Polyethylene & Tribology

JECOT Rabat, September 2010

A. Rodriguez MD; PhD

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HISTORY OF POLYETHYLENES

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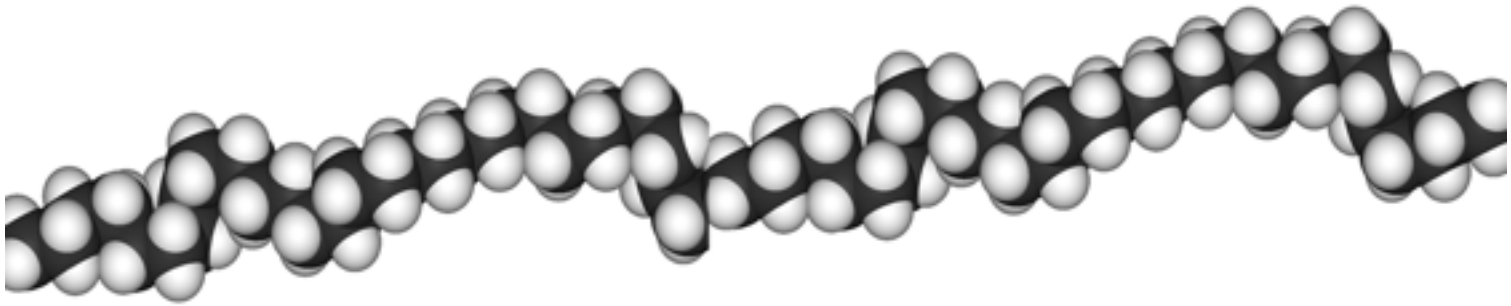
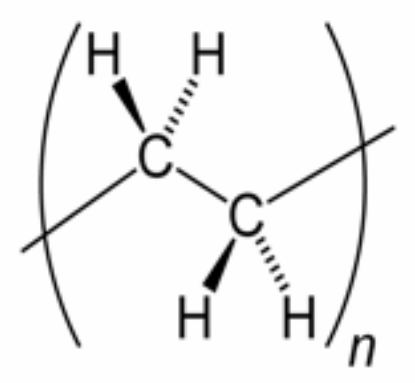


- 1898 Accidentally discovery by a German chemist Hans von Pechmann
- 1939 Beginning of the production of low density polyethylene
- 1951 Development of the Phillips catalyst
- 1953 Development of the Ziegler catalyst
- 1962 First implantation by J. Charnley

