Short Report: Study of the Background Produced inside the Liquid Hydrogen Target using FLUKA

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Abstract

This report presents the results from the study of the background produced in the liquid hydrogen target itself. Among others, the contribution of the secondary reactions in the liquid hydrogen target to the increase of the counting rate in the detector counting Moller electrons is significant, ~87 %. At the same time, the background rates increase by a factor of more than 10. The results are based on FLUKA simulation.

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While in the previous short report [SIMI2024] we studied the background produced in the air surrounding liquid hydrogen target in this report we'll try to estimate the contribution of the secondary reactions in the liquid hydrogen target (LH2) to the measured electron rates. The results are obtained using FLUKA [FERRARI 2005, BATTISTONI 2007], a fully integrated particle physics Monte Carlo simulation package with many applications in high energy experimental physics and engineering, shielding, detectors and telescopes design, cosmic ray studies, dosimetry, medical physics and radiobiology. The physical mechanisms implemented in today's simulation software are very accurate and the differences between the simulated and measured results are in the most cases negligible.

The inputs for the simulation were obtained from Lorenzo Zana depository [ZANA 2022] but were slightly modified.

Figure 1. shows the side view of the Moller experiment set-up in Hall A as defined in the input file from Lorenzo Zana depository [ZANA 2022]. Figure 2. shows detailed geometry around the liquid hydrogen target. Lastly, Figure 3. shows the relative position of the detector plane next to the beam line 2650 cm downstream from the center of the target.

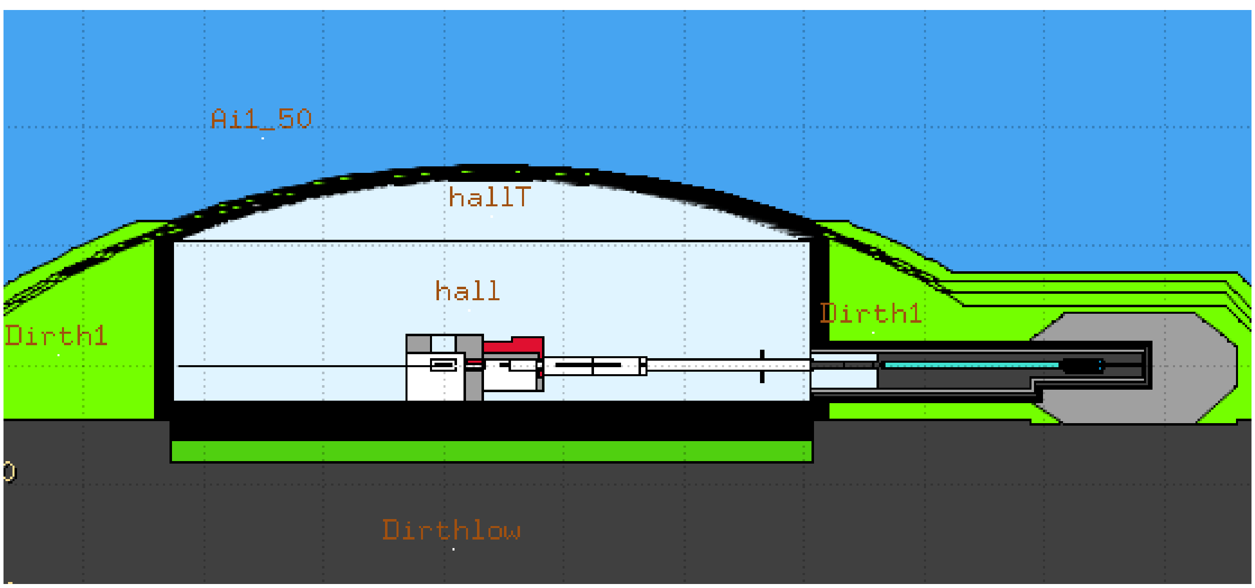

Figure 1. Side view of the Moller experiment set-up in Hall A as defined by the input file from Lorenzo Zana depository [ZANA 2022].

