the barite are shown in Table 5.3-2.

Sodium sulphate resistance of the fine aggregate is low and meet TS 706 (Turkish standard) requirement.On the other hand,resistance of the coarse aggregate is not high according to TS 706,an indication that,in all probabilities concrete containing this aggregate will be suitable for use for exposition to freezing-thawing action.

Ordinarily,TS 706 specifications for the Los Angeles abrasion test require that acceptable coarse aggregate shall not loose more than 10% in 100 revolutions or more than 50% in 500 revolutions.The high losses of 25.1% and 74.9% respectively can be seen in barite aggregates.Table 5.3-2 indicates that an abnormal amount of breakdown will occur during handling and processing,and probably during mixing.

5.4.Conventional barite concrete

As stated in previous sections,the minimum requirement of the barite concrete were a workable mix(slump 5 to 9 cm),a minimum compressive strength of 210 kg/cm^2 at 28 days,and a minimum density 3.5 g/cm^3 at the same age. In making barite concrete,it is not difficult to meet the requirements of that specification.

From the same test,it was found that aggregate grading when held within practical limits had little effect on the desired concrete properties other than that of workability.Also the use of a plasticizer and a plastiment was found to increase density and benefit workability,without detrimentally effecting the other properties of the concrete. A summary of several properties is given in Table 5.4-1.

Table 5.4-1. A summary of the composition and properties of the mixes of barite concretes (3x6 in. cylinders)

Composition number	1	2	3	4	5	6	7
Ingredient or property							
Composition by (dry) weigth(kg/m^3)							
Barite sand	630	630	630	630			
Barite fine gravel	770	770	770	770	1070	1070	-
Barite gravel	1070	1070	1070	1070			
Barite coarse gravel	800	800	800	800	1550	1550	1870
Colemanite	-	-	-	-	40	40	-
İzmir Karaçalı sand	-	-	-	-	-	-	877
Concrete plasticizer	-	0.600	-	-	-	-	-
Waterproofing agent	-	-	-	1.5	-	-	-
Retarders	-	-	3	-	-	-	-
Cement	300	300	300	300	425	300	300
Water	157	150	150	143	157	150	136
W/c ratio	0.52	0.50	0.50	0.44	0.52	0.50	0.45
Density (g/cm^3)	3.410	3.420	3.404	3.436	3.319	3.339	3.019
Air %	1.1	1.5	1.2	1.5	1.1	1.1	1.5
Slump (cm)	5.5	5	5	5	9	3.5	5
Compressive strength (kg/cm^2)							
after 7 days (1)	110	120	116	127	175	94.50	187
after28 days (1)	160	178	155	166	232	75	246

(1) This value is the average of three samples.

The selected barite rock, crushed to sand and gravel (3/4 in maximum) sizes; portland cement produced in Yozgat are used in all concrete mixes. The chemical composition and phy physical properties of cement used is given in Table 5.4-2.

Table 5.4-2. Chemical and physical properties of the cement used in concrete mixes.

Date of report: 30.5.1980

Report of Chemical Analysis and Physical Tests of Cement

Name of sample: Yozgat cement   Lab.No. : 344

CHEMICAL ANALYSIS	%	PHYSICAL TESTS	
SiO_2	22.8	Density(g/cm^3)	3.08
Al_2O_3	7.4	Sieve analysis	
Fe_2O_3	2.6	on the 200 sieve(%)	0.3
CaO	58.2	on the 90 sieve(%)	8.1
MgO	3.4	Specific surface(cm^2/g)	
Mn_2O_3	-	with Blaine apparatus	2715
SO_3	2.5	Initial setting time(hr)	$2.^{\underline{50}}$
Combustion losses	1.6	Final setting time (hr)	$3.^{\underline{70}}$
Insoluble residue	7.0	Compressive strength(kg/cm^2)	
Na_2O+0.658 K_2O	0.75	after 7 days	237
		after 28 days	325
		Breaking strength(kgf/cm^2)	
		after 7 days	46
		after 28 days	61
		Change in cement volume total expansion(c-a),(mm)	4

Note: This cement meets the requirements of TS 19.

Mineral borocalcite is a calcium borate similar to colemanite, and containing 52% B_2O_3 in its pure form. It has been u used as a boron additive in two types of concretes shown in Table 5.4-1. The colemanite ore used in bothsshield (column 5 and 6) was about 43.30 percent B_2O_3.

Colemanite (Calcium borate,$Ca_2B_6O_{11}\cdot 5H_2O$),often found in boron containing materials are detrimental to the setting of portland cement concrete.The effect of colemanite on the setting time was not severe and surprisingly was less than for barite.At the same time the colemanite reduced the strength of concrete.

5.5.Radiation source and the experiment

The experimental set-up consists of the following main parts: 3x3 in.NaI(Tl) scintillation detector,a linear amplifier and a 4096 channel PHA.Thin concrete blocks of 200x100x50 mm,were prepared by using barite aggregates instead of ordinary aggregate.In order to fixed experimental conditions,a bar in 600mm length,placed between the source and detector.The shape of the experimental set-up is given in Fig.5.5-1

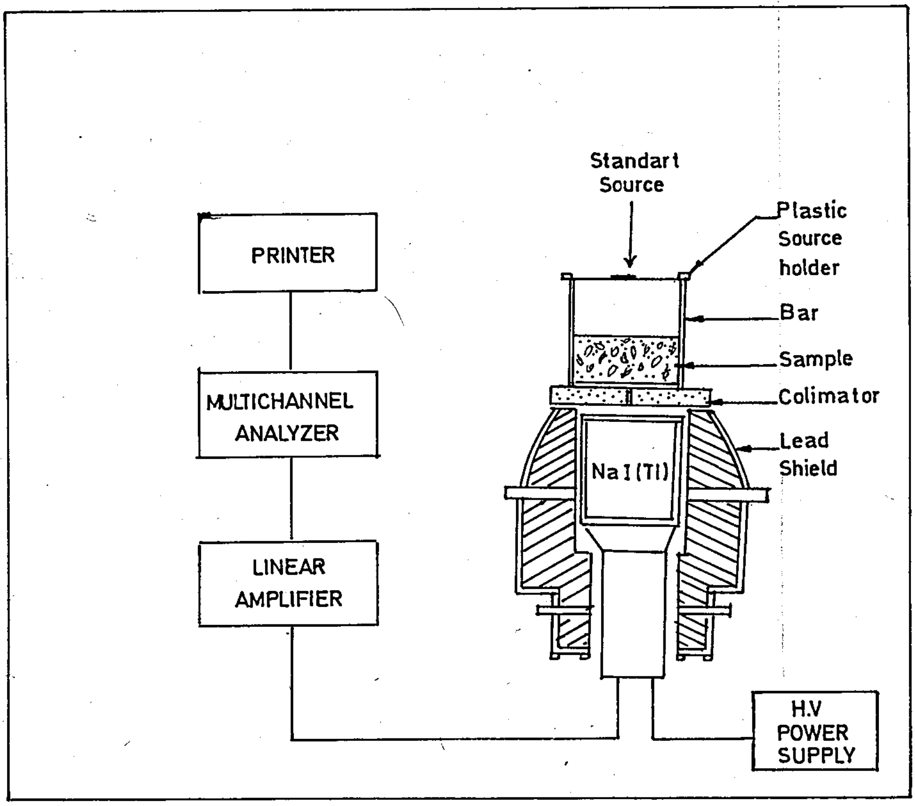


Fig.5.5-1. Experimental set-up

The gamma ray spectrum of the Co-60 (1.17-1.33 Mev) and Cs-137 (0.662 Mev) were taken using experimental apparatus for each of the concrete block.The counting time was chosen as 600 sec for each spectrum.

To find the attenuating factor,the least squares method was applied to Eq.(1.3.2-2) by a computer program.

Further more Am.Be. fast neutron source was used. These fast neutrons were attenuated in the range of water thickness of 7 cm.All tests were done again by using detector filled with BF_3 gas and the counter.The counting time was chosen as 300 sec. for the Am.Be.Attenuation factors for neutrons was then calculated.

A summary of the results obtained is given in Table 5.5-1 and data lists are given in Appendix **5**.