ULTRA HIGH MOLECULAR WEIGHT

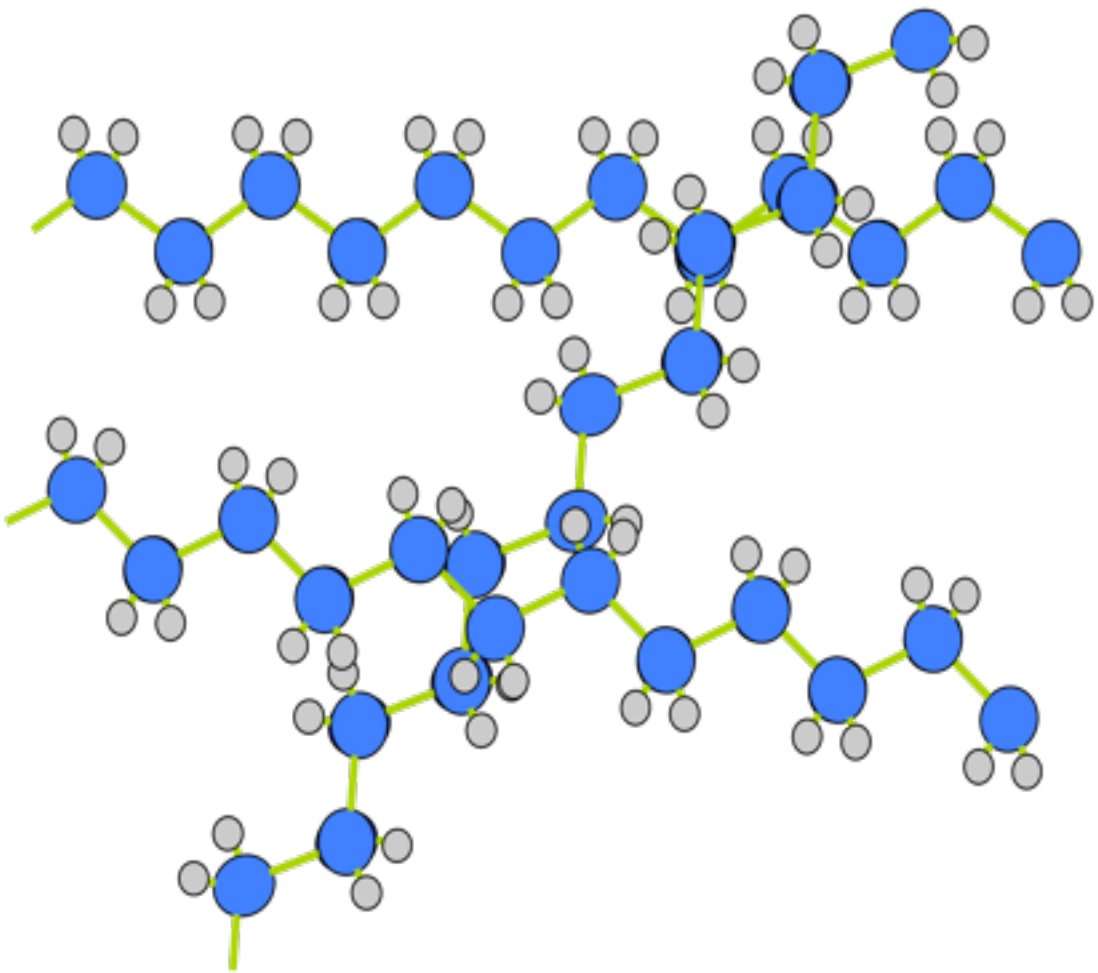


- Molecular weight usually between 2 and 6 million

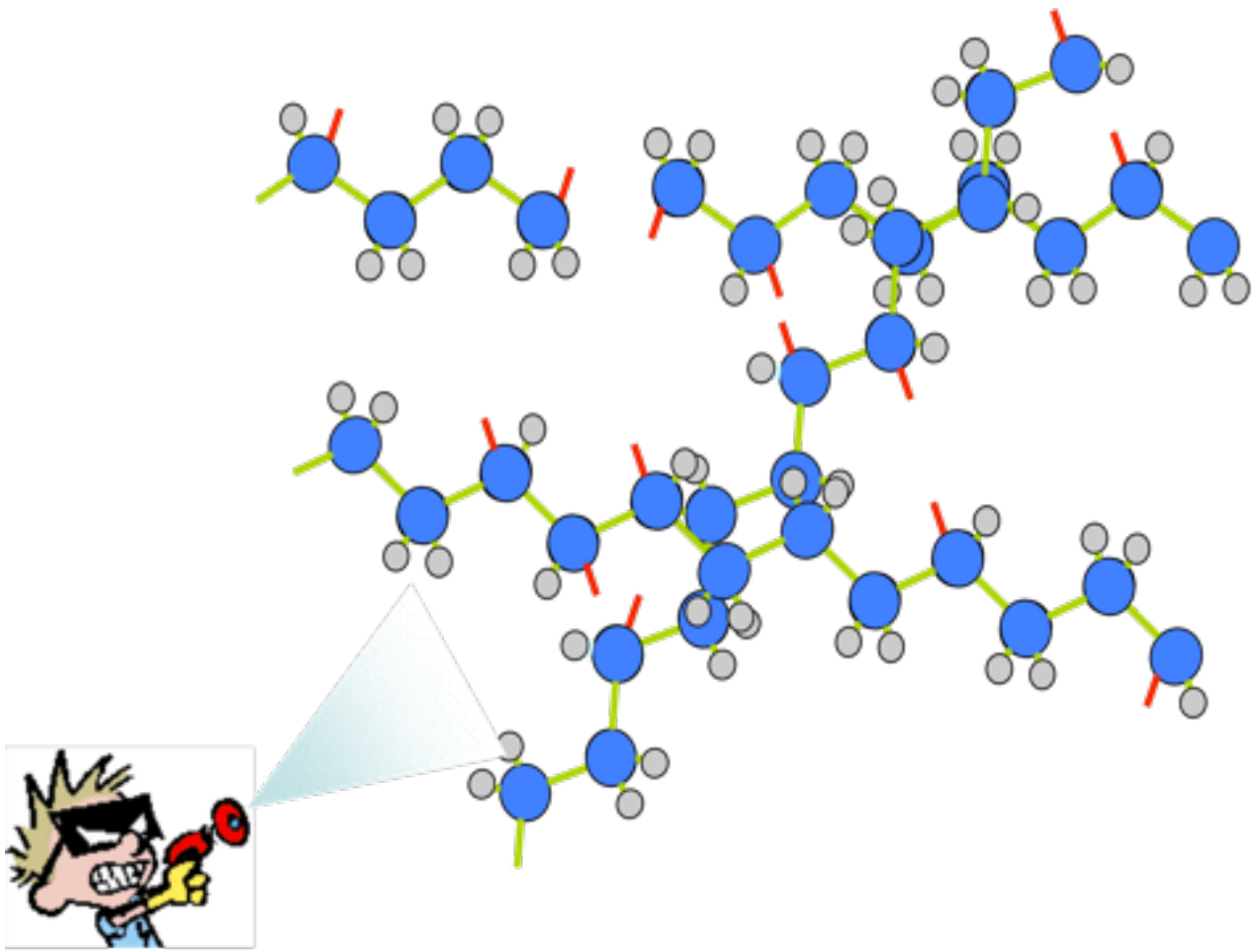
- Typical application:
  - Joint replacement
  - Skis and snowboards
  - Ice hockey and field hockey sticks

PRODUCTION

CROSS-LINKING OF UHMWPE



DEVELOPMENT OF HIGHLY CROSS-



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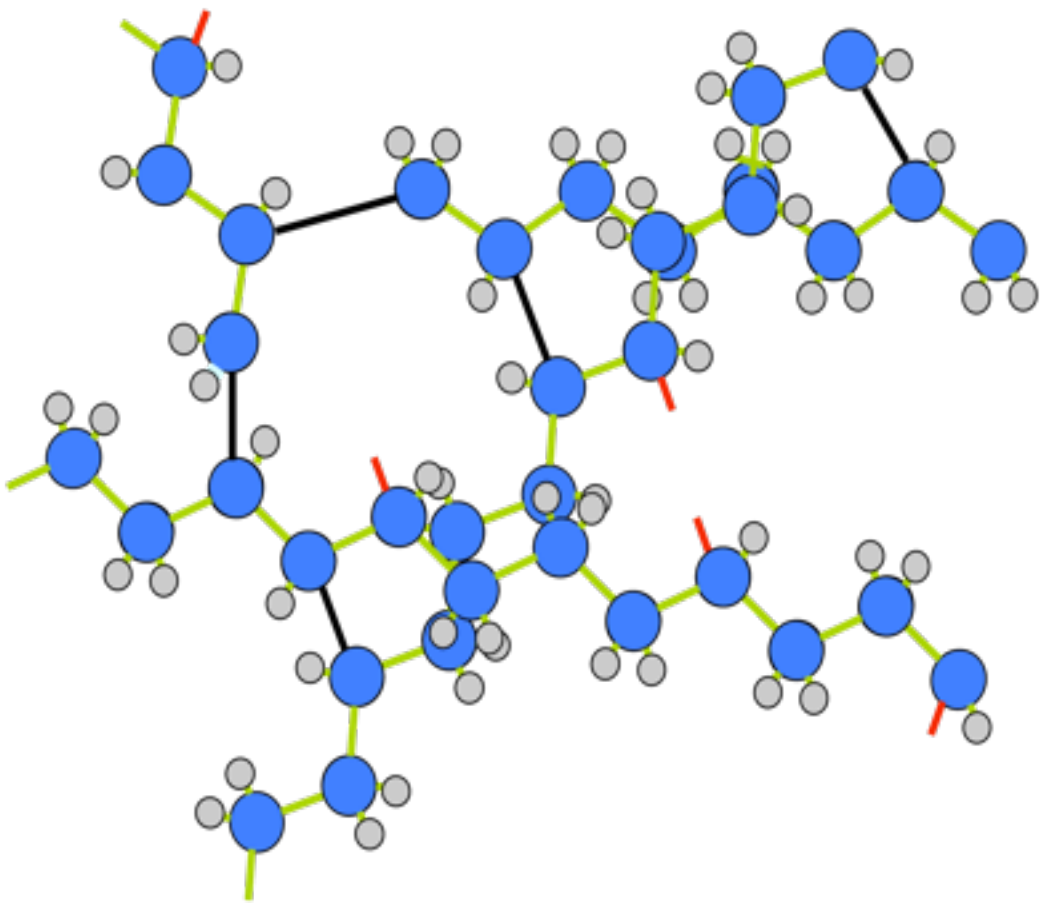

