Electron Beam Technology for Re-processing of Personal Protective Equipment

Min Huang[a], Md Kamrul Hasan[a], Suresh D. Pillai[b], Matt Pharr[a], David Staack[a]

[a]Department of Mechanical Engineering, Texas A&M University, 3123 Spence St, College Station, TX 77840, USA

[b]National Center for Electron Beam Research, Texas A&M University, College Station, TX 77840, USA

*dstaack@tamu.edu

Paper Abstract:

Beginning with the outbreak of COVID-19 at the dawn of 2020, the continuing spread of the pandemic has challenged the healthcare market and the supply chain of Personal Protective Equipment (PPE) around the world. Moreover, the emergence of the variants of COVID-19 occurring in waves threatens the sufficient supply of PPE. Among the various types of PPE, N95 Respirators, surgical masks, and medical gowns are the most consumed and thus have a high potential for a serious shortage during such emergencies. Considering the unanticipated demand for PPE during a pandemic, re-processing of used PPE is one approach to continue to protect the health of first responders and healthcare personnel. This paper evaluates the viability and efficacy of using FDA-approved electron beam (eBeam) sterilization technology (ISO 11137) to re-process used PPE. PPEs including 3M N95 Respirators, Proxima Sirus gowns, and face shields were eBeam irradiated in different media (air, argon) over a dose range of 0-200 kGy. Several tests were then performed to examine surface properties, mechanical properties, functionality performance, discoloration phenomenon, and liquid barrier performance. The results show a reduction of filtration efficiency to about 63.6% in the N95 Respirator; however, charge regeneration may improve the re-processed efficiency. Additionally, mechanical degradation was observed in Proxima Sirus gown with increasing dose up to 100 kGy. However, no mechanical degradation was observed in the face shields after 10 times donning and doffing. Apart from the face shield, N95 Respirators and Proxima Sirus gown both show significant mechanical degradation with dose over sterilization doses (>25 kGy), indicating that eBeam technology is not appropriate for the re-processing these PPEs.

Keywords: N95 Respirator, Medical Gown, Face Shield, Electron Beam, Reprocessing, Personal Protective Equipment

S-Table 1. Replicates number for each material characterization method

	Strap Tensile Testing	Particulate Filtration Testing	Surface Wettability Testing	Yellowness Index	Hydrostatic Testing	Water Impact Penetration	Surface Morphology Testing	Mechanical Testing
Replicate Number	1	1	3/6	2	3	1	1	3/4

S-Table 2. Surface Wettability Testing for 3M N95 Respirator Filter

Surface Wettability/Water Contact Angle [°]								
	Frontside				Backside			
Condition (ppm-min)	Control	Open air-25 kGy	Sealed argon-25 kGy	Sealed air-100 kGy	Control	Open air-25 kGy	Sealed argon-25 kGy	Sealed air-100 kGy
Sample#								
1	134.7	138.9	135.8	134.5	143.7	145.4	143.6	142.6
2	137.4	139.7	132.9	133.1	140.5	146.0	144.2	142.7
3	136.0	139.0	130.4	131.3	138.9	145.6	145.7	143.1
4	137.5	133.1	134.9	132.7	140.8	145.4	142.1	140.5
5	133.1	135.3	133.6	131.0	142.5	146.1	147.5	142.8
6	133.1	140.0	132.3	136.3	143.8	146.8	144.0	142.6

S-Table 3. Surface Wettability Testing for Proxima Gown

Surface Wettability/Water Contact Angle [°]												
	Frontside						Backside					
Condition (ppm-min)	Control	25 kGy	50 kGy	75 kGy	100 kGy	200 kGy	Control	1800	3700	75 kGy	100 kGy	200 kGy
Sample#												
1	144.5	141.2	137.9	151.5	134.6	144.6	130.8	134.1	134.0	131.0	141.9	140.2
2	137.5	148.6	146.9	141.7	144.8	141.8	137.2	135.1	144.2	132.0	133.3	132.6
3	138.4	147.8	134.9	133.8	138.7	140.7	139.9	135.2	130.7	138.6	138.7	135.0
4	136.2	141.2	142.9	140.7	141.3	140.2	134.7	130.0	139.8	133.1	140.2	136.9
5	150.2	140.9	145.7	146.7	138.0	143.9	142.0	141.0	137.3	N/A	132.7	133.2
6	145.0	140.9	145.7	143.3	142.9	139.3	137.8	142.0	132.1	139.2	137.4	136.7