Table 5.5-1.Asummary of the results obtained

Energy (Mev)	Samples						
	1	2	3	4	5	6	7
0.662	0.2280	0.2108	0.2240	0.2316	0.2014	0.1983	0.2006
1.173	0.1112	0.1136	0.0623	0.0868	0.1184	0.1235	0.1413
1.332	0.1336	0.0871	0.0840	0.0972	0.1142	0.1061	0.1339
10^6neut.(1)	0.1186	0.1107	0.1089	0.1023	0.2316	0.1258	0.2476

(1)Neutron output of source:n/s.Ci^{-1}

6.SUMMARY AND CONCLUSIONS

The selected barite contained 97.25 percent barium sulphate,had a specific gravity of 4.45,and other chemical properties were suitable.It is a relatively soft mineral with numerous fractures which are practically or completely filled with materials composed of the fine barite, clay,calcium,ferric oxide and silica.As the aggregate size is reduced by crushing,the fractures become fewer and less apparent since the barite breaks along these planes of wakness.The effect of fracturing is reflected in the abrasion. On the basis of these tests(Table 5.3-2) barite is definitely not of first quality for use as concrete aggregate.It was found to be satisfactory in the remaining tests performed (Tables 5.3-1,-2,5.5-1) and since the concrete developed adequate strength and density,the barite was considered acceptable.

Table 5.4-1 gives a summary of results of tests on various concretes.Barite behaves similarly as crushed aggregates commonly used for making concrete.

A conventional barite concrete(Mix 1,Table 5.4-1) containing 3/4 in.maximum size aggregate of 1:4.6:6.2 parts and having a water-cement ratio of 0.52 all by weigth was satisfactorily workable,and produced a minimum compressive strength of 160 kg/cm^2 at 28 days.

The ingredient of the other mixes were summarized in Table 5.4-1 .

Concrete made with barite aggregate of 3/4 in. maximum size,when fog cured for 28 days developed high compressive strengths such as 246 kg/cm^2 for water-cement ratio of 0.45.The results of compressive strength test had shown that it will be better the use of ordinary sand instead of barite sand.

The linear attenuation coefficients for some concrete types are given in Table 6-1 from literature.The linear attenuation coefficients are given for three different energies gamma rays.The comparison of ordinary and barite concretes with concretes in Table 6-1 shows that the ordinary and barite concretes can be used for shielding against gamma rays.

A general evaluation for use of other heavy metal minerals as aggregate(hematite,magnetite and limonite) can be done after examining the gamma ray shielding properties of heavy concretes made with these aggregates.

Table 6-1. Total gamma ray linear attenuation coefficients (cm^{-1}) of concretes [10]

Type of concrete	Density	0.5 Mev	1 Mev	2 Mev
BA-OR(1)	3.30	0.2964	0.2030	0.1436
I-1a (1)	3.50	0.2997	0.2173	0.1535
I-1b (1)	3.39	0.2902	0.2103	0.1486

(1) Composition not reported

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TS 706 ,TS 707,TS 802,TS-687-TS 192 TS 24

APPENDIX 1

A.THE ATTAINMENT OF MAXIMUM DENSITY

In order to obtain a dense concrete with the maximum density,the largest possible amount of coarse aggregate per unit volume of concrete should be used;the size of the coarse aggregate should also be as large as is permitted by the cross section of the structure under construction,the arrangement and amount of reinforcement and inserts and the conditions of mixing.Its granular composition should meet the requirements of screening curves in accordance with publicized standards.

The densities of special(heavy or hydrated) vibrator compacted concretes,determined immediately after preparation,are derived from the data in Table A.1-1.

Table A.1-1.Density ranges of various types of concrete

Type of concrete	Density(t/m^3)	
	Minimum	Maximum
Ordinary(portland) concrete	2.3	2.4
Limonite concrete	2.3	3.0
Magnetite concrete	2.8	4.0
Iron-portland concrete(a)	3.7	5.0
Concretes with limonite sand		
-and normal aggregates	2.4	2.6
-and barytes aggregates	3.0	3.2
-and magnetite aggregates	2.9	3.8
-and metal scrap	3.6	5.0
Serpentine concrete with iron shot and boron carpide	3.5	4.0

(a) Scrap-based concrete

The composition, strength and placeability of a special heavy concrete with a particular density are calculated as follows:

The quantity of cement required per m^3 of concrete is calculated from the selected cement/water ratio. (c/w) and the water consumption W per m^3 of concrete by

$$C = c/w \cdot W \qquad (A.1-1)$$

From the known values of the water and cement consumptions per m^3 of concrete and the required density of the concrete it is possible to calculate the necessary amount of aggregates A per m^3 of concrete to give the required density of vibrator-compacted concrete:

$$A = V \; - (c+w) \qquad (A.1-2)$$

where V is the concrete weight per m^3.

The calculation of the total weight of aggregate per m^3 is broken down to the weight of fine and the coarse aggregate as follows. The content q' of fine aggregate, assuming that the grains of fine aggregate do not seperate the grains of coarse aggregate, is calculated by the equation

$$q' = \frac{(1+b)\;_f}{\;_c + (1-b)\;_f} \qquad (A.1-3)$$

Here

b the volume fraction of coarse aggregate (= $_c / {}'_c$);
$_c'$ crystalline specific gravity of the coarse aggregate;
$_f$ apparent specific gravity of the fine aggregate;
$_c$ apparent specific gravity of the coarse aggregate.

The apparent specific gravity of the coarse aggregate is determined in the vibration-compacted state.

The value of q' calculated by Eq.(A.1-3) is increased by 0.1, and the density of the concrete is then calculated from the q value obtained and the previously-established values of A, C and W.

If the designed density of the concrete does not exceed that prescribed by more than 10 %, this composition is accepted and a trial batch is made up. If on the other hand, the density exceeds the prescribed figure more than 10 % the necessary correction is effected by changing the amount of coarse aggregate, and the trial batch is then repeated. Reduction of the density of special heavy concretes below the prescribed figure is not permitted.

The strength of the concrete made from local materials should be experimentally checked and relationship between compressive strength and the cement-water ratio established.

During the mixing of the trial batch the index of stiffness (using a technical viscometer), the slump and density are determined in accordance with the applicable standards. The amounts of material per m^3 of concrete are corrected in the light of density. During determination of the index of stiffness, the sufficiency or excess of sand in the mix is established by external inspection, and the composition is corrected by reducing the sand content to the minimum possible without causing seperation of materials or imporing is put into production.

B. EXAMPLE OF A CALCULATION OF DENSITY FOR A VERY HEAVY CONCRETE

The problem is to calculate the composition of a vibrated concrete based on portland cement with a strength of 400 kg/cm^2 and dense magnetite chippings with hardening under natural conditions. The prescribed slump is 2 to 3 cm. The strength of the completed concrete is set at 200 kg/cm^2.

Let R_δ be desired strength of the concrete to be used in kg/cm^2,and R_c be the strength of the hardened cement to be used (no aggregate) in kg/cm^2.Let c be the weight of cement to be used and W the weight of water used(c/w therefore being the cement-water ratio).Then the formula

$$R_\delta = 0.55R_c(c/w - 0.5) \quad \text{kg/cm}^2 \qquad (B.1-1)$$

can be used to determine approximately the cement-water ratio giving the required strength for well-compacted vibrated concrete based on normal dense stone chippings,baryte aggregate in lean compositions(by weigth) of not less than 1:12,magnetite aggregates in lean compositions of 1:8,and limonite sand with a coarse aggregate in the form of scrap iron or hard rock chippings.
From Eq.(B.1-1) we find

$$\frac{c}{w} = \frac{R_\delta}{R_c.0.55} + 0.5 = \frac{200}{400x0.55} + 0.5 = 1.41$$

Fig.B.1-1 contains a curve intended to facilitate the calculation for selecting the required cement-water ratio for a cement strength R_c=400 kg/cm^2,with the upper line referring to Eq.(B.1-1)[10]

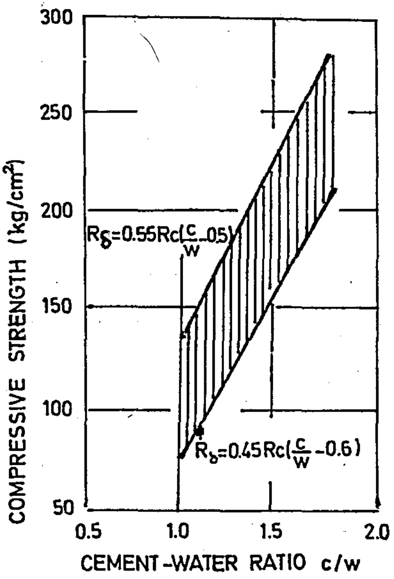


Fig.B.1-1.Dependence of the compressive strength of concrete on c/w,for cement with a strength of 400 kg/cm^2