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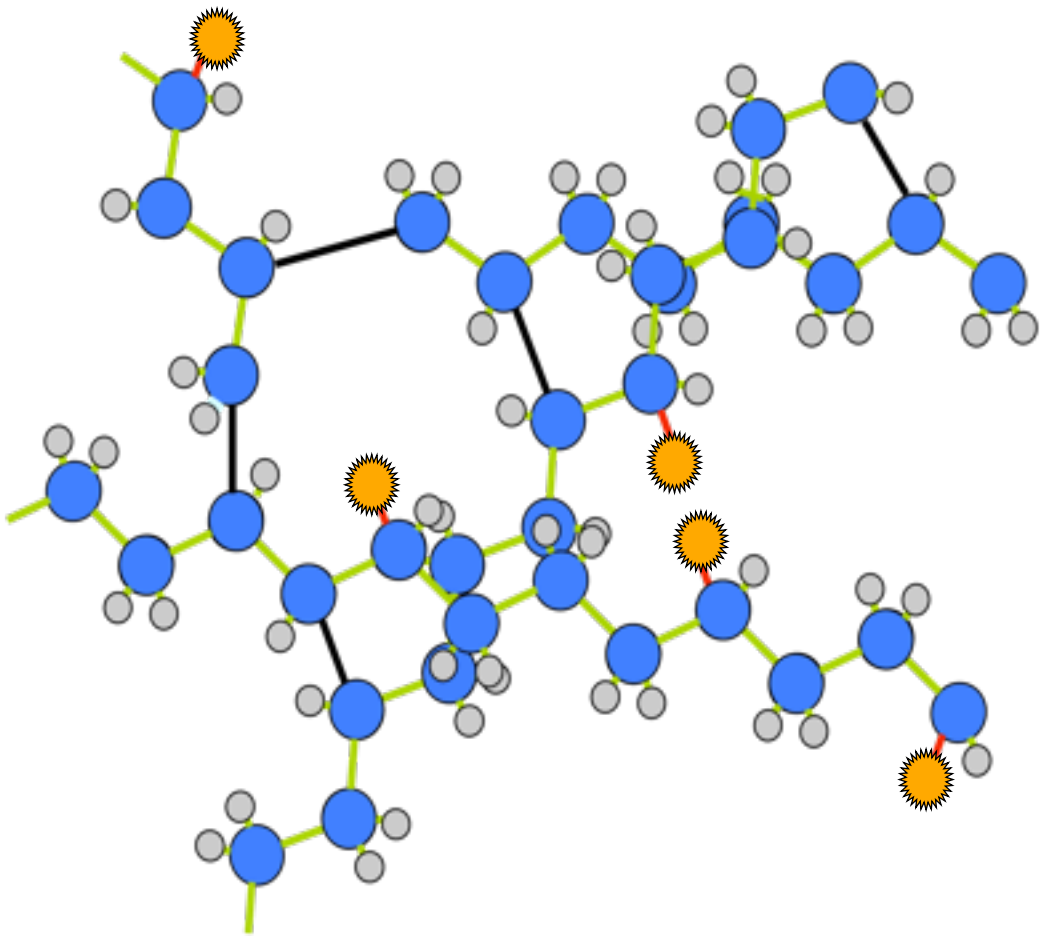
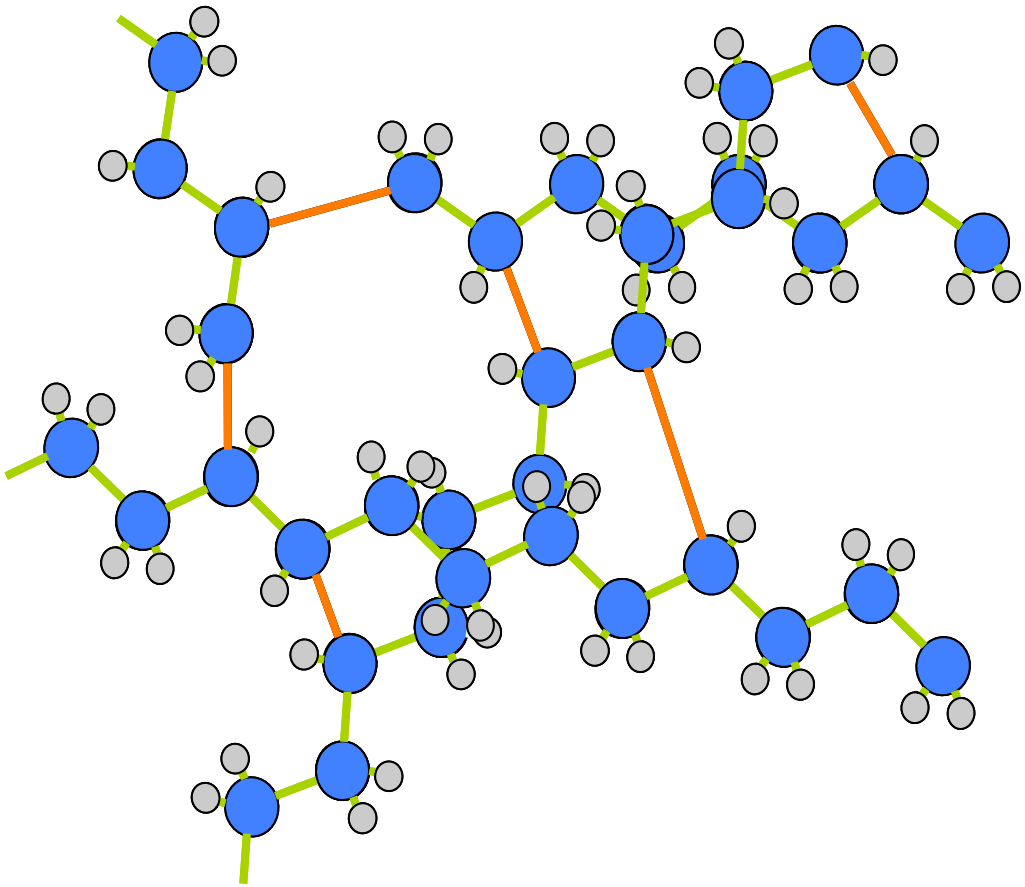


