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RADIATION LEVELS AND ACTIVATION AT THE ILC POSITRON SOURCE*

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Abstract

An undulator-based positron source is recommended as baseline design for the International Linear Collider (ILC). Photons generated by electrons passing an undulator hit a rotating target and create electron-positron pairs. The positrons are captured and accelerated. An advantage of this source is the significantly lower radiation level in comparison to a conventional positron source which uses the electron beam directly to produce electron-positron pairs. The fluxes of neutrons and photons have been calculated for both type of sources with the particle transport code FLUKA [1]. The activation of the positron source components has been estimated depending on the parameters of the source. The results for undulator-based and conventional positron sources are compared and presented.

POSITRON SOURCE DESCRIPTION

The undulator based system uses a helical undulator placed at the 150 GeV (or 250 GeV) point of the ILC electron linac. The electron beam passing through this undulator generates circularly polarized photons. The energy distribution of the photons are shown in Fig. 1. The photons hit a thin Ti-6Al-4V target of 0.4 radiation length (X_0) and produce electron-positron pairs.

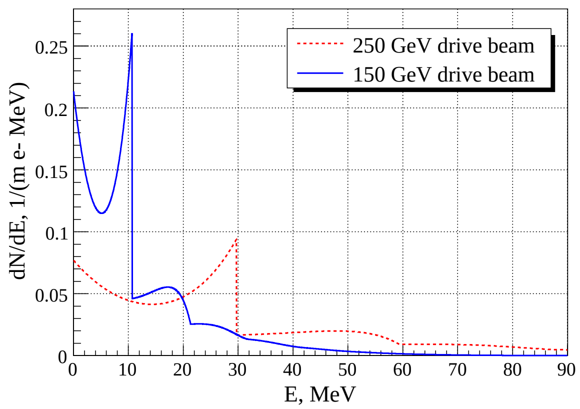

Figure 1: Energy distribution function of photons generated by an electron passing one meter of the undulator (period of undulator of 1 cm, magnetic field of 1.07 T and $K = 1$).

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In the conventional positron source, a primary electron beam passing a thick target (4.5 X_0) creates the required photons for positron production via bremsstrahlung. The target compounds are 75% of W and 25% of Re.

The positrons emerging from the target are collected and accelerated in the capture section. The capture section consists of the adiabatic matching device (AMD) and a RF structure embedded in a focusing solenoid [2]. The structure is modelled as an "effective" collimator with an aperture corresponding to the size of the iris of the accelerating structures. Fig. 2 shows the ILC positron source model used in the simulations.

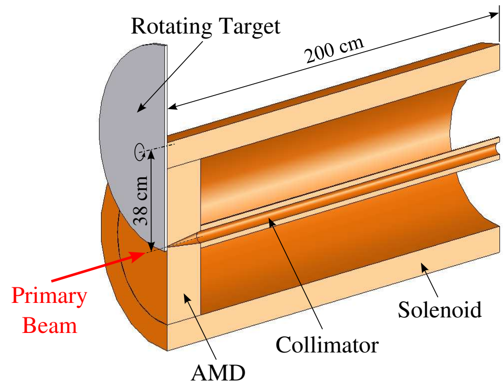

Figure 2: Model of the positron source.

The AMD is a tapered solenoid starting with an initial field of 6 T which is reduced adiabatically down to a constant field of 0.5 T. The AMD allows to match the positron beam emerging from the target with small spot size and large divergence to the acceptance of the solenoid. After the capture section and an acceleration up to energies of 250 MeV the positrons are separated from electrons and photons and accelerated to the damping ring energy of 5 GeV. A yield of 1.5 positrons per electron travelling through the undulator has been chosen for the design as an operational safety factor. In comparison to the conventional source the undulator based source has a smaller positron beam divergence after the conversion target. This results in a higher capture efficiency: $k_{\rm capt} = 0.35$ for the undulator based source and $k_{\rm capt} = 0.12$ for the conventional source.

In order to compare different sources the number of positrons at the ILC interaction point $N_{e+}^{\rm IP}$ is selected as a reference point. The positron yield of the conversion target, Y_{e^+}, as well as the photon yield of the undulator, Y_γ, have to be known to calculate the required number of primary electrons, $N_{e^-}^{\rm pr}$, and the undulator length, $L_{\rm U}$. In case of the undulator based source Y_{e+} is the number of positrons produced by one incident photon and for the conventional source Y_{e+} is the positron yield per incoming electron. The photon yield of the undulator, Y_γ, gives the number of photons radiated by one electron passing one meter of the undulator. For example, the undulator length could be found from the equation

$$N_{e^+}^{\mathrm{IP}} = N_{e^-}^{\mathrm{pr}} Y_\gamma L_{\mathrm{U}} Y_{e+} k_{\mathrm{capt}} / k_{\mathrm{safety}}^{\mathrm{DR}},$$

where $k_{\mathrm{safety}}^{\mathrm{DR}}$ is defined as the ratio $N_{e^+}^{\mathrm{DR}}/N_{e^+}^{\mathrm{IP}}$. In Table 1 the most important parameters of the simulated sources are summarized.