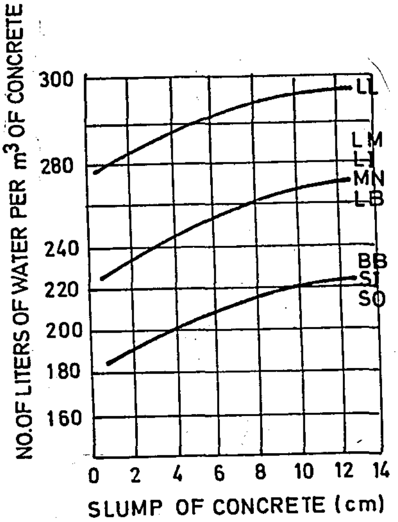
For richer compositions using magnetite aggregates(richer than 1:8),and also for concretes based on limonite aggrerates,on limonite sand with a coarse aggregates in the form of magnetite or baryte chippings and on normal sand and scrap iron.The approximate strength of the concrete should be calculated by the formula

$$R_\delta = 0.45R_c(c/w - 0.6)\ \text{kg/cm}^2 \qquad \text{(B.1-2)}$$

A typical value of R_c is 400 kg/cm^2.
The lower line in Fig.(B.1-1) shows the dependence of R_δ on the cement-water ratio for a cement strength R_c=400 kg/cm^2, with the lower line referring to Eq.(B.1-2).The strength of the cement is determined from the results of tests with stiff mortars.

Taking from Fig.(B.1-1) the average value in the shaded area for R_δ = 200,we find that c/w = 1.55 .

The approximate water consumption per m^3 to give the required mobility,determined by the slump of a standard cone,of a mix based on 400 kg/cm^2 strength portland cement is determined from the graph in Fig.B.1-2.[10]



Key:First letter:Fine agg.
Second letter:Coars agg.

L :Limestone, M :Magnetite
I :Iron scrap, B :Barytes
O :Trap rock, S :Ouartz sand

Fig.B.1-2.Amount of water required per cubicmeter of concrete to produce concrete with a desired slump

In Fig.B.1-2 we find from the curve for dense stone chippings that to obtain a 2 to 3 cm slump we must use 170 lt of water per m^3 for concrete based on dense magnetite chippings.

The desired weigth V of the freshly-placed magnetite concrete is 3 t/m^3 or 3000 kg/m^3.

The cement consumption will be:

$$c = w \frac{c}{w} = 170x1.55 = 263 \text{ kg}$$

The consumption of aggregates per m^3 of concrete per m^3 of concrete will be

$$A = V - (c+w) = 3000-(263+170)$$
$$=2567 \ kg/m^3$$

We calculate the fine aggregate content by using Eq.(A.1-3), knowing that

$'_f$ =crystalline specific gravity of fine aggregate =4;
$'_c$ =crystalline specific gravity of the coarse aggregate =4.35;
$_f$ =loose density of the fine aggregate =2.4 g/cm^3;
$_c$ =loose density of the coarse aggregate =2.5 g/cm^3;
b =volume fraction of coarse aggregate =2.5/4.35 =0.58

we have

$$q' = \frac{(1,b)\ _f}{_c + (1-b)\ _f} = \frac{(1-0.58)(2.4)}{2.5+(1-0.58)(2.4)} = 0.28$$

Adding 0.1 we find that q=0.38

Thus, the composition of magnetite concrete to meet the specified requirements will be :

Cement	263 kg
Water	170 kg
Fine aggregate	975 kg(2567x0.38)
Magnetite chippings	1592 kg(2567x0.62)
Total weight	3000 kg

This represents the required weigth in the freshly-prepared state.

The calculated composition must meet the three requirements of strength, slump and prescribed density.

In a test checking the calculated compositions employing dense magnetite aggregate, the following results were obtained on various compositions, as shown in Table B.1-1

Table B.1-1. Results of tests made on various mixes of magnetite concrete (a)

Cement water ratio	Index of placeability (technical viscosity s)	Density (t/m^3)	Amount of basic material used (kg/m^3) Cement	Water	Compressive strength (kg/cm^2)
1.73	15	2.98	315	183	203
1.88	30	3.0	280	149	253
1.52	30	2.95	230	152	194
1.62	50	2.92	230	143	228
1.59	30	3.0	230	146	229
1.66	50	3.0	230	140	239

(a) Tests performed by the third auther of the ref.[10]

The strength values lie in the shaded area of Fig.B.1-1, therefore to obtain 200 kg/cm^2 strength as required, the cement-water ratio used should be between 1.5 and 1.7, depending on the slump required of the mix.

C.RECOMMENDATIONS FOR MIXING AND PLACING VERY HEAVY CONCRETES

1. The materials used for very heavy and hydrated concretes must comply with the requirements of sec.3.8

2. A concrete mix laid in a very thick structure with few inserts, tubes and openings should have a 0 to 2 cm slumps, while in other structures the figure should be 2 to 4 cm.

3.The mix should normally be prepared in gravity mixtures.

4.Mixes based on scrap iron,serpentine,magnetite or limonite are more difficult to prepare in a mixer and the mixing time should therefore be increased,mixing time should not be less than 4 minutes,the optimum time being established by experience.

5.In order to prevent the breakdown of mixes due to overloading,the volume of the batch should be reduced in inverse proportion to the density of the mix used,taking that the normal concrete as 23000 kg/m^3.For example,for a heavy concrete with a designed density of 3.2 g/cm^3.The nominal volume of the batch for a mixer of 500 liter capacity should not exceed

$$\frac{500x2.3}{3.2} = 350 \text{ L.}$$

It is recommended that in the case of drum mixers the batch should not be reduced by more than 25 %.

If a heavie r batch is used,a more powerful motor should be used in order to insure the correct number of revolutions in the drum.

6.The forms receiving the concrete should be designed for the higher pressure exested by vibrated concrete based onsheavy aggregates.The pressure within the radius of action of the vibrator is equal to the hydrostatic pressure from the compacted freshly-placed concrete plus the additional pressure caused by dumping the batch in to the forms.

7.Concrete based on heavy aggregates should be transported using tubes with openings in the bottom or in the truckmounted mixers.The use of belt and vibration transporters or other means of transport leading to seperation of the mix should not be permitted for heavy aggregate concretes.The free fall of the mix should not exceed 1 m.

8.Heavy concrete should be placed and compacted using vibrators,care being taken that seperation does not occur during placing.The mix must not be placed by hand.If seperation occurs during placing accompanied by the appearance of excess cement mortar and grout on the surface.The cause of this should be eliminated at once and the concrete already placed should be rectified by adding coarse aggregates and vibrator compacting them.Stiff concrete mixes are less subject to seperation and should therefore be preferred to high slump mixes,but in this case proper compacting of the concrete must extend throughout the shielding,and in particular around inserts,tubes and openings.

9.Limonite sands should be used to increase the viscosity of the mix instead of normal sands,as they have 10 to 15 times greater viscosity.For the same purpose betonite clay can also be added to normal mortars in amount not exceeding 1% of the weigth of the sand or blast-furnace dust. 10.The use of limonite sands and additives to increase viscosity and reduce seperation makes compact placement of the concrete more difficult.In order to facilitate placement while avoiding seperation of the materials,it is advisable to use plasticizing cements or additives.

11.The slump of mix in this case should be between 2 and 4 cm.The use of stiffer mixes with zero slump is recommended for shielding of great thickness with few inserts tubes or openings.

11.The mix can be delivered to the point of placement by tubing,vibrating or not provided that the mix fills the whole cross section of the tube.

12.Heavy-aggregates mixes should be placed in horizontal layers with careful compaction of each layer preferably by internal vibrators;the depth of each layer should not be greater than the length of the vibrator element.The structural joints in the concrete should be horizontal with aggregate protruding on the surface by half its diameter.

13.Limonite aggregate mixes absorbe moisture to a certain extent and then lose it again easily during vibrator compaction,causing seperation of the layers.An excess of water should therefore not be added to limonite concrete mixes.

14.The thickness of concrete placed by normal means should not exceed 200 mm if the layer is treated with surface vibrators.

15.When a mix is vibrator-compacted,complete homogeneity of the concrete should be insured both through the depth of each layer and horizontally.