CROSS-LINKING OF UHMWPE



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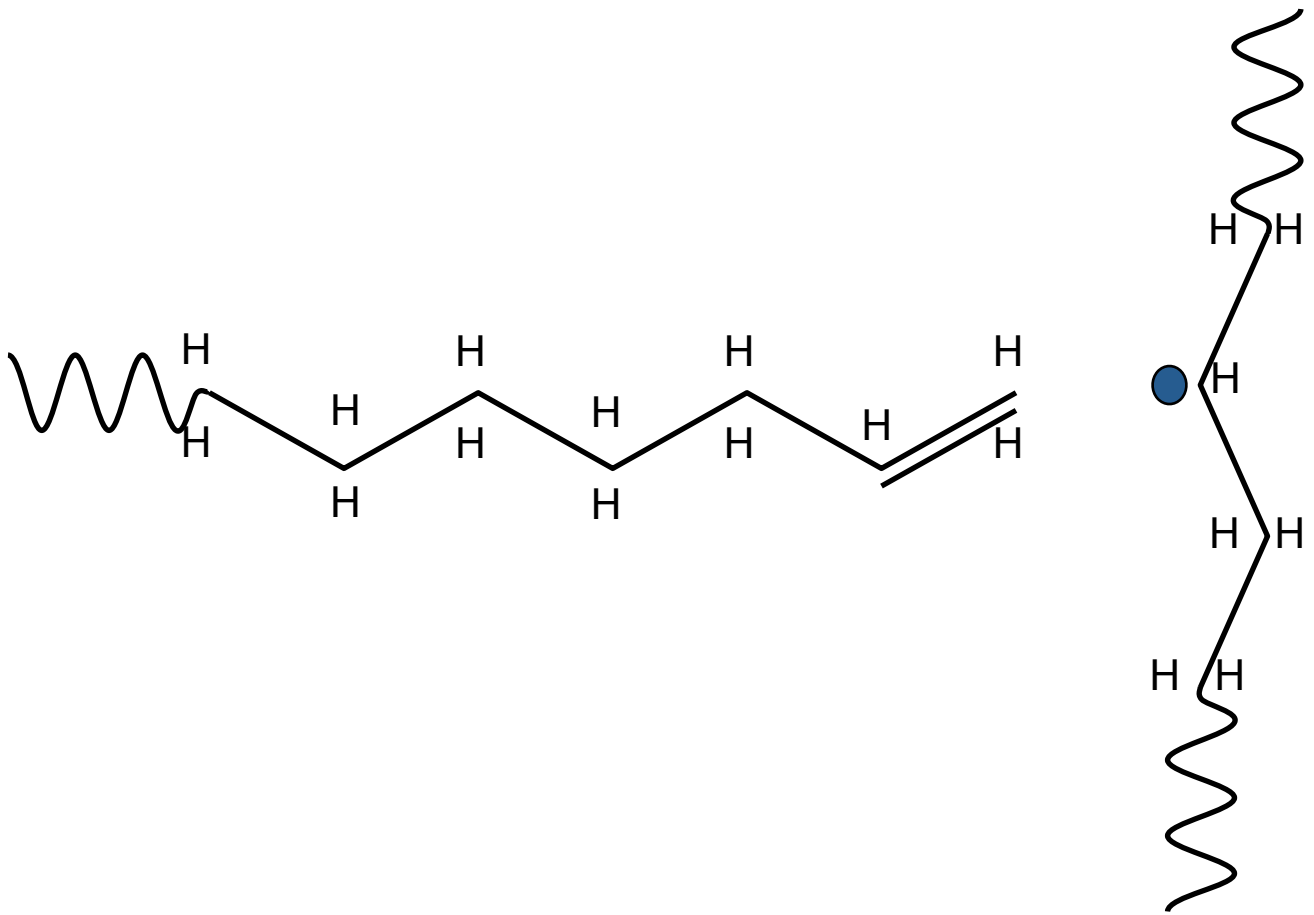