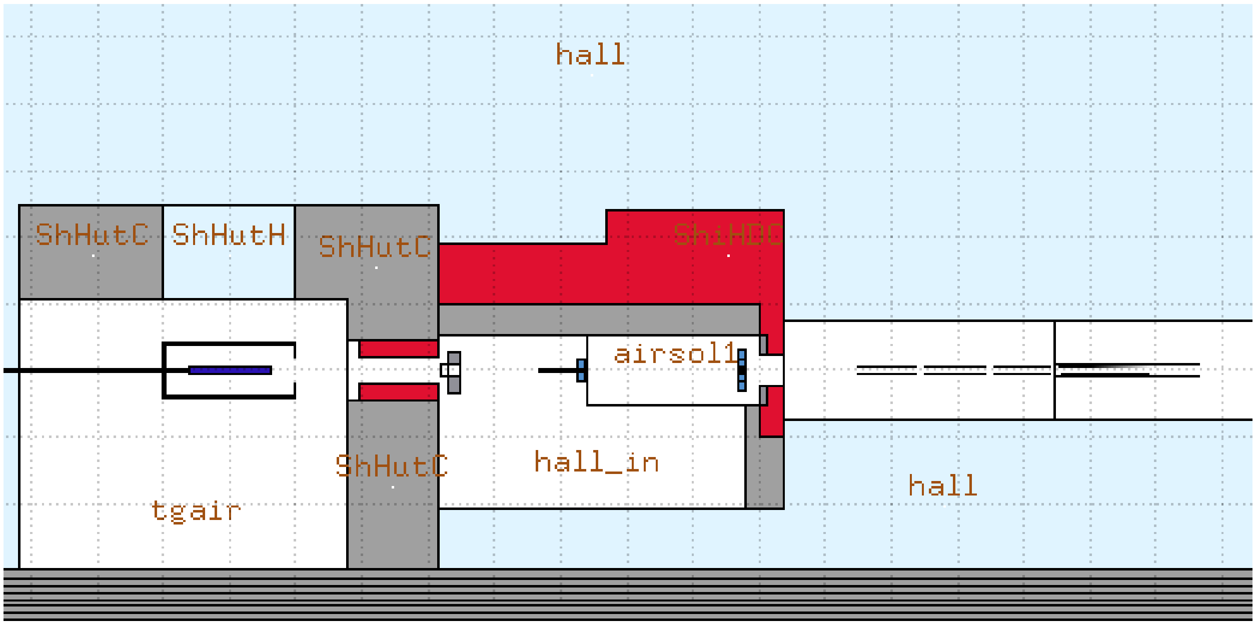

Figure 2. Side view of the Moller experiment set-up around in the liquid hydrogen target as defined by the input file from Lorenzo Zana depository [ZANA 2022].

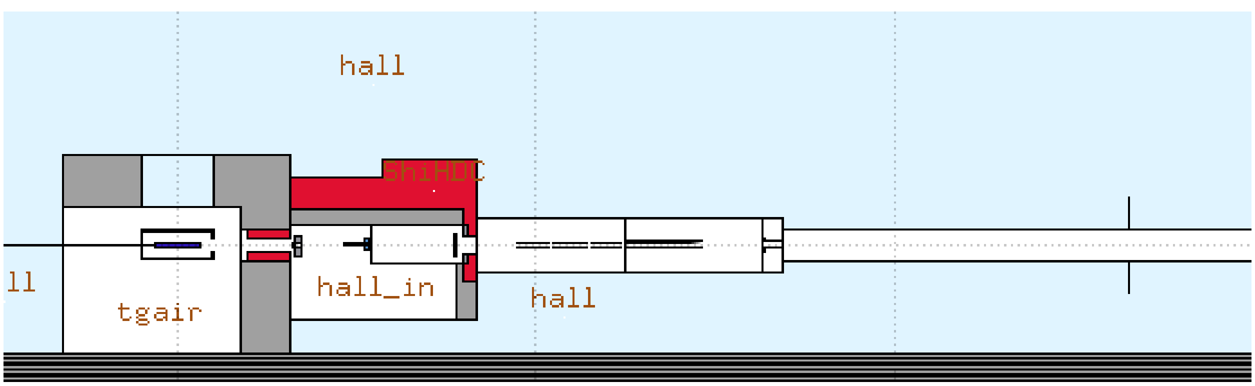

Figure 3. Side view of the Moller experiment as defined by the input file from Lorenzo Zana depository [ZANA 2022], with the detector plane next to the beam line at the position of 2650 cm downstream from the center of the target.