Table 1: Positron yield.

Source type	Conv.	U150	U250
E_{e^-}, GeV	6.2	150	250
$N_{e^+}^{\mathrm{IP}}$, e$^+$/s	$2.82 \cdot 10^{14}$		
$k_{\mathrm{safety}}^{\mathrm{DR}}$	1.5		
k_{capt}	0.115	0.35	
Y_{e+}	14.42	0.0257*	0.0752*
$N_{e^-}^{\mathrm{pr}}$, e$^-$/s	$2.55 \cdot 10^{14}$	$2.82 \cdot 10^{14}$	
Y_γ, $\gamma/(\mathrm{e^- m})$	–	2.575	
L_{U}, m	–	64.72	22.14

* The positron yields of the Ti-5Al-2.5Sn target for U150 and U250 are 0.0262 and 0.0755 respectively.

Table 2 shows the power of the primary and secondary beams and the power deposited to the components of the source. For a comparison of the different sources all calculated values were normalized to the power of the primary beam. The power of electrons and positrons has been determined without taking into account their acceleration in the capture section, because FLUKA allows only for magnetic fields, not yet electric fields.

Table 2: Power of primary and secondary beams (P_{pr}; P_γ, P_{e^-}, P_{e^+}) and power, ΔP, deposited in the source.

		Ti-6Al-4V		Ti-5Al-2.5Sn	
Source type	Conv.	U150	U250	U150	U250
P_{pr}, kW	253.1	90.2	85.7	88.4	85.3
P_γ, %	17.4	82.1	80.4	82.9	81.0
P_{e^-}, %	3.4	1.8	2.9	1.6	2.9
P_{e^+}, %	3.2	1.1	2.3	0.9	2.3
ΔP_{Tgt}, %	19.1	8.0	4.7	7.4	4.4
ΔP_{AMD}, %	19.4	5.7	6.0	5.7	5.8
ΔP_{Col}, %	33.8	0.7	3.0	0.8	3.0
ΔP_{Sol}, %	3.2	0.1	0.3	0.1	0.3
	99.4	99.4	99.7	99.5	99.7

NEUTRON PRODUCTION RATE AND ACTIVATION OF SOURCE PARTS

A major advantage of the FLUKA code [1] is its capability to calculate neutron fluxes and the activation of the source parts. The Monte Carlo code has been proven to be well suited to calculate residual nuclei in electromagnetic and hadronic cascade processes [3].

Figure 3 shows the accumulated neutron track density projected onto the x-z plane for the U150 source after one second of operation. The total neutron production rates, $\dot{N}_n$, calculated as total number of neutrons passing per second the closed surface around the source are shown for the different sources in Table 3. The rate, $\dot{N}_n$, of the conventional source is 8.6 times higher than that of the U150 source. The neutrons are mainly produced in the target. Therefore, more detailed calculations have been performed for the target region.

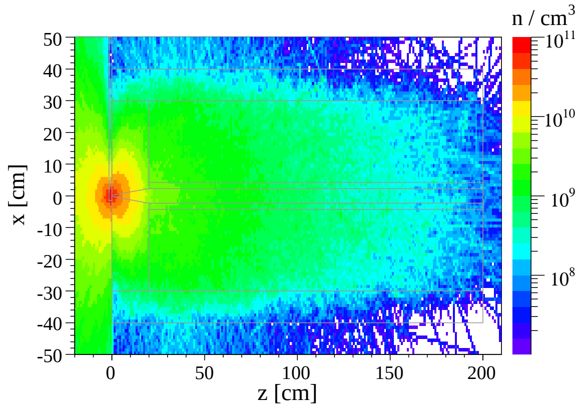

Figure 3: Neutron density for the U150 source.

Table 3: Neutron production rate.

Source type	Conv.	U150	U250
$\dot{N}_n$, n/s	$2.71 \cdot 10^{14}$	$3.15 \cdot 10^{13}$	$2.32 \cdot 10^{13}$

Figures 4 and 5 show the neutron density distribution in the target regions for the U150 and the conventional source. In the U150 source the neutron density along the beam axis is rising immediately within the first millimeter of the target. The neutron density remains almost constant over the full thickness of the Ti-alloy target. In case of the conventional source, the neutron density is increasing linearly following the development of the electron-induced shower development in the W-25Re target. The maximum neutron density in the target of the U150 source is $2.2 \cdot 10^{14}$ n/s; this corresponds to a neutron irradiation dose of $3.6 \cdot 10^{25}$ n/m^2 after 5000 hours of source operation. A target rotation reduces this value to $1.5 \cdot 10^{23}$ n/m^2 if the target axis is 38 cm off the incident beam axis (see also Figure 2). The maximal acceptable neutron fluence which does not result in significant changes of mechanical properties of the Ti-alloy target is in the range $(2 \div 8) \cdot 10^{24}$ n/m^2 [4].