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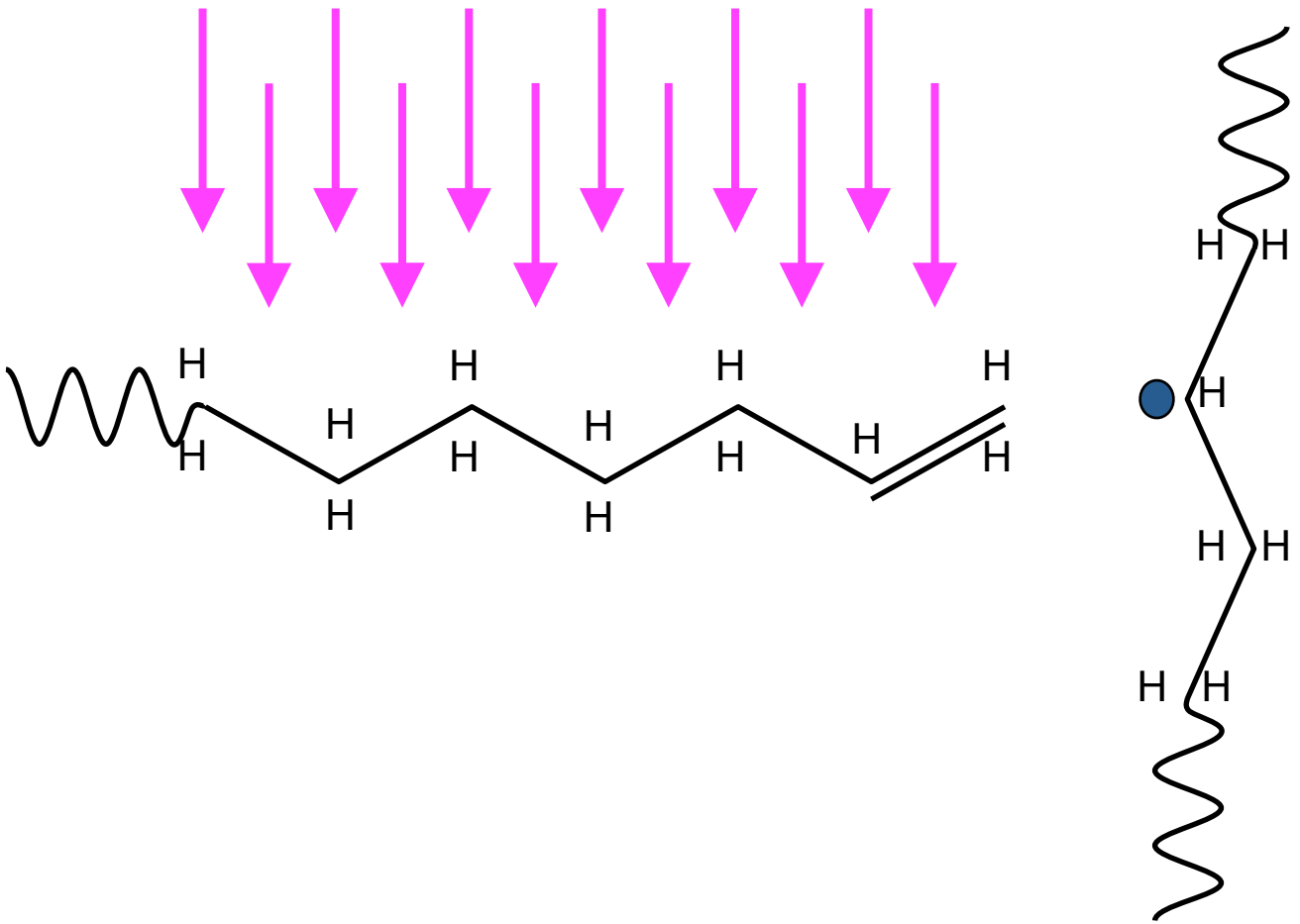

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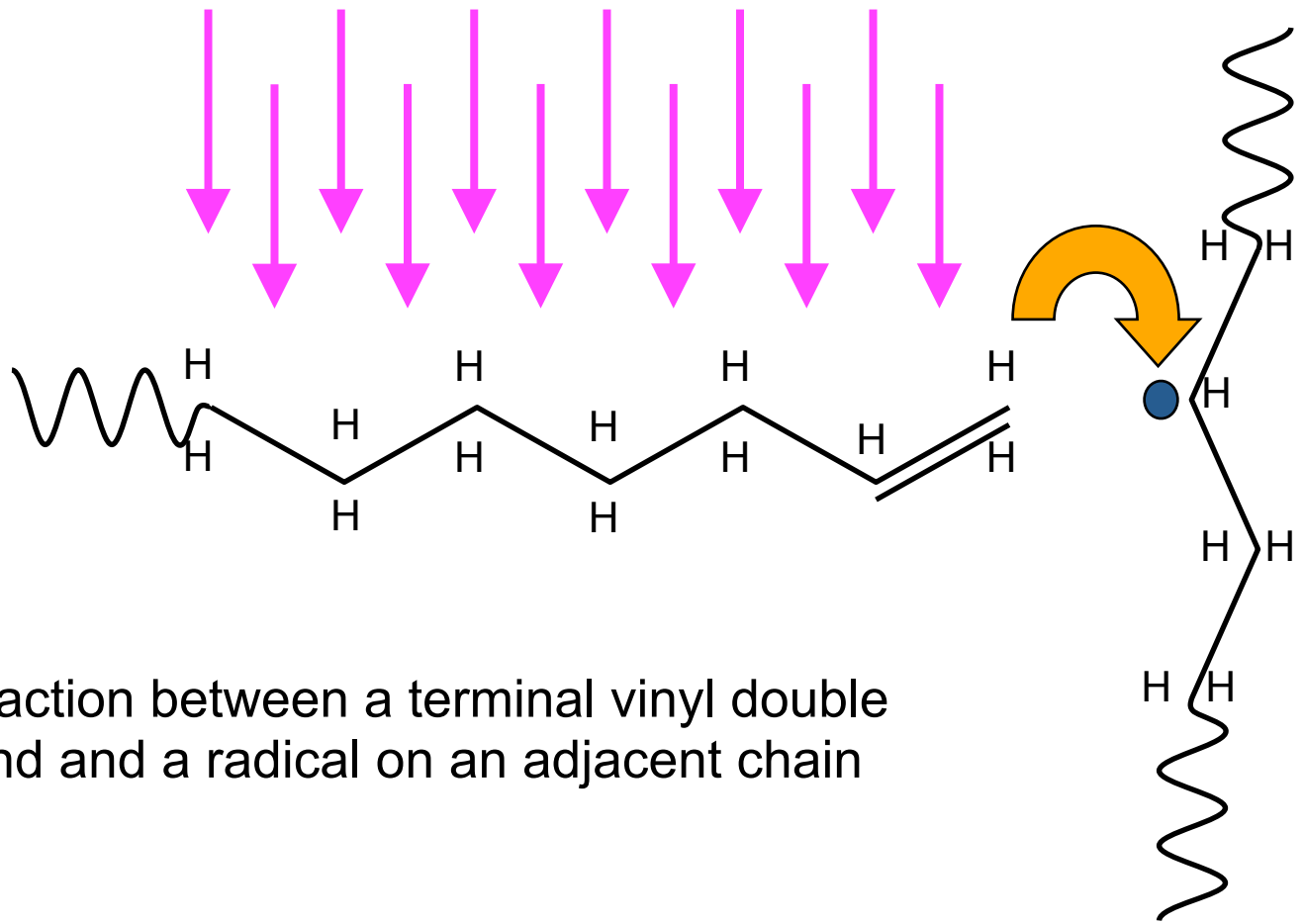
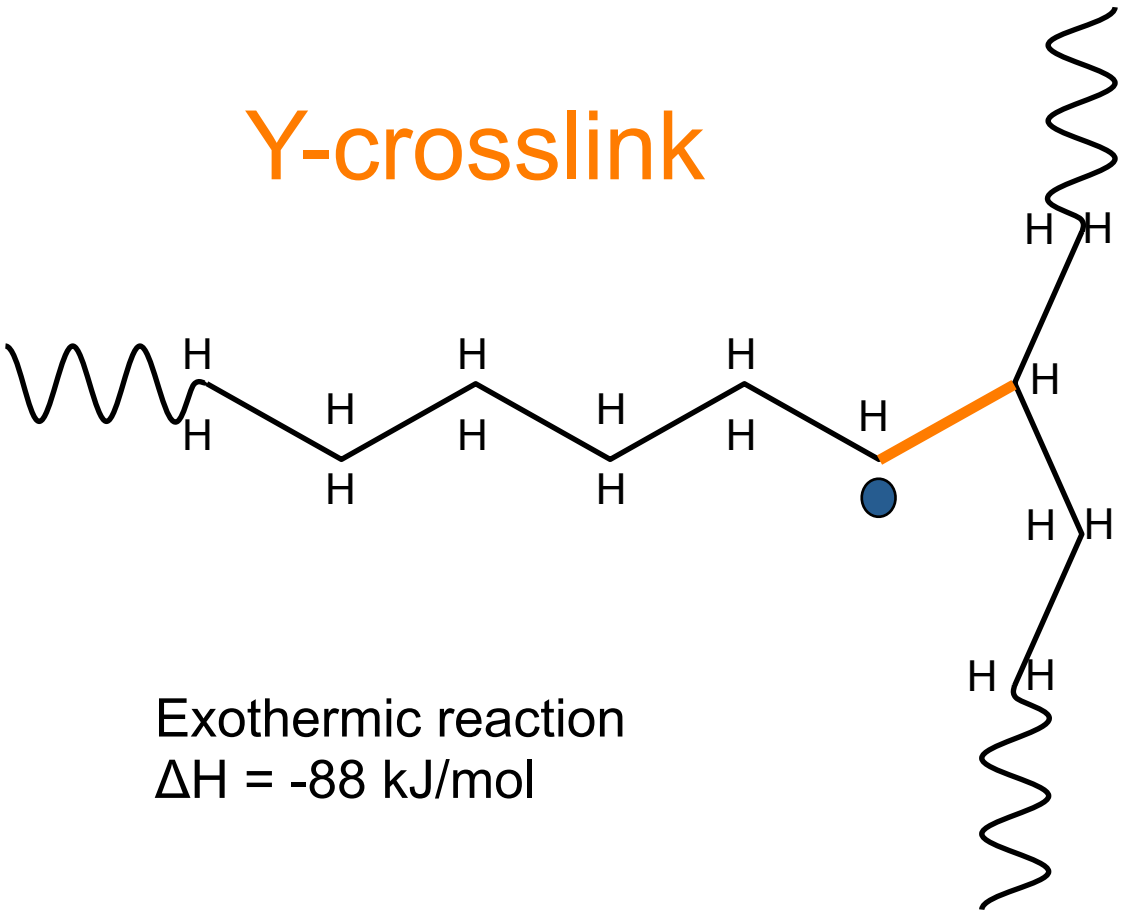