16.The prepacked concreting method is permissible for the construction of shielding from very heavy and hydrated concretes only if the mix is pumped into previously placed and compacted aggregate under special conditions by experts in the field.

17.If the shielding is to be assembled from blocks,it is advisable to prepare the blocks on platform vibrators,preferably having to frequencies,(Frequencies of 3000 and 600 vib/min at amplitudes of 0.4 and0.15 mm respectively)which insure more homogenous concrete throughout blocks of up to 600 to 700 mm in thickness.Single frequency vibrators operating at 3000 vib/min and an amplitude of 0.5 mm are suitable for treating low slump(2 to 4 cm) mixes if the block isnot more than 250 to 300 mm thick.

18.In work with serpentine or limonite concrete with added shot and boron carbide,the mixes used should not have a technical viscosity index of less than 25 seconds, and the amount of mixing water should not exceed 285 kg/m^3 for concrete with a shot content in the aggregate mixture of approximately 55 wt %.

19.It should be born in mind that the addition of boron carbide retards hardening of the concrete during the first 3 to 7 days,after which hardening proceeds normally, Large additions of boron carbide (up to 30 %) impair placeability.

20.Calcium borate dihydrate has no effect on the setting time of the cement.

21.In order to insure the greatest possible amount of bound water,concrete shielding should be kept moist for the greatest length of time permitted by the conditions of installation,whether cast in situ or constructed of ready-made blocks.

APPENDIX 2

A.STANDARD SPECIFICATION FOR CHEMİCAL ADMIXTURES FOR CONCRETE

A.1.Scope

According to ASTM,there are five types of admixtures as follows:

a) Type A - Water reducing admixtures
b) Type B - Retarding admuxtures
c) Type C - Accelerating admixtures
d) Type D - Water-reducing and accelerating admixtures
e) Type E - Water-reducing and accelerating admixtures

A.2.Definitions

2.1.Water reducing admixture

An admixture that reduces the quantity of mixing water required to produce concrete of a given consistency.

2.2.Retarding admixture

An admixture that retards the setting of concrete.

2.3Accelerating admixture

An admixture thataccelerates the setting and early strength development of concrete.

2.4.Water-reducing and retarding admixture

An admixture that reduces the quantity of mixing water required to produce concrete of a given consistency and retards the setting of concrete.

2.5.Water-reducing and accelerating admixture

An admixture that reduces the quantity of mixing water required to produce concrete of a given consistency and accelerates the setting and early strengtn development of concrete.

In this appendix extra information about the admixtures we used is given,as they are advertised by their producers

A. PLASTIMENT BV.40

Plastiment BV.40 is an admixture ready to use on a basis of lignin sulphonate. Plastiment BV.40 is non-toxic non-inflammable and contains no chloride.

Dark brown liquid with a specific gravity of 1.2 kg/lt.

Its properties improves workability, makes considerable water reduction, increases strength at equal workability. It is used advantageously whenever high quality concrete is required; workability must be imroved; high-quality exposed concrete surfaces are of importance; placing conditions are difficult.

The dosage of plastiment BV.40 is between 0.2% and 0.5 % of the cement weight, at 0.3% the normal efficiency can be obtained.

B. PLASTOCRETE-N

Plastocrete is an admixture ready to use on a basis of lignin sulphate. Plastocrete is an waterproofing agent which is an additive in cases where maximum impermeability is required.

It is especially suitable for slender, heavily reinforced concrete structures standing in water, for reservoirs, foundations, building elements exposed to weather and frost, as well as for underwater in general.

Plastocrete-N gives the following properties to the concrete:

-Better waterproofing, frost resistance
-Workability of fresh concrete
-Maintenance of high strength
-Normal setting time

The dosage of plastocrete-N is the 0.5% of the cement weigth.

C. RETARDER

Retarder is a an agents which retards the setting time of phosphate basis.

It is non-toxic and inflammable. It gives the following properties to the concrete.

- Longer setting time
- Quicker hardening time after setting
- Higher final strength
- Plastigication of the fresh concrete

Retarder is used in the concrete production when a time delay is necessary and when the repeated vibration is required.

It is a liquid and the dosage is the 0.2% to 2% of the cement weigth approximately.

APPENDIX 3

STAHDARD DESCRIPTION NOMENCULATURE OF CONSTITUENTS OF AGGREGATES FOR RADIATION SHIELDING CONCRETE

A.Types of materials

There are two classes of materials which were described in the preceeding sections.

The first class consists of minerals and rocks formed from them,and synthetic materials,that high specific gravity and in addition contain substatial proportions of atoms of high or moderately high atomic weigth.They are referred to as heavy or high density aggregates.The second class consists of minerals and synthetic glasses of substatial boron content that are particularly effective in absorbing thermal neutron without producing highly penetrating gamma rays.The boron frit glasses are included because of their frequent use.

B.Heavy aggregates

Members of this group have higher specific gravities than aggregates in general use.Six are iron minerals of which five are important iron ore minerals and the sixth is an ore of titanium.Two are barium minerals worked as principal sources of barium salts.The other is ferrophosphorous, a mixture of synthetic iron phosphides.

The constituents are described below as minerals.

C.Iron minerals and ores

C.1.Hematite(Fe_2O_3)

Hematite has a specific gravity of 5.26 in the pure mineral.The color varies from bright red to dull red to steel gray;luster varies from metallic to submetallic to dull;the streak is cherry red or reddish brown;it is nonmagnetic.

C.1.1.Hematite ores

Rocks of which hematite is the major constituent vary in specific gravity,thoughness,compactness,amount of impurities,degree of weathering and suitability for use as concrete aggregate.From one deposit to another and within the deposite.Hematite appears to be the iron ore mineral most expdited as a source of iron.Hematite ores dust in handling, the dust ranging in color from moderate red to dusky red to moderate reddish brown.

C.2.Ilmenite ($FeTiO_3$,with minor Mg and Mn)

Ilmenite has specific gravity of 4.72 ∓ 0.04 in the pure mineral.The cclor is iron black with metallic to submetallic luster;the streak is black;it is feebly magnetic.

C.2.1.Ilmenite ores

Ilmenite ores consist of crystalline ilmenite with either magnetite or hematite and constituents of the associated gabbroic or anorthositic rocks.Massive ilmenite ores can form coarsely crystalline massive tough rocks but vary in specific gravity,composition,hardness and suitability for use as concrete aggregate from deposit to deposit and within a deposit.

One of the most widely used types of heavy aggregate is ilmenite ore.

C.3.Lepidocrocite(FeO(OH))

Lepidocrocite has specific gravity of 4.09 in the pure mineral.The color varies from ruby red to reddish brown and the streak is dull orange.Lepidocrocite and goethite occur together and lepidocrocite may be a constituent of goethite and limonite ores.

C.4.Goethite has the same chemical composition as lepidocrocite but crystallizes differently.The specific gravity is 4.28 ∓ 0.01 in the pure mineral and 3.3 to 4.3 in massive goethite.The color varies with the form,from crystals that are blackish brown with imperfect adamantine-metallic luster to dull or silky luster in fibrous varieties;massive goethite is yellowish brown to reddish brown;clayly materials is yellow to ocher yellow.

C.4.1.Goethite ores

Goethite ores range from hard tough massive rock to soft crumbling earths;these alternations frequently occur within fractions of an inch.

C.5.Limonite

A general name for hydrous iron oxides of unknown composition,frequently cryptocrystalline goethite with absorbed and capilary water,and probably mixtures of such goethite with similar hematite with capilary water.The specific gravity ranges from 2.7 to 4.3 and the color brownish black through browns to yellowsLimonites of high iron content are also called brown iron ores.Frequently they contain sand, colloidal silica,clays and other impurities.

C.6.Magnetite ($FeFe_2O_4$)

Magnetite has specific gravity of 5.17 in the pure mineral form;it is strongly magnetic;the color is black with metallic to semimetallic luster;the streak is black.

C.6.1.Magnetite ores

Magnetite ores can form dense,tough,usually coarse-grained rocks with few impurities;magnetite ores are associated with metamorphic or igneous or sedimentary rocks and therefore,the impurities associated with magnetite ores may include a wide variety of rockforming and accesory minerals magnetite occurs in association with hematite and ilmenite magnetite ores are widely distributed,but many are not suitable for use as heavy aggregate because the magnetite occurs disseminated through rock rather than as a major rock-forming mineral.One of the most widely used types of heavy aggregates is magnetite ore.