The overall simulation is straightforward. It consists of propagating 11 GeV electron beam through 125 cm long liquid hydrogen target with the inclusion of all possible reactions as defined in FLUKA, and counting scattered electrons at the position of the detector plane. For this simulation the material assigned to the volumes *tgair*, *hall_in*, and *airsol1* shown in Figure 2. was *vacuum*. Radial distributions of the electrons were recorded at the detector plane. All the dimensions were taken from MOLLER Technical Design Report [TDR 2024]. The magnetic field was taken from Lorenzo Zana depository [ZANA 2022]. While the description of the magnetic field will be improved in future, for the purpose of this study small uncertainty in the description of the magnetic field is not very important if the same field is applied in all cases. The expected radial distribution of the electrons at the detector plane is shown in Figure 4.

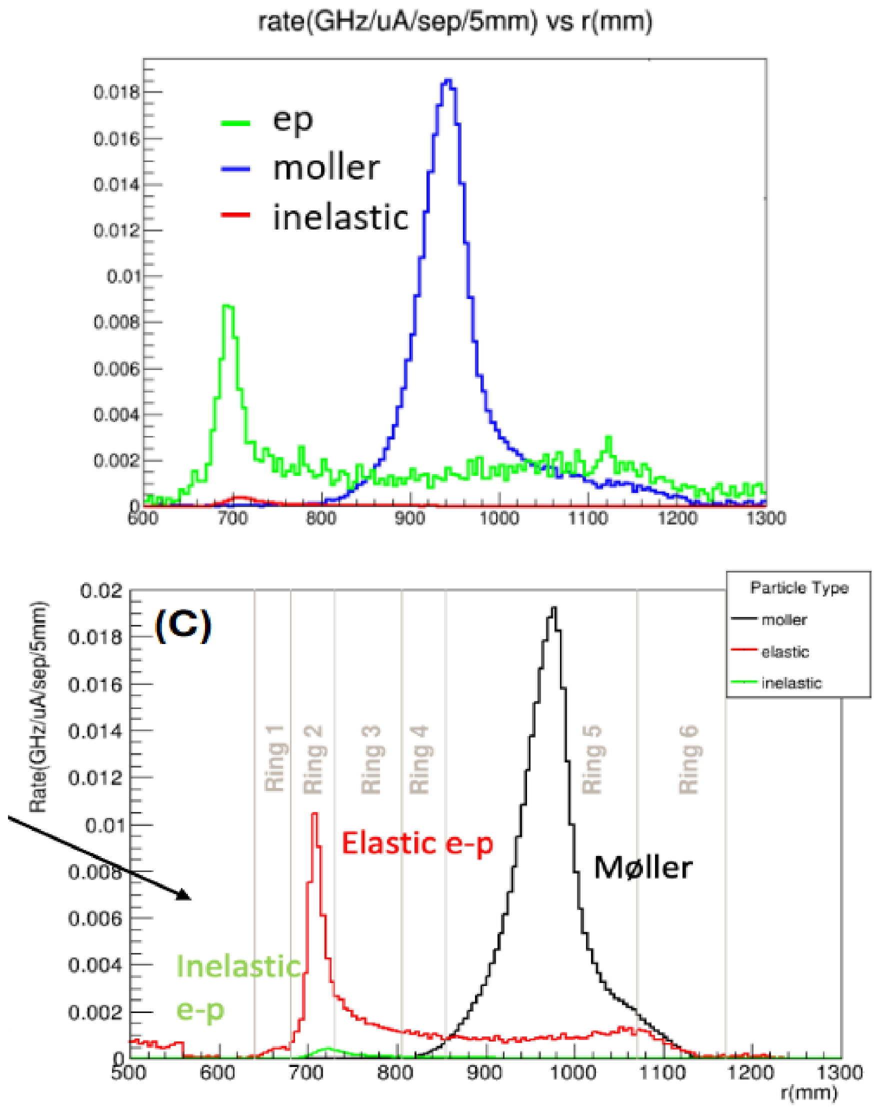

Figure 4. Radial distribution of the electrons at the detector plane **taken from the Technical Design Report (top)** ***[TDR 2024], and from the preliminary poster by Sayak Chatterjee (bottom) [SAYAK 2024]. "Rings" represent the names of the detectors occupying a particular radial position.***

The simulation is based on comparing the electron rates created in the gas hydrogen target, where the secondary reactions are highly suppressed, with the electron rates created in the liquid hydrogen target [CARL 2024]. The rates are scaled for the difference in the density.