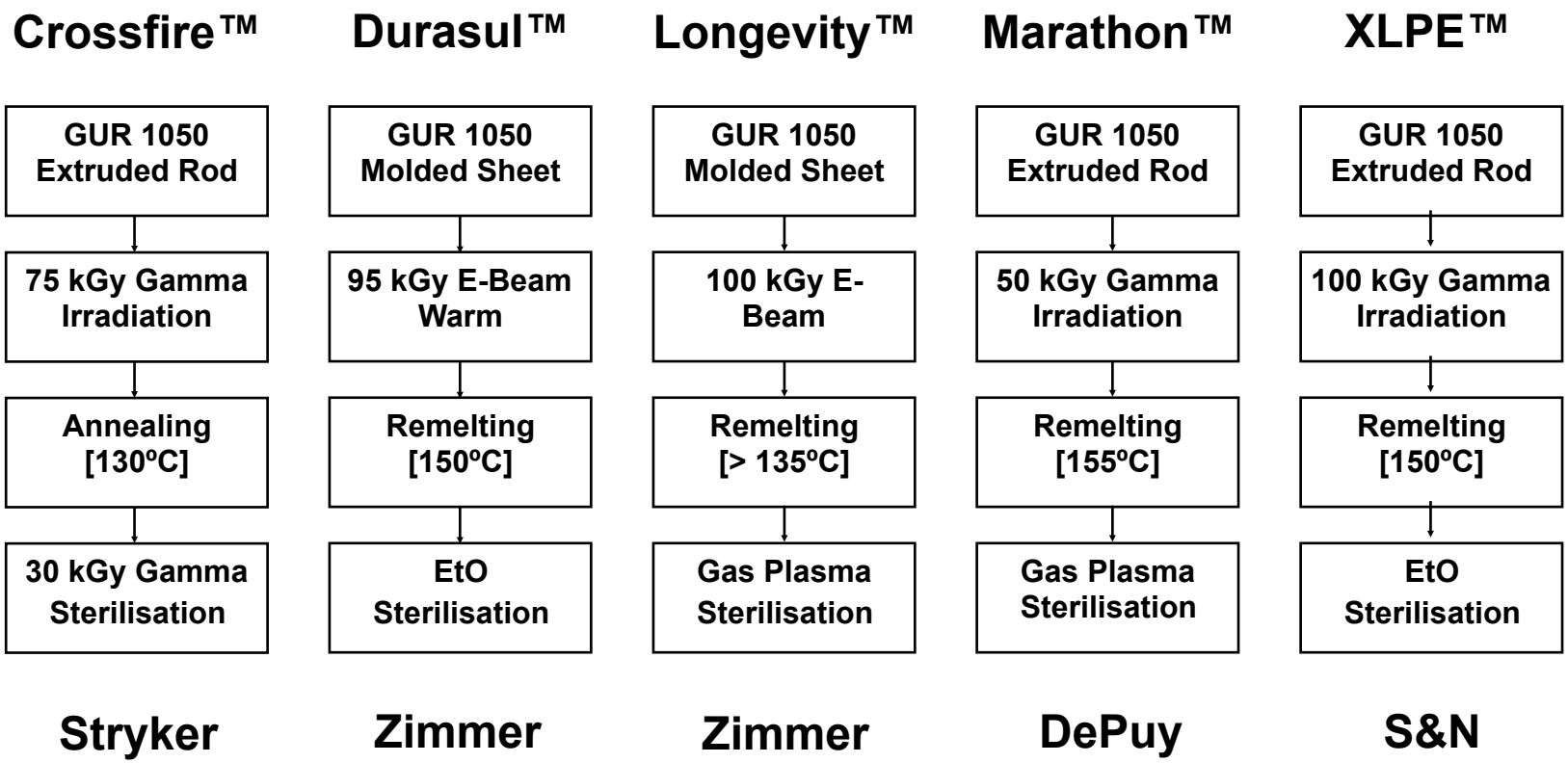
Reaction between a terminal vinyl double bond and a radical on an adjacent chain