S-Table 4. Surface Wettability Testing for Proxima Gown (frontside) with 3 sec, 60 sec, and 180 sec delayed measurements.

Surface Wettability/Water Contact Angle [°]						
	Control – 0 kGy			200 kGy		
Condition (ppm-min)	3 s	60 s	180 s	3 s	60 s	180 s
Sample#						
1	140.0	145.9	144.5	135.5	138.9	133.2

2	139.3	144.9	143.2	134.9	137.5	134.1
3	145.0	145.7	147.8	131.1	133.5	131.7

S-Table 5. Yellowness Index Testing for 3M N95 Respirator Filter

Yellowness Index – 3M N95 Respirator Filter								
	Inside				Outside			
Condition (ppm-min)	Control	Open air-25 kGy	Sealed argon-25 kGy	Sealed air-100 kGy	Control	Open air-25 kGy	Sealed argon-25 kGy	Sealed air-100 kGy
Replicates								
1	3.00	5.44	4.87	4.85	7.78	3.53	2.79	8.85
2	4.21	6.53	6.31	6.01	8.12	5.08	3.15	4.97

S-Table 6. Hydrostatic pressure Testing for Proxima Gowns

Hydrostatic pressure Testing for Proxima Gowns			
Condition (ppm-min)	Control	100 kGy	200 kGy
Replicates			
1	1.191	0.796	0.923
2	1.267	1.078	0.553
3	1.182	1.159	1.128

S-Table 7. Water Impact Penetration Testing for Proxima Gowns

Water Impact Penetration Testing for Proxima Gowns			
Condition (ppm-min)	Control	100 kGy	200 kGy
Replicates			
1	0.05	0.72	0.87

S-Table 8. Mechanical Testing for 3M N95 Respirators

Inner Layer				
Condition (ppm-min)	Force at Break [N]			
	Replicate-1	Replicate-2	Replicate-3	Replicate-4
Control-0	23	20.5	18.1	20.8
Open air-25 kGy	31.7	14.2	24.6	10.3
Sealed argon-25 kGy	13.1	16.4	18.3	18.7
Sealed air-100 kGy	20.2	17.5	27.8	15.1
	Displacement at Break [mm]			
	Replicate-1	Replicate-2	Replicate-3	Replicate-4
Control-0	3.7	4.6	5.4	4.8