Figure 5 shows the radial distribution of the electrons at the detector plane obtained by FLUKA in the case of the gas hydrogen target. The gas rates are multiplied by factor 846.5 to account for the difference in the density between gas and liquid hydrogen. Figure 6 shows the radial distribution of the electrons at the detector plane obtained by FLUKA in the case of liquid hydrogen target.

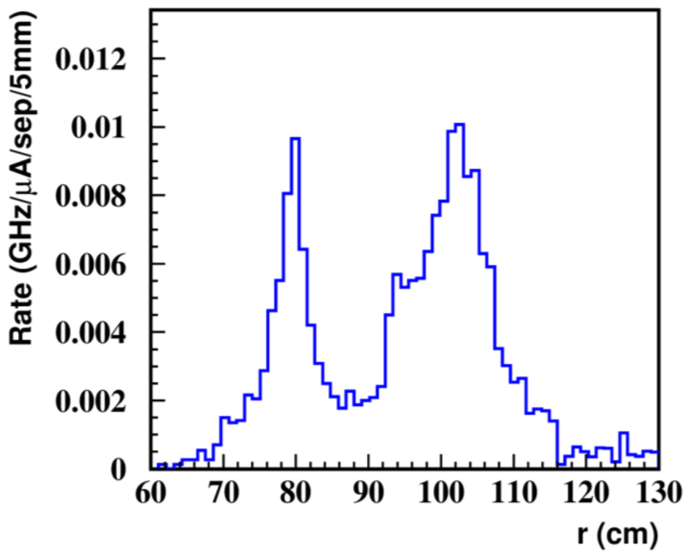

Figure 5. Radial distribution of the electrons created in the gas hydrogen target at the detector plane. The electrons are generated by FLUKA in the same scale as Figure 4. The rate is multiplied by 846.5 to account for the difference in the density between gas and liquid hydrogen.

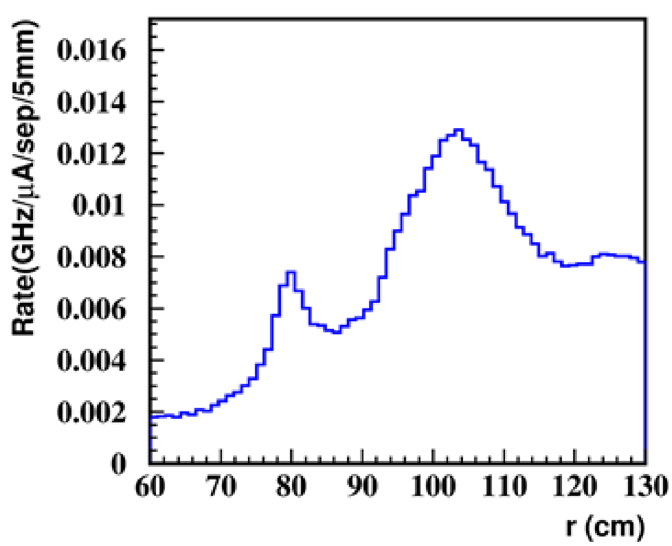

Figure 6. Radial distribution of the electrons created in the liquid hydrogen target at the detector plane. The electrons are generated by FLUKA in the same scale as Figures 4 and 5.

There are several observations. Comparing Figure 5 and 6 one notices that there is, as expected, negligible background in the case of gas hydrogen target shown in Figure 5. For this reason, electron distribution in Figure 5 is very similar to the distribution in Figure 4. But, if one compares Figure 5 and Figure 4, one notices that the eP electron distributions are very similar, but the peaks in the ee Moller distributions are different by approximately factor of two. Now, if we plot the rates for the beam current of 65 μA on a scale appropriate to obtain the integrated rates, shown in Figure 7, we obtain for the total ee Moller rates of ~130 GHz, comparable to the rate of 134 GHz in the Technical Design Report [TDR 2024], which suggest that the distribution in the Figure 5 must be correct. By the way, integrating eP distribution we obtain for the total eP rates ~60 GHz. The estimated errors for these rates are ~10%.