CROSS-LINKING OF UHMWPE



Exothermic reaction
ΔH = -88 kJ/mol

DEVELOPMENT OF HIGHLY CROSS-



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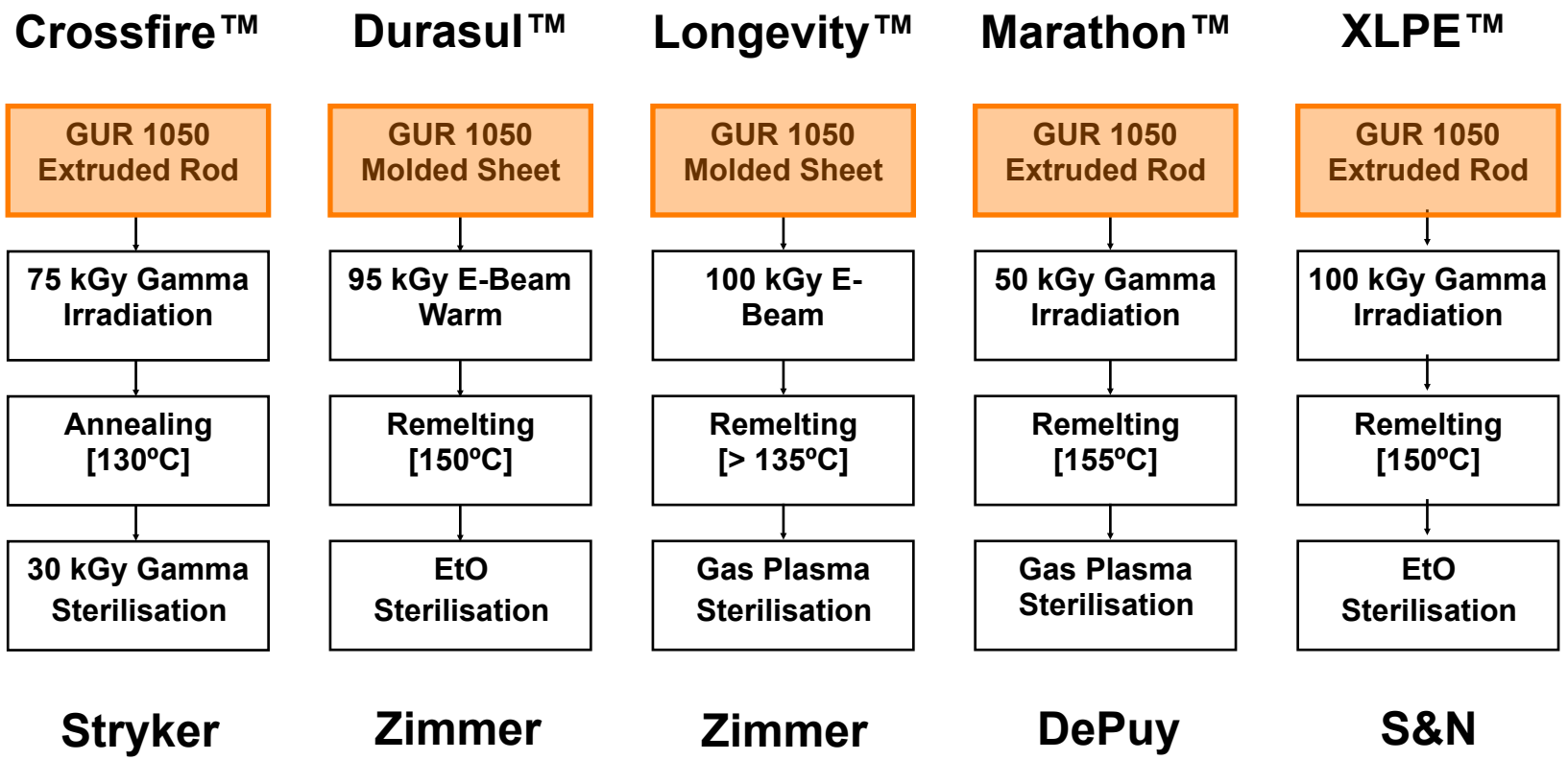