	Replicate-1	Replicate-2	Replicate-3	Replicate-4
Open air-25 kGy	4.1	2.1	2.6	2.3
Sealed argon-25 kGy	3.4	3.4	2.9	5.3
Sealed air-100 kGy	2.7	3.5	3.2	2.0
	Elongation at break [%]			
	Replicate-1	Replicate-2	Replicate-3	Replicate-4
Control-0	11.5	14.2	16.7	14.7
Open air-25 kGy	12.5	6.4	8.1	7.0
Sealed argon-25 kGy	10.6	10.6	9.0	16.2
Sealed air-100 kGy	8.4	10.8	9.9	6.3
	Middle Layer			
Condition (ppm-min)	Force at Break [N]			
	Replicate-1	Replicate-2	Replicate-3	Replicate-4
Control-0	4.1	3.8	3.8	3.8
Open air-25 kGy	3.1	2.6	2.7	2.5
Sealed argon-25 kGy	4	3.4	3.3	3.5
Sealed air-100 kGy	0.8	0.7	0.6	0.5
	Displacement at Break [mm]			
	Replicate-1	Replicate-2	Replicate-3	Replicate-4
Control-0	2.1	2.3	2.6	2.8
Open air-25 kGy	2.6	2.1	1.8	2.3
Sealed argon-25 kGy	1.4	1.8	1.6	1.9
Sealed air-100 kGy	0.4	0.3	0.4	0.3
	Elongation at break [%]			
	Replicate-1	Replicate-2	Replicate-3	Replicate-4
Control-0	6.5	7.0	8.0	8.5
Open air-25 kGy	8.0	6.5	5.4	7.0
Sealed argon-25 kGy	4.4	5.4	4.9	5.9
Sealed air-100 kGy	1.3	0.8	1.3	0.8
	Outer Layer			
Condition (ppm-min)	Force at Break [N]			
	Replicate-1	Replicate-2	Replicate-3	Replicate-4
Control-0	11.9	18.6	21.9	16.8
Open air-25 kGy	18.6	16	19	10.2
Sealed argon-25 kGy	15.7	15	17.4	13.8
Sealed air-100 kGy	19.1	12.3	13.2	14.5
	Displacement at Break [mm]			
	Replicate-1	Replicate-2	Replicate-3	Replicate-4
Control-0	1.9	3.6	3.2	2.1
Open air-25 kGy	2.7	3.1	3.5	1.8

	Replicate-1	Replicate-2	Replicate-3	Replicate-4
Sealed argon-25 kGy	2.8	2.4	2.9	3.4
Sealed air-100 kGy	2.9	1.9	2.1	3.3
Elongation at break [%]				
	Replicate-1	Replicate-2	Replicate-3	Replicate-4
Control-0	5.9	11.0	9.9	6.4
Open air-25 kGy	8.3	9.5	10.9	5.4
Sealed argon-25 kGy	8.5	7.5	9.0	10.6
Sealed air-100 kGy	8.8	5.9	6.5	10.1
Elastomer Band				
Condition (ppm-min)	Force at Break [N]			
	Replicate-1	Replicate-2	Replicate-3	Replicate-4
Control-0	7.8	8.2	5.1	4.5
Open air-25 kGy	5.5	4.6	4.5	5.3
Sealed argon-25 kGy	10.9	5.8	4.8	14.1
Sealed air-100 kGy	15.0	13.8	14.9	14.6
Displacement at Break [mm]				
	Replicate-1	Replicate-2	Replicate-3	Replicate-4
Control-0	461.1	432.9	322.6	271.3
Open air-25 kGy	335.4	275.2	258.5	303.4
Sealed argon-25 kGy	550.8	331.6	279.0	629.0
Sealed air-100 kGy	686.7	638.0	657.2	676.5
Elongation at break [%]				
	Replicate-1	Replicate-2	Replicate-3	Replicate-4
Control-0	461.1	432.9	322.6	271.3
Open air-25 kGy	335.4	275.2	258.5	303.4
Sealed argon-25 kGy	550.8	331.6	279.0	629.0
Sealed air-100 kGy	686.7	638.0	657.2	676.5
Note: Distance between grips = 32.5 mm Apparent elongation: (displacement/distance between grips) *100				

S-Table 9. Mechanical Testing for Proxima Gowns

3M N95 Respirators			
Condition (kGy)	Force at Break [N]		
Control-0	34	31.4	32.8
25	21.4	23.8	26.1
50	21.4	21.5	24.7
75	17.8	18.3	17.3
100	11.7	10.2	11.7
200	9.2	8.3	9.1

	Displacement at Break [mm]		
Control-0	24.8	25.8	24.3
25	13.3	16.3	16.8
50	13.8	12.8	15.3
75	7.8	8.8	8.8
100	2.7	2.8	3.3
200	2.3	1.8	2.8
	Elongation at Break [%]		
Control-0	24.8	25.8	24.3
25	13.3	16.3	16.8
50	13.8	12.8	15.3
75	7.8	8.8	8.8
100	2.7	2.8	3.3
200	2.3	1.8	2.8
Note: Distance between grips = 100mm Apparent elongation: (displacement/distance between grips) *100			