NUCLID PRODUCTION WITH CYCLOTRONS AND RADIATION PROTECTION PROBLEMS

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With cyclotrons it is possible to produce nuclids used for medical and biological examinations with short halftime in a simple manner. The short halftime is the benefit for the mean irradiation of patients but it has the disadvantage that the production rate of the nuclids has to be very high. The time between production and administration of the nuclid to the patient is responsible of the produced activity of the radioactive agens. The longer this time and the shorter the half time is, results the irradiation risk. It shall be calculated the dependence of these factors and measures will be layed down to optimize the risks of the production and use of the radioactive agens.

DIE AUSWIRKUNG DER PRODUKTION VON NUKLIDEN IM ZYKLOTRON AUF DEN STRAHLENMSCHUTZ

Das Zyklotron bietet die Möglichkeit Radionuklide herzustellen, die für nuklearmedizinische Untersuchungen neue Methoden und dies bei wesentlich geringerer Strahlenbelastung des Patienten ergibt. Die hiebei erzeugten Radionuklide besitzen eine kürzere Halbwertszeit, müssen also in höherer Konzentration bzw. Aktivität angewendet werden, um die erforderlichen Resultate zu liefern. Die Aktivität, die im Zyklotron erzeugt werden muß, hängt davon ab, nach welcher Zeit die Nuklide verabreicht werden und die Messung erfolgt. Je länger diese Zeit ist und je kürzer die Halbwertszeit des Nuklids ist, desto größer ist das Risiko einer Strahlenbelastung. In welchem Ausmaß dieses Risiko durch die Erzeugung erhöht und bei der Anwendung vermindert wird,soll berechnet werden, und wie weit zusätzliche bzw. andere Strahlenschutzmaßnahmen erforderlich sind, soll angegeben werden.

PRINCIPLE

The conventional cyclotron consists of a circular, evacuated chamber situated in a uniform magnetic field. Inside this chamber are two hollow electrodes with an electrostatic difference of potential where a positive ion is accelerated to high energy E = 4.8x10e-11(HRZ)2/A, where E is expressed in MeV,H in gauss,R in cm and A,Z are the mass and the atomic number of the accelerated positive ion. The magnetic field strength of the order of tens of kilogauss limits the design of the cyclotron. Protons and Alfa particle are accelerated with a magnetic field strength of 15 kilogauss and a dee diameter of 76 cm to about 15 MeV. For the installation in medical institutions smaller compact cyclotrons are used, where the magnetic field varies with azimuthal angle, which are called AVF azimuthally varying field cyclotron. There are more than 80 short-lived radionuklides used by medical institutions, most with physical half-lives less than a few days, produced approximately 50% by cyclotrons. Most of interest /2

for medical purposes for instance for the Positron Emitter Tomography (PET) are the „physiological" radioisotopes (11C,13N,15O,18F). The estimated radionuclidic production with a 40 MeV cyclotron is as following:
14N(p,4He)11C, 20.30 m Half-Life, 45.5 TBq Activity, 11 h/w Production
16O(p,4He)13N, 9.96 m Half-Life, 4.8 TBq Activity, 3 h/w Production
14N(d,n)15O, 2.02 m Half-Life, 6.8 TBq Activity, 3 h/w Production
18O(p,n)18F, 109.80 m Half-Life, 34.6 TBq Activity, 13 h/w Production
20N(d,4He)18F, 109.80 m Half-Life, 2.1 TBq Activity, 2 h/w Production
124Xe(p,2n)123I, 13.00 h Half-Life, 2.3 TBq Activity, 4 h/w Production
Other Radioisotopes, 43.0 TBq, 8 h/w Production
The main areas of the cyclotron are the vault of the cyclotron and two target bunkers with automatic pneumatic transportation systems to manipulation and labelling laboratories and the PET area and also with shielding wagon running on a monorail to connect bunkers with hot radiochemical laboratories.
The generation of neutron and photon fluxes into the vault and the bunkers needs ordinary concrete shielding with an addition of 1% of borate materials with a thickness of about 250 cm. Lower shielding levels of about 50 cm of concrete has to be projected for the hot radiochemical laboratories. The calculation of the shielding walls will be made with an overestimation of about tenfold to protect the workers. The nuclei present in the air and in the dust are responsible for radioactive gaseous effluents mainly from the interaction of primary and secondary particles.Therefore an air circulation system of 0.5-1 time/h during the run and 8-10 after the decay time is necessary to protect workers and population. The following main isotopes contribute the airborne radioactivity:
14N(n,2n)13N, Half-Life 9.96 m, Beta+(1.25 MeV)
16O(n,2n)15O, Half-Life 122 s, Beta+(1.7 MeV)
16O(n,p)16N, Half-Life 7.20 s, Beta+,Gamma
40Ar(n,4He)37S, Half-Life 5.06 m, Beta-(4.8 MeV)
40Ar(n,p)40Cl, Half-Life 1.40 m, Beta-(7.5 MeV)
40Ar(n,Gamma)41Ar, Half-Life 1.83 h, Beta-,Gamma
It was found that the proportion of the gamma dose near the accelerators is generally negligible considering the neutron dose equivalent. This means,that the control of the gamma dose alone is insufficient for the accidental dosimetry around cyclotrons.
Possible sources of radioactive liquid waste are from accidental releases from the cooling water circuit, from the radiochemical laboratory, from the PET area and their treated patients.
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CALCULATIONS
The production of radioactive sources for medical diagnostic methods with a cyclotron needs a very different way compared with using long-living nuclids. To have the same measurement effects with short-living nuclids you must use /3