(The total rate for the Moller scattering is estimated to be 134 GHz [TDR 2024]. Our estimate is 150 GHz. Actually, if one takes the luminosity from the TDR report of $2.4 \cdot 10^{39}$ cm^{-2} sec^{-1} and the cross section of ~60 μbarn the total rate in Table 1 in TDR should be 144 GHz.)

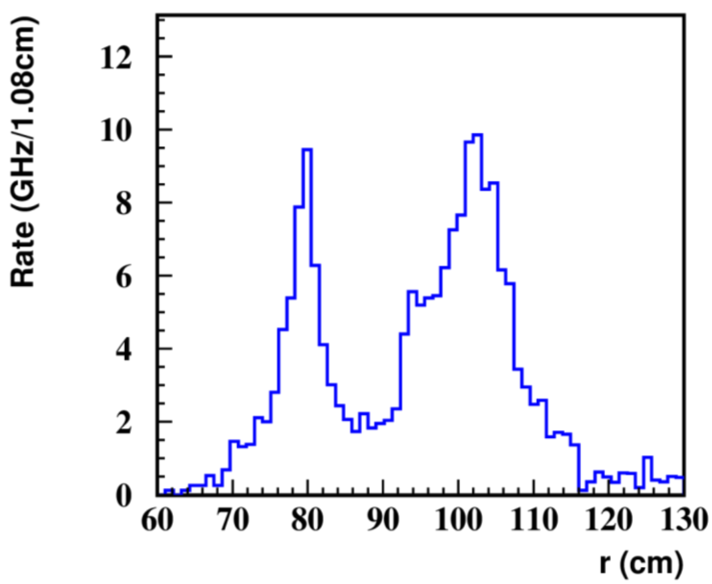

Figure 7. Radial distribution of the electrons created in the gas hydrogen target at the detector plane in the absolute rate scale for the beam current of 65 μA. The electrons are generated by FLUKA. The rate is multiplied by 846.5 to account for the difference in the density between gas and liquid hydrogen.

Figure 8 shows the overlay of the radial distributions of the electrons generated in the hydrogen gas and hydrogen liquid targets in the absolute rate scale for the beam current of 65 μA on a scale appropriate to compare integrated rates. The hydrogen gas rate is scaled for the difference in the density of gas and liquid hydrogen. The difference between the distribution of the electrons produced in the liquid hydrogen target and the electrons produced in the gas hydrogen target, shown in Figure 9, represent the background generated in the liquid hydrogen target. Negative background means that the primary electrons disappeared from the original reaction channel due to secondary interactions.

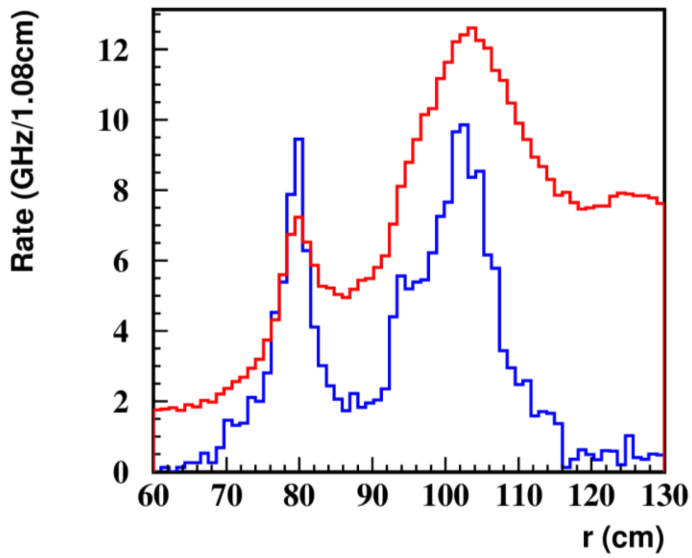

Figure 8. Overlay of radial distributions of electrons at the detector plane generated by FLUKA in the absolute rate scale. The top (red) curve are the electrons produced in liquid hydrogen target and the lower (blue) curve are the electrons produced in gas hydrogen target scaled for the difference in the gas and liquid hydrogen density. The beam current was 65 μA.