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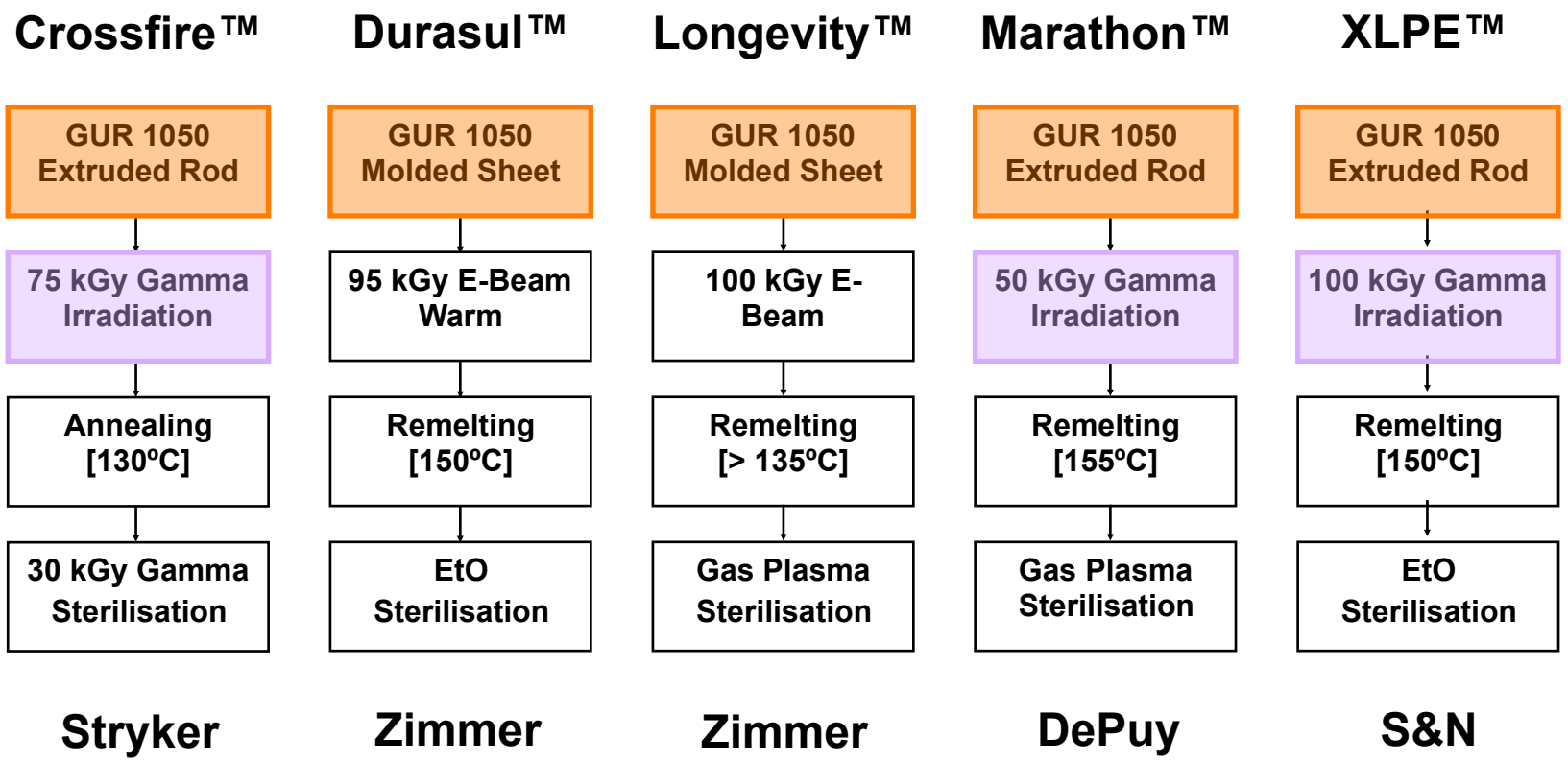

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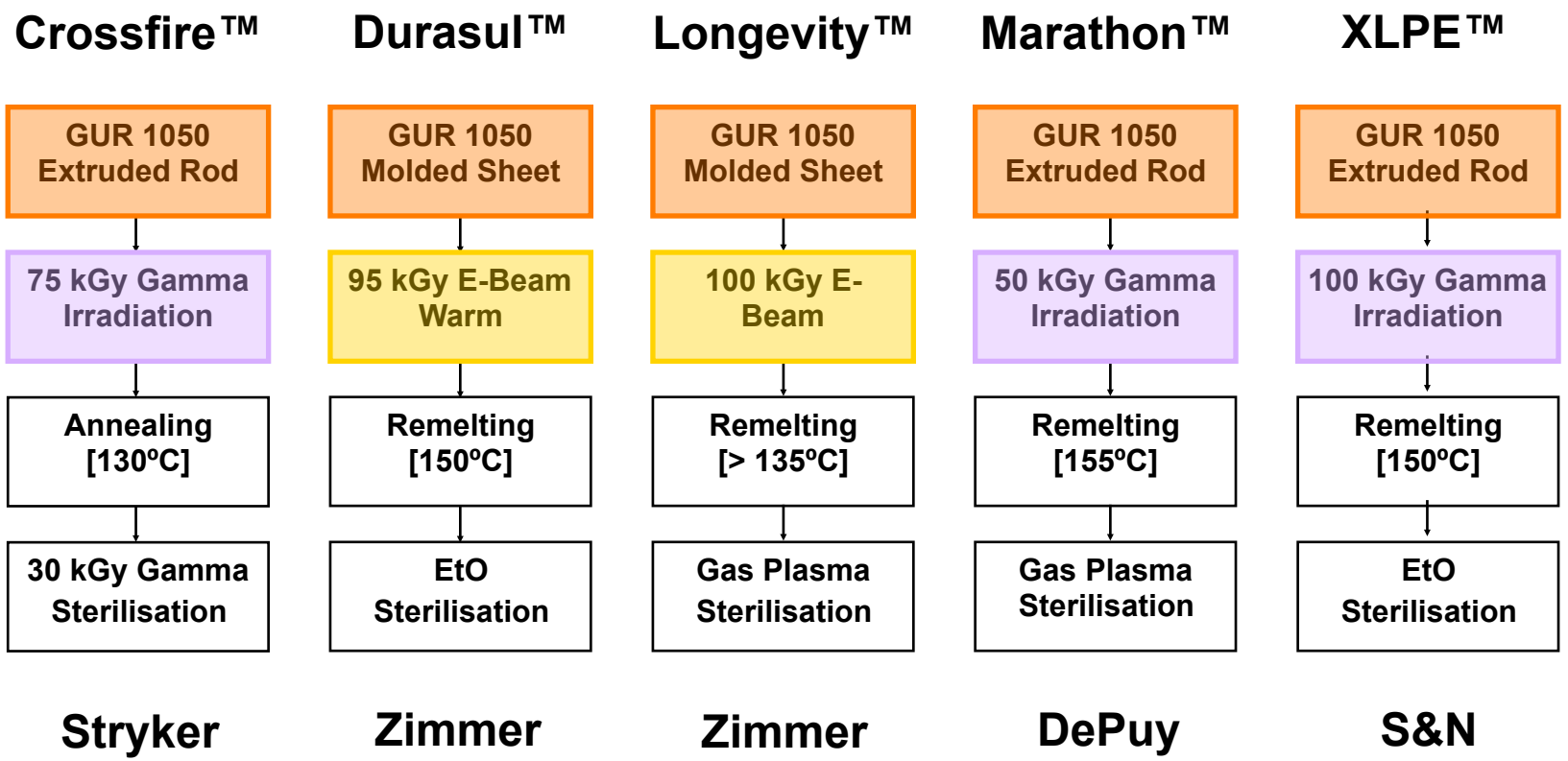

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