D.Barium minerals

D.1.Witherite($BaCO_3$)

Witherite has a specific gravity of 4.29 in the pure mineral.The color ranges from colorless to white to grayish or many pale colors.Like calcite and aragonite,witherite is decomposed with effervescence by dilute hydrochloric acid(HCl).Witherite,the second most common barium mineral,occurs with barite and galena.

D.2.Barite ($BaSO_4$)

Barite has a specific gravity of 4.50 in the pure mineral.The color ranges from colorless to white to many usually pale colors.

Barite is the most common barium mineral and the major barium ore.It occurs in veins transecting many kinds of rocks,concentrated in sedimentary rocks.

E.Ferrophosphorous

Ferrophosphorous,a material produced in the production of phosphorous,consists of a mixture of iron phosphides,and has been used as coarse and fine aggregate in radiation-shielding concrete.Published specific gravities range from 5.72 to 6.50 for coarse aggregate.The coarse aggregate is reported to degrade easily and has been associated with extreme retardation of set in concrete.Ferrophosphorous in concrete releases flammable,and possible toxic gases which can develop high pressure if confined.

Several iron phosphides are known,including silver-gray to blue-gray Fe_2P,with specific gravity of 6.50, FeP_2 with specific gravity of 5.07 and Fe_3P and FeP.Ferrophosphorous aggregates are silver-gray but develop some rusty staining on exposure.

F.Boron-containing materials

F.1.Boron minerals

The gamma rays that result from neutron capture by the lighter isotope of boron,boron-10,are much less penetrating than those which result from neutron capture by hydrogen(which is present in water);and for this reason boron and boron compounds are often used in neutron shields.The usually high capture capability of boron-10 permits its use in relatively small quantities.Boron is most frequently incorporated in the concrete as borate minerals or synthetic boron frits.Both methods cause some retardation of set of the concrete,which can be counteracted by the use of calciumchloride.

Minerals that are commercially important sources of boron are principally sodium,calcium and magnesium borate precipitates from waters in arid volcanic regions or alteration products of such precipitates.These hydrated minerals include some that are easily altered by changes in relative humidity and temperature.Some of them are soluble in or partly decomposed by cold water.Clay,gypsum and salt are found in borate deposits.The presence of one or more of these in varying unknown amounts in a borate ore used in shielding concrete may raise problems in making concrete with controlled strength,setting time,volume stability and workability, aside from the problem of varying degrees of retardation as the composition and thus the solubility of the borate ore may range from lot to lot or within a lot.

Turkish borate ores,which have been referred to as "borocalcite",but probably are ulexite or colemanite or mixtures of the two,have been used in shielding concrete in Germany and Japan.

Boron minerals that are stable and insoluble are usually not available in large quantities for use as aggregates.

F.1.1.Paigeite ($(Fe^{++}Mg)Fe^{+++}BO_5$)

It has a specific gravity ranging from 4.7 at the paigeite end to 3.6 at ludwigite end of paigeite-ludwigite series.It is coal black or greenish black and insoluble in water and tough.It is high temperature mineral occuring with magnetite in contact metamorphic deposits.Paigeite has been ubed as heavy boron-containing aggregate in Japan.

F.1.2.Turmaline$(Na(Mg,Fe,Mg,Li,Al)_3Al_6\ Si_6O_{18}$

$(BO_3)_3(OH,F)_4)$

It has a specific gravity ranging from 3.03 to 3.25;it ranges widely in color,but common varieties are brown or black.It is characteristically a mineral of granites, pegmatites and pneumatolytic veins,but persists as a detrital mineral in sediments.Concrete having effective neutron-shielding characteristics has been described in which the coarse aggregate was serpentine and the fine aggregate a tourmaline sand concrete.

G.Boron-frit glasses

Boron-frit glasses are clear,colorless,synthetic glasses produced by fusion and quenching,used in making ceramic glazes.They may be obtained in many compositions;but those most useful in shielding concrete contain calcium,relatively high amounts of silica and alumina,and low amounts of alkalies.Increased silica and alumina decrease the solubility of the frits and thus diminish their retarding effect in shielding concrete.

APPENDIX 4 - TEST METHODS

We taught that it would be useful to explain some of the laboratory tests used in this research.Not all of them but the basic tests and their procedures can be found in this section as a summary.

A.Slump of portland cement concrete

A.1.Scope

This method covers determination of slump of concrete both in the laboratory and in the field.The slump test is performed to check the workability and consistency of concrete

A.2.Apparatus

A.2.1.Mold

The test specimen is formed into a mold made o metal.The mold is in the form of lateral surface of the frustum of a cone with the base 20 cm in dia.,the top 10 cm in dia.and the height 30 cm.The base and the top shall be open and parallel to each other at right angles to axis of the cone.

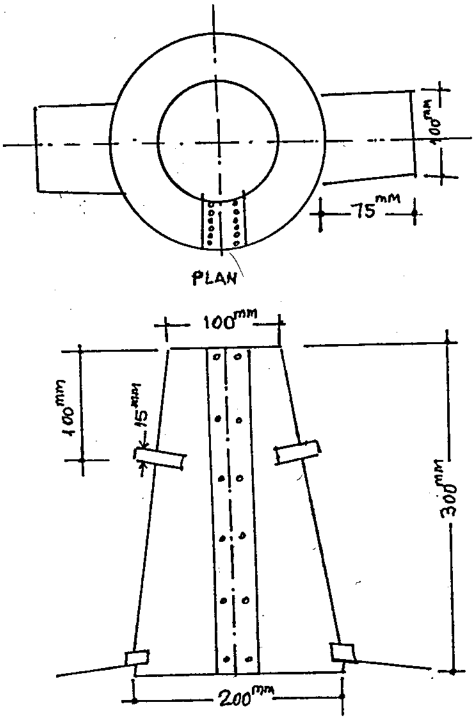


Fig.A.1-1

A.2.2.Tamping rod

The tamping rod is a round,straight steel rod 16 mm in diameter and approximately 60 cm in length,having the damping end rou nded to a hemispherical tip the diameter of which is 3/8 in.

A.3.Procedure

The mold is dampened and placed on a flat, moist,nonabsorbent(rigid surface.It should be held firmly in place during filling by the operator standing on the two foot pieces and filled by fresh concrete in three layers,each approximately one third volume of the mold,25 strokes of tamping is applied to each layer before a new layer is poured in?The strokes should be uniformly distributed over the cross section. After the mold is filled and the top of the concrete is leveled gently,the mold is removed immediately from the concrete by raising it carefully in a vertical direction.

It is immediately measured the slump by determining the difference between the height of the mold and the height over the original center of the base of the specimen.

B.Air content of the freshly mixed concrete by the pressure method.

Thismethod covers determination of the air content of freshly mixed concrete from observation of the change in volume of concrete with a change in pressure.

B.1.Apparatus

An airmeter consisting of a measuring bowl and cover assembly(Fig.B-1.) confirming to the requirements of measuring bowl and cover assembly.

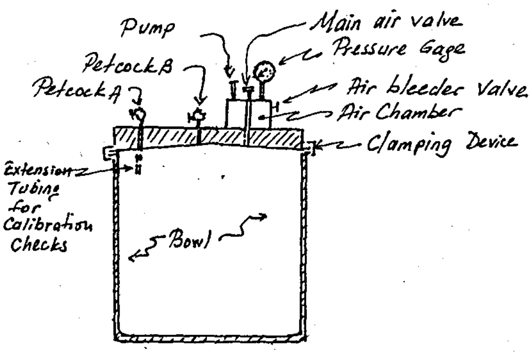


Fig.B-1. Schematic diagram

B.2.Procedure

The air bleeder valve on the air chamber is closed and pumped air into the air chamber until the gage hand is on the initial pressure line.For the compressed air to cool to normal temperature is allowed a few second.The gage hand at the initial pressure line is stabilized by pumping or bleeding off air as necessary,tamping the gage lightly.Both petcocks on holes through the cover are closed.The air valve is opened between the air chamber and the measuring bowl.Tap the sides of the measuring bowl sharply to releive local restraints.Lightly tap the pressure gage to stabilize the gage hand and the percentage of air is read on the dial of the pressure gage.The pressure is released by opening both petcocks(Fig.B-1) before removing the cover.