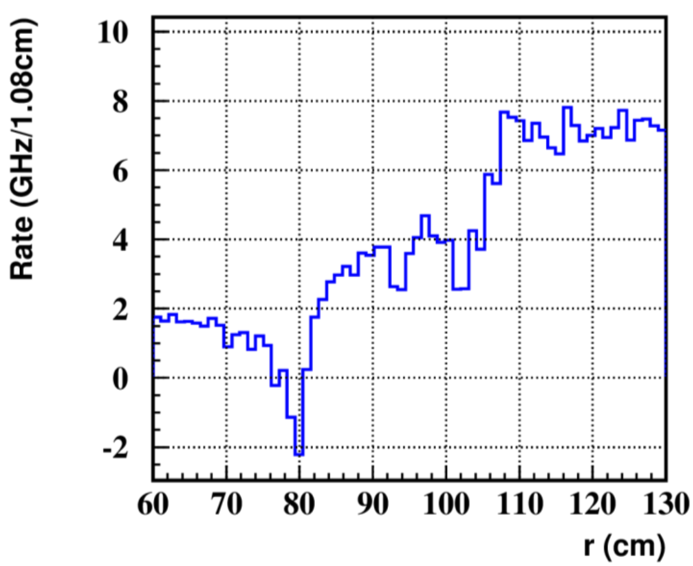

Figure 9. The difference between the distribution of the electrons produced in the liquid hydrogen target and the electrons produced in the gas hydrogen target for the beam current of 65 μA.

The rates obtained integrating the differential rates from Figure 8 are shown in Table 1.

From the results shown in Table 1 we see a significant difference in the rates between the liquid hydrogen target and density normalized gas hydrogen target. In the background regions outside the detector acceptances the rate changes from 2.5 to 18 GHz (a factor of ~6) or from 5.4 to 83 GHz (a factor of ~14). In the ee Moller scattering region covered by Ring 5 detector the rate changes from 120 to 224 GHz (an increase of 87 %). In the region covered by Ring 2 the rate changes from 43.6 to 46.6 GHz. At first this looks as a small change, but as seen in Figure 8, the loss of the primary eP elastic counting due to secondary reactions is compensated by the increase in rate due to the secondary reactions in the liquid hydrogen target. This means that even in the Ring 5 the contribution of the secondary reaction channels is worse than estimated 87 %, since there we also expect the loss of rate in the primary ee Moller reaction channel due to the secondary scattering in liquid hydrogen target.

Independently, if we compare the Moller scattering rate for the Ring 5 detector for the liquid hydrogen target from Table 1 of 224 GHz to the theoretically estimated rate of 134 GHz [TDR 2024] we still get an increase in rate of 67 % due to the secondary reaction channels. Also, if we compare the Moller scattering rate for the Ring 5 detector for the normalized gas hydrogen target from Table 1 of 120 GHz to the theoretically estimated rate of 134 GHz [TDR 2024] we get a loss in primary ee Moller rate of ~10 %.

Rates							
	Total (all Rings: 72-124 cm)	eP (Ring 2: 75-82 cm)	eP at maximum	ee (Ring 5: 93-114 cm)	ee at maximum	Backgrnd (60 -70 cm)	Backgrnd (120 -130 cm)
Normalized gas H target	196 GHz	43.6 GHz	9.5 GHz	120 GHz	9.9 GHz	2.5 GHz	5.4 GHz
Liquid H target	412 GHz	46.6 GHz	7.2 GHz	224 GHz	12.6 GHz	18 GHz	83 GHz
Difference	216 GHz	3 GHz	-2.3 GHz	104 GHz	2.7 GHz	15.5 GHz	77.6 GHz
Background	110 %	6.8 %	-24 %	87 %	27 %	620 %	1437 %

Table 1. Integrated electron rates for electrons produced in the gas hydrogen and liquid hydrogen targets. The dimensions of the Ring detectors did not change, but positions were shifted according to the shift of electron peaks due to the difference in the applied magnetic fields.

Conclusion

We have presented the results from the study of the background produced in the liquid hydrogen target itself. While the details can be found in Table 1, the most important findings is that the secondary reactions in the liquid hydrogen target increase the counting rate in the detector counting Moller electrons significantly, by ~87 %. Also, the background rates increase by a factor between 6-14.

The results are based on FLUKA simulation. Because of the consequences of these results, we suggest that those results are independently verified.

References

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