The activation of a positron source induced by photons from 250 GeV electrons passing a 35 m long undulator with a wiggler field of 1.7 T was calculated by N. Tesch [5]. His approach has been used to estimate the dose rates from

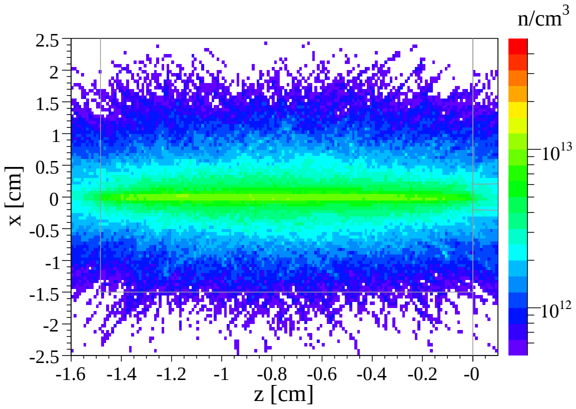

Figure 4: Neutron density in the Ti-6Al-4V target of the undulator based source.

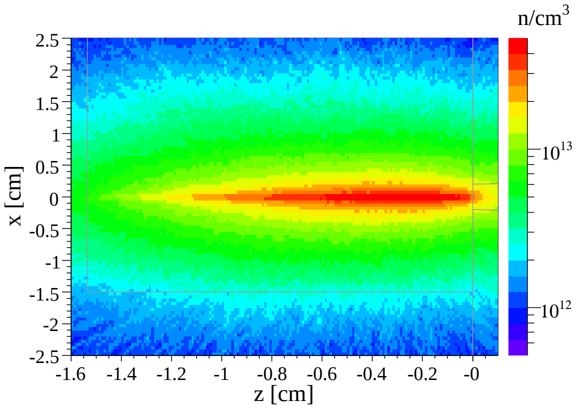

Figure 5: Neutron density in the W-25Re target of the conventional source.

the activity. The saturation activity, $A_{\rm sat}$, and the activity after 5000 hours of operation, $A_{\rm 5000h}$, have been calculated by FLUKA. The equivalent dose rates in soft tissue at a depth of 10 mm at a distance of 1 m from the source have been estimated after 5000 hours of operation, $\dot{D}_{\rm 5000h}$, and followed by one week of shut down, $\dot{D}_{\rm +1w}$. Table 4 lists the activation and dose rate for the U150 source. For the Ti-alloy target wheel 93% of the γ-dose rate $\dot{D}_{\rm +1w}$ is due to ^{46}Sc with $T_{1/2}$ = 84 d. ^{46}Sc radiates photons of 1.1 MeV.

Table 4: Activation and dose rates for U150 source.

	$A_{\rm sat}$ GBq	$A_{\rm 5000h}$ GBq	$\dot{D}_{\rm 5000h}$ mSv/h	$\dot{D}_{\rm +1w}$ mSv/h
Target	5288	3421	437	164
AMD	3689	3566	81	0.08
Collimator	1090	1077	21	0.08
Solenoid	943	932	2.7	~ 0
	11011	8996	542	164

Although the activity $A_{\rm 5000h}$ of the Ti-5Al-2.5Sn target is about 17% higher that of the Ti-6Al-4V target, no significant difference in $\dot{D}_{\rm +1w}$ has been obtained.

The total activation of the different sources is shown in Table 5. The dose rate of the conventional source is much higher than that of the undulator based source. A remote target handling is required for both types of positron sources.

Table 5: Comparison of the total activation and dose rates.

	Conv.	U150	U250
$A_{\rm 5000h}$, GBq	602850	8996	10849
$\dot{D}_{\rm +1w}$, mSv/h	4007	164	130

The influence of positron acceleration inside the capture section has been estimated. The positrons emerging from the target wheel have been tracked in an accelerating electrical field up to the inner surface of the “effective” collimator using the ASTRA code. The resulting coordinates and momenta of the positrons have been transmitted into FLUKA. No significant changes in the radiation levels have been found. But the energies deposited in the collimator and the solenoid have been slightly increased due to a larger positron energy and higher photon flux in radial direction.

SUMMARY

FLUKA calculations for the undulator based and the conventional positron sources have been performed. Neutron fluxes, activation of source parts and dose rates have been studied. The dose rate of the conventional source is about 24 times higher than that of the undulator based source (150 GeV drive beam). In the conventional source 8.6 times more neutrons are generated than in the undulator based source. The annual neutron irradiation dose of the Ti-alloy target is about ten times smaller than the maximal acceptable neutron fluence which does not result in significant changes of the mechanical properties of the target material.

ACKNOWLEDGEMENT

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