C.Determination of specific gravity of fine aggregate

C.1.Apparatus

Balance,Pycnometer,Mold,Tamper

C.2.Procedure

Place 800 gr of fine aggregate in a pan and cover it with water,and permit to stand 24 hours.Spread the sample on a flat surface exposed to a gently moving current warm air.Place some of the sample into the conical mold and lift the mold gently.Continue this process until the specific surface dry condition is reached,when the partiçles spread freely immediately after lifting the cone.The sample then be divided into two parts,one will be weighed(B) and dried to a constant weight(A).The other section will be placed in a flaks.The flaks will be filled up to the 500 ml mark with water wirst and weighed,then saturated surface dry sample(B) will be poured and it will be weighed after the water in the flaks will be brought to the 500 ml mark again.The difference of two weigths is the weight in water(C).

Apparent specific gravity = A/(A-C)
Bulk specific gravity = A/(B-C)
SSD Bulk specific gravity = B/(B-C)
Absorbtion %(by weight) = (B-A) x 100/A
Absorption %(by volume) = 100(B-A)x(Bulk Sp.Gr.)/A

D.Specific gravity of coarse aggregates

D.1.Apparatus:

Same as C.

D.2.Procedure

Immerse the sample in water for 24 hours. Remove the sample from the water and roll in a cloth until visible films of water is removed.Obtain weight B (Saturated surface dry weight).After weighing place it in a wire basket and determine the weight in water(C).Dry the sample in oven and weigh(A).

By u sing these values we can calculate the necessary specific gravities and the water absorption with the formula shown in section C.

E.Determination of the unit weigth

E.1.Balance,tamping rod,measure

E.2.Compact weigth determination

The sample aggregate will be room dry and throughly mixed.The measure shall be filled one thirds and tamped with a rod.The measure will be filled in 3 layers.Net weigth of the aggregates will be determined.Unit weigth can be calculated by dividing the weigth to volume.

E.2.Loose weigth determination

The measure will be filled by a shower and weighed.No tamping will be filled by a shower and weighed. No tamping will be applied.

F.Maximum density test

F.1.Apparatus

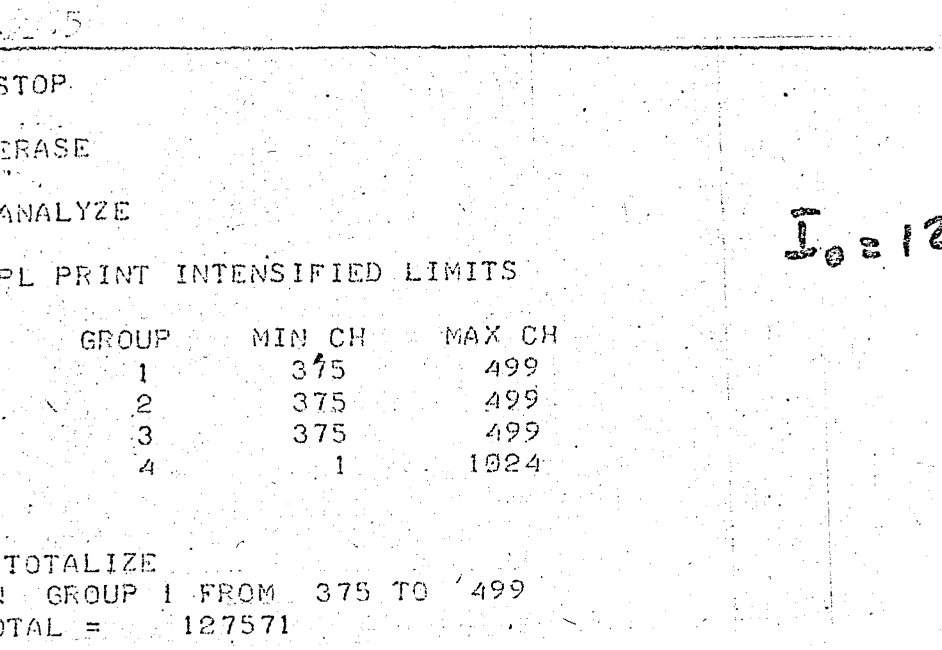
Balance,tamping rod,measure

F.2.Procedure

The maximum density of a mixture which contains two types of aggregates can be calculated as follows:

Aggregates A and B are mixed throughly with different proportions and the unit weigth of each mixture are determined as described in section E.For example aggregate A is added to aggregate B as it is the 10 % of the total mix. Then its percentage is increased as 20 %,30 % etc.of the total mixture by weigth.If we plot the unit weigths on the y axis and the percentages of A on the x axis we can draw the graph of density variation with different proportions of A and B.The peak value of the curre gives the maximum density on the X,axis

APPENDIX-5



```
STOP

ERASE

ANALYZE

PL PRINT INTENSIFIED LIMITS

     GROUP     MIN CH     MAX CH
       1        375        499
       2        375        499
       3        375        499
       4          1       1024


TOTALIZE
  GROUP 1 FROM  375 TO  499
OTAL =    127571
```

$I_0 = 127571$

```
ANALYZE

@L PRINT INTENSIFIED LIMITS
J
      GROUP     MIN CH     MAX CH
          1        375        503
          2        375        503
          3        375        503
          4          1       1024

SMOOTH DATA
J  GROUP 1
RANSFER TO GROUP 1

TOTALIZE
J  GROUP 1 FROM  375 TO  503
OTAL =      46541
```

```
ANALYZE

PL PRINT INTENSIFIED LIMITS
J
      GROUP     MIN CH     MAX CH
          1        375        503
          2        375        503
          3        375        503
          4          1       1024

SMOOTH DATA
J  GROUP 1
RANSFER TO GROUP 1

TOTALIZE
J  GROUP 1 FROM  375 TO  503
OTAL =      52197
```

```
ANALYZE

@OTALIZE
J  GROUP 1 FROM  375 TO  503
OTAL =      46022
```