much higher activities. Additionally you need yet higher activities produced by the cyclotron. This means that the level of radiation protection must be higher to protect workers on the one side and lower to protect the population on the other hand and vice versa.
To estimate the necessary protection, the activities of cyclotron produced radionuclides will be calculated and compared with the activities using long-living nuclides. Finally the dose ratio will be calculated dependent from the half-lifes for workers and patients.
The activity of the nuclid originated in the cyclotron is Ao. After the time To the intake of the nuclid of the patient is beginning and continues until Td.
After To is the activity Ad=Ao.exp(-To.ln2/T), with the Half-life T. From this results the proportional dose D= Ao.(-T/ln2).(exp(-(To+Td).ln2/T)-exp(-To.ln2/T))
The dose comparison between two nuclids with different half-lifes after the Td leads to the unknown activity Ax=A.(T/Tx).exp(-Td.ln2/T.(1-T/Tx)).
The activity at the time of the production can be calculated as follows:
A=Ao.exp(-To.ln2/T) and Ax=Axo.exp(-To.ln2/Tx). Therefore is
Ao=A.exp(To.ln2/T) and Axo=A.(T/Tx).exp(-Td.ln2(1/T-1/Tx)).exp(to.ln2/Tx)
Important is the ratio Axo/Ao=(T)TX(-ln2.(To+Td).(1/T).(1-T/Tx)).
Also important is the proportional dose ratio DX/D=exp(-Td.ln2.(1(T).(1-T/Tx)).
wherein is
Ao the activity of the known nuclid at the production in the cyclotron
Axo the activity of the nuclid produced in the cyclotron
T the half-life of the nuclid used without cyclotron
Tx the half-life of the cyclotron produced nuclid
Td the time of the measurement and
To the time between the production of the nuclid in the cyclotron and the begin of the measurement.
The exposure factor of the patient result from following equation if you use the effective half-life: EFP=Ax(Txeff)/A(Teff), 1/Teff=1/Tphys.+1/Tbiol.
For Txbiol.>>Txphys. and Tphys.>>Tbiol. is EFP -- Txphys./Tbiol.
Also you can define the exposure factor of the worker EFW which result from the time between the cyclotron production or the delivery of the nuclid intil the measurement.
With the manipulationtime Tm is EFW=T/Tx.exp((Td+Tm)(1-T/Tx)ln2/T)
This gives the result for T>>TX and Td+Tm=Tx of EFW --(T/2)/Tx.

CONCLUSIONS

The activity of the nuclids produced in a 40 MeV cyclotron is about 100 TBq / week.
The medical examinations with 99mTc, 131J use activities from 1.5 til 740 MBq dependent from the radiopharmakon. From the standpoint of the patient the radiation protection is much higher using cyclotron produced nuclids because of the short half-life. On the other hand the shorter the half-life the higher is the required activity production and also the risk of irradiation. It is also more difficult to control the intake of workers. Therefore the radiation production expense will increase very intensively with decrease of risk.