~~ERASE~~

```
 ANALYZE

 @L PRINT  INTENSIFIED  LIMITS
N
      GROUP     MIN CH     MAX CH
         1        375        502
         2        375        502
         3        375        502
         4          1       1024


 SMOOTH DATA
N  GROUP 1
RANSFER TO GROUP 1

 TOTALIZE
N  GROUP 1 FROM  375 TO  502
OTAL =       51021
 ANALYZE

 HL PRINT  INTENSIFIED  LIMITS
N
      GROUP     MIN CH     MAX CH
         1        386        499
         2        385        499
         3        385        499
         4          1       1024


 SMOOTH DATA
N  GROUP 1
RANSFER TO GROUP 1

 TOTALIZE
N  GROUP 1 FROM  386 TO  499
OTAL =       52905
 ANALYZE

 PL PRINT  INTENSIFIED  LIMITS
N
      GROUP     MIN CH     MAX CH
         1        386        500
         2        385        499
         3        385        499
         4          1       1024

* SMOOTH DATA
N  GROUP
RROR        1912

* SMOOTH DATA
IN  GROUP 1
TRANSFER TO GROUP 1

*.TOTALIZE
IN  GROUP 1 FROM  386 TO  500
TOTAL =       42088
```

```
* ANALYZE

* PL PRINT INTENSIFIED LIMITS
N
      GROUP     MIN CH     MAX CH
         1        386        500
         2        386        500
         3        386        500
         4          1       1024


* SMOOTH DATA
IN  GROUP 1
RANSFER TO GROUP 1

* TOTALIZE
IN  GROUP 1 FROM  386 TO  500
OTAL =       43031
```

```
* ANALYZE

* ZMOOTH DATA
IN  GROUP 1
RANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
      GROUP     MIN CH     MAX CH
         1        326        421
         2        326        421
         3        326        421
         4          1       1024


* TOTALIZE
IN  GROUP 1 FROM  326 TO  421
OTAL =       50107
```

```
* ANALYZE

* SMOOTH DATA
IN  GROUP 1
RANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
      GROUP     MIN CH     MAX CH
         1        326        410
         2        326        410
         3        326        410
         4          1       1024


* TOTALIZE
IN  GROUP 1 FROM  326 TO  410
OTAL =       48038
```

```
ANALYZE

ZMOOTH DATA
N. GROUP 1
RANSFER TO GROUP 1

PL PRINT INTENSIFIED LIMITS
N
    GROUP     MIN CH     MAX CH
      1        325        410
      2        325        410
      3        325        410
      4          1       1024


TOTALIZE
N GROUP 1 FROM  325 TO  410
OTAL =       39970
```

```
ANALYZE

SMOOTH DATA
N  GROUP 1
RANSFER TO GROUP 1

PL PRINT INTENSIFIED LIMITS
N
    GROUP     MIN CH     MAX CH
      1        325        410
      2        325        410
      3        325        410
      4          1       1024


TOTALIZE
N GROUP 1 FROM  325 TO  410
OTAL =       50961
```

```
ANALYZE

SMOOTH DATA
N. GROUP 1
RANSFER TO GROUP 1

PL PRINT INTENSIFIED LIMITS
N
    GROUP     MIN CH     MAX CH
      1        316        402
      2        316        401
      3        316        401
      4          1       1024


TOTALIZE
N GROUP 1 FROM  316 TO  402
OTAL =       47574
```

```
 ANALYZE

 AMOOTH DATA
N  GROUP 1
RANSFER TO GROUP 1

 PL PRINT INTENSIFIED LIMITS
N
      GROUP     MIN CH     MAX CH
         1        316        408
         2        316        408
         3        316        408
         4          1       1024


 TOTALIZE
N  GROUP 1  FROM  3[illegible]1 TO  40[illegible]
OTAL =       28[illegible]56

* TOTALIZE
IN  GROUP 1 FROM  316 TO  408
TOTAL =      47557

* ANALYZE


* SMOOTH DATA
IN  GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
      GROUP     MIN CH     MAX CH
         1        316        404
         2        316        404
         3        316        404
         4          1       1024


* TOTALIZE
IN  GROUP 1 FROM  316 TO  404
TOTAL =      56809

* ANALYZE

* SMOOTH DATA
IN  GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
      GROUP     MIN CH     MAX CH
         1        313        404
         2        313        404
         3        313        404
         4          1       1024


* TOTALIZE
IN  GROUP 1 FROM  313 TO  404
```

```
* ANALYZE

* SMOOTH DATA
IN  GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
       GROUP     MIN CH    MAX CH
          1       312       402
          2       311       402
          3       311       402
          4         1      1024

* TOTALIZE
IN  GROUP 1 FROM  312 TO  402
TOTAL =      51621

* ANALYZE

* SMOOTH DATA
IN  GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
       GROUP     MIN CH    MAX CH
          1       308       399
          2       308       398
          3       308       398
          4         1      1024

* TOTALIZE
IN  GROUP 1 FROM  308 TO  399
TOTAL =      46298

* ANALYZE

* SMOOTH DATA
IN  GROUP 1
TRANSFER TO GROUP 1

* TOTALIZE
IN  GROUP 1 FROM
TOTAL =     117455

* PL PRINT INTENSIFIED LIMITS
IN
       GROUP     MIN CH    MAX CH
          1       309       403
          2       309       402
          3       309       402
          4         1      1024

* TOTALIZE
IN  GROUP 1 FROM  309 TO  403
```

```
* ANALYZE

* SMOOTH DATA
IN  GROUP 1
TRANSFER TO GROUP 1

* PL PRINT  INTENSIFIED LIMITS
IN
        GROUP       MIN CH      MAX CH
           1          305         399
           2          305         399
           3          305         399
           4            1        1024

* TOTALIZE
IN  GROUP 1 FROM  305 TO  399
TOTAL =       49712

* ANALYZE

* CMOOTH DATA
IN  GROUP 1
TRANSFER TO GROUP 1

* PL PRINT  INTENSIFIED LIMITS
IN
        GROUP       MIN CH      MAX CH
           1          305         404
           2          304         403
           3          304         403
           4            1        1024

* TOTALIZE
IN  GROUP 1 FROM  305 TO  404
TOTAL =       46601

* ANALYZE

* CMOOTH DATA
IN  GROUP 1
TRANSFER TO GROUP 1

* PL PRINT  INTENSIFIED LIMITS
IN
        GROUP       MIN CH      MAX CH
           1          303         404
           2          303         404
           3          303         404
           4            1        1024

* TOTALIZE
IN  GROUP 1 FROM  303 TO  404
TOTAL =       47911
```

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```
  SMOOTH DATA
IN   GROUP 1
TRANSFER TO GROUP 1

* PL PRINT  INTENSIFIED LIMITS
IN
        GROUP        MIN CH       MAX CH
           1           444          490
           2           444          490
           3           444          490
           4             1         1024


* TOTALIZE
IN  GROUP 1 FROM  444 TO  490
TOTAL =       30971
```

→ 1.17 Mev

$I_{o_1} = 30971$

```
* PL PRINT INTENSIFIED LIMITS
IN
        GROUP        MIN CH       MAX CH
           1           510          551
           2           510          551
           3           510          551
           4             1         1024


* TOTALIZE
IN  GROUP 1 FROM  510 TO  551
TOTAL =       24767
```

→ 1.33 Mev

$I_{o2} = 24767$

```
* ANALYZE

* SMOOTH DATA
IN   GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
        GROUP       MIN CH      MAX CH
            1         439         500
            2         439         500
            3         439         500
            4           1        1024


* TOTALIZE
IN  GROUP 1 FROM  439 TO  500
TOTAL =       17960
```

1.33

```
* PL PRINT INTENSIFIED LIMITS
IN
        GROUP       MIN CH      MAX CH
            1         511         558
            2         511         558
            3         511         558
            4           1        1024


* TOTALIZE
IN  GROUP 1 FROM  511 TO  558
TOTAL =       12459
```

```
* ANALYZE

* SMOOTH DATA
IN  GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
        GROUP     MIN CH     MAX CH
          1        442        499
          2        442        498
          3        442        498
          4          1       1024


* TOTALIZE
IN  GROUP 1 FROM  442 TO  499
TOTAL =      19031
```

1.33

```
* PL PRINT INTENSIFIED LIMITS
IN
        GROUP     MIN CH     MAX CH
          1        510        559
          2        510        559
          3        510        559
          4          1       1024


* TOTALIZE
IN  GROUP 1 FROM  510 TO  559
TOTAL =      14125
```

```
* ANALYZE

* SMOOTH DATA
IN  GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
        GROUP     MIN CH     MAX CH
          1        440        502
          2        440        502
          3        440        502
          4          1       1024


* TOTALIZE
IN  GROUP 1 FROM  440 TO  502
TOTAL =      20028
```

1.33

```
* PL PRINT INTENSIFIED LIMITS
IN
        GROUP     MIN CH     MAX CH
          1        508        561
          2        508        561
          3        508        561
          4          1       1024


* TOTALIZE
IN  GROUP 1 FROM  508 TO  561
TOTAL =      14756
```

```
* ANALYZE

* SMOOTH DATA
IN   GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
        GROUP     MIN CH     MAX CH
          1         435        505
          2         435        505
          3         435        505
          4           1       1024


* TOTALIZE
IN   GROUP 1 FROM  435 TO  505
TOTAL =      18161
```

4.33

```
* PL PRINT INTENSIFIED LIMITS
IN
        GROUP     MIN CH     MAX CH
          1         502        576
          2         502        576
          3         502        576
          4           1       1024


* TOTALIZE
IN   GROUP 1 FROM  502 TO  576
TOTAL =      15490
```

```
* ANALYZE

* SMOOTH DATA
IN   GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
        GROUP     MIN CH     MAX CH
          1         437        499
          2         437        499
          3         437        499
          4           1       1024


* TOTALIZE
IN   GROUP 1 FROM  437 TO  499
TOTAL =      18230
```

4.33

```
* PL PRINT INTENSIFIED LIMITS
IN
        GROUP     MIN CH     MAX CH
          1         502        565
          2         502        565
          3         502        565
          4           1       1024


* TOTALIZE
IN   GROUP 1 FROM  502 TO  565
TOTAL =      15741
```

```
* ANALYZE

* SMOOTH DATA
IN   GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
       GROUP      MIN CH      MAX CH
          1         429        489
          2         428        489
          3         429        489
          4           1       1024


* TOTALIZE
IN   GROUP 1 FROM  429 TO  489
TOTAL =        16804
```

1.33

```
* PL PRINT INTENSIFIED LIMITS
IN
       GROUP      MIN CH      MAX CH
          1         504        582
          2         504        582
          3         504        582
          4           1       1024


* TOTALIZE
IN   GROUP 1 FROM  504 TO  582
TOTAL =        16910
```

```
* ANALYZE

* SMOOTH DATA
IN   GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
       GROUP      MIN CH      MAX CH
          1         424        504
          2         423        504
          3         423        504
          4           1       1024


* TOTALIZE
IN   GROUP 1 FROM  424 TO  504
TOTAL =       23188
```

1.33

```
* PL PRINT INTENSIFIED LIMITS
IN
       GROUP      MIN CH      MAX CH
          1         499        587
          2         499        587
          3         499        587
          4           1       1024


* TOTALIZE
IN   GROUP 1 FROM  499 TO  587
TOTAL =        20129
```

```
* ANALYZE

* SMOOTH DATA
IN   GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
        GROUP      MIN CH      MAX CH
          1         421         511
          2         421         511
          3         421         511
          4           1        1024


* TOTALIZE
IN   GROUP 1 FROM  421 TO  511
TOTAL =      26541
```

1.55

```
* PL PRINT INTENSIFIED LIMITS
IN
        GROUP      MIN CH      MAX CH
          1         505         563
          2         505         563
          3         505         563
          4           1        1024


* TOTALIZE
IN   GROUP 1 FROM  505 TO  563
TOTAL =      16899
```

```
* ANALYZE

* SMOOTH DATA
IN   GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
        GROUP      MIN CH      MAX CH
          1         422         508
          2         422         508
          3         422         508
          4           1        1024


* TOTALIZE
IN   GROUP 1 FROM  422 TO  508
TOTAL =      21747
```

1.53

```
* PL PRINT INTENSIFIED LIMITS
IN
        GROUP      MIN CH      MAX CH
          1         510         577
          2         510         577
          3         510         577
          4           1        1024


* TOTALIZE
IN   GROUP 1 FROM  510 TO  577
TOTAL =      14830
```

```
* SMOOTH DATA
IN   GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
          GROUP      MIN CH      MAX CH
             1         438         503
             2         437         503
             3         437         503
             4           1        1024


* TOTALIZE
IN   GROUP 1 FROM  438 TO  503
TOTAL =       20115

*
```

1.33

```
* PL PRINT INTENSIFIED LIMITS
IN
          GROUP      MIN CH      MAX CH
             1         507         560
             2         507         560
             3         507         560
             4           1        1024


* TOTALIZE
IN   GROUP 1 FROM  507 TO  560
TOTAL =       14340
```

```
* ANALYZE

* SMOOTH DATA
IN   GROUP 1
TRANSFER TO GROUP 1
```

```
* PL PRINT INTENSIFIED LIMITS
IN
          GROUP      MIN CH      MAX CH
             1         432         493
             2         432         493
             3         432         493
             4           1        1024


* TOTALIZE
IN   GROUP 1 FROM  432 TO  493
TOTAL =       21848
```

1.33

```
* PL PRINT INTENSIFIED LIMITS
IN
          GROUP      MIN CH      MAX CH
             1         505         558
             2         505         558
             3         505         558
             4           1        1024


* TOTALIZE
```

```
* ANALYZE

* SMOOTH DATA
IN  GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
       GROUP     MIN CH     MAX CH
         1        435        498
         2        435        498
         3        435        498
         4          1       1024


* TOTALIZE
IN  GROUP 1 FROM  435 TO  498
TOTAL =      23854
```

1.33

```
* PL PRINT INTENSIFIED LIMITS
IN
       GROUP     MIN CH     MAX CH
         1        500        552
         2        500        552
         3        500        552
         4          1       1024


* TOTALIZE
IN  GROUP 1 FROM  500 TO  552
TOTAL =      17224

* ANALYZE

* SMOOTH DATA
IN  GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
       GROUP     MIN CH     MAX CH
         1        436        493
         2        436        492
         3        436        492
         4          1       1024


* TOTALIZE
IN  GROUP 1 FROM  436 TO  493
TOTAL =      18568
```

1.33

```
* PL PRINT INTENSIFIED LIMITS
IN
       GROUP     MIN CH     MAX CH
         1        502        551
         2        502        551
         3        502        551
         4          1       1024


* TOTALIZE
IN  GROUP 1 FROM  502 TO  551
TOTAL =      14126
```

```
* ANALYZE

* SMOOTH DATA
IN  GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
       GROUP     MIN CH     MAX CH
         1         439        490
         2         438        489
         3         439        490
         4           1       1024


* TOTALIZE
IN  GROUP 1 FROM  439 TO  490
TOTAL =      19435
```

1.33

```
* PL PRINT INTENSIFIED LIMITS
IN
       GROUP     MIN CH     MAX CH
         1         501        552
         2         501        552
         3         501        552
         4           1       1024


* TOTALIZE
IN  GROUP 1 FROM  501 TO  552
TOTAL =      15990
```

```
* ANALYZE

* SMOOTH DATA
IN  GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
       GROUP     MIN CH     MAX CH
         1         441        487
         2         441        487
         3         441        487
         4           1       1024


* TOTALIZE
IN  GROUP 1 FROM  441 TO  487
TOTAL =      15909
```

1.33

```
* PL PRINT INTENSIFIED LIMITS
IN
       GROUP     MIN CH     MAX CH
         1         506        553
         2         507        553
         3         506        553
         4           1       1024


* TOTALIZE
IN  GROUP 1 FROM  506 TO  553
TOTAL =      13668
```

```
* ANALYZE

* SMOOTH DATA
IN  GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
       GROUP     MIN CH     MAX CH
         1         443        487
         2         443        487
         3         443        487
         4           1       1024


* TOTALIZE
IN  GROUP 1 FROM  443 TO  487
TOTAL =      16542
```

1.33

```
* PL PRINT INTENSIFIED LIMITS
IN
       GROUP     MIN CH     MAX CH
         1         506        552
         2         506        552
         3         506        552
         4           1       1024


* TOTALIZE
IN  GROUP 1 FROM  506 TO  552
TOTAL =      14454
```

```
* ANALYZE

* SMOOTH DATA
IN  GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
       GROUP     MIN CH     MAX CH
         1         442        488
         2         442        488
         3         442        488
         4           1       1024


* TOTALIZE
IN  GROUP 1 FROM  442 TO  488
TOTAL =      17275
```

1.33

```
* PL PRINT INTENSIFIED LIMITS
IN
       GROUP     MIN CH     MAX CH
         1         502        550
         2         502        550
         3         502        550
         4           1       1024


* TOTALIZE
IN  GROUP 1 FROM  502 TO  550
```

```
* ANALYZE

* SMOOTH DATA
IN  GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
       GROUP     MIN CH     MAX CH
         1        441        490
         2        441        490
         3        441        490
         4          1       1024


* TOTALIZE
IN  GROUP 1 FROM  441 TO  490
TOTAL =     18971
```

1.33

```
* PL PRINT INTENSIFIED LIMITS
IN
       GROUP     MIN CH     MAX CH
         1        502        554
         2        502        554
         3        502        554
         4          1       1024


* TOTALIZE
IN  GROUP 1 FROM  502 TO  554
TOTAL =     16495

* ANALYZE

* SMOOTH DATA
IN  GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
       GROUP     MIN CH     MAX CH
         1        443        494
         2        443        494
         3        443        494
         4          1       1024


* TOTALIZE
IN  GROUP 1 FROM  443 TO  494
TOTAL =     16509
```

1.33

```
* PL PRINT INTENSIFIED LIMITS
IN
       GROUP     MIN CH     MAX CH
         1        506        556
         2        506        555
         3        506        555
         4          1       1024


* TOTALIZE
IN  GROUP 1 FROM  506 TO  556
TOTAL =     13427
```

```
* ANALYZE

* SMOOTH DATA
IN  GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
      GROUP     MIN CH     MAX CH
        1        445        494
        2        445        494
        3        445        494
        4          1       1024


* TOTALIZE
IN  GROUP 1 FROM  445 TO  494
TOTAL =      14939
```

1.33

```
* PL PRINT INTENSIFIED LIMITS
IN
      GROUP     MIN CH     MAX CH
        1        512        561
        2        512        561
        3        512        561
        4          1       1024


* TOTALIZE
IN  GROUP 1 FROM  512 TO  561
TOTAL =      12368
```

```
* ANALYZE

* SMOOTH DATA
IN  GROUP 1
TRANSFER TO GROUP 1

* PL PRINT INTENSIFIED LIMITS
IN
      GROUP     MIN CH     MAX CH
        1        440        490
        2        440        490
        3        440        490
        4          1       1024


* TOTALIZE
IN  GROUP 1 FROM  440 TO  490
TOTAL =      15948
```

1.33

```
* PL PRINT INTENSIFIED LIMITS
IN
      GROUP     MIN CH     MAX CH
        1        502        553
        2        502        553
        3        502        553
        4          1       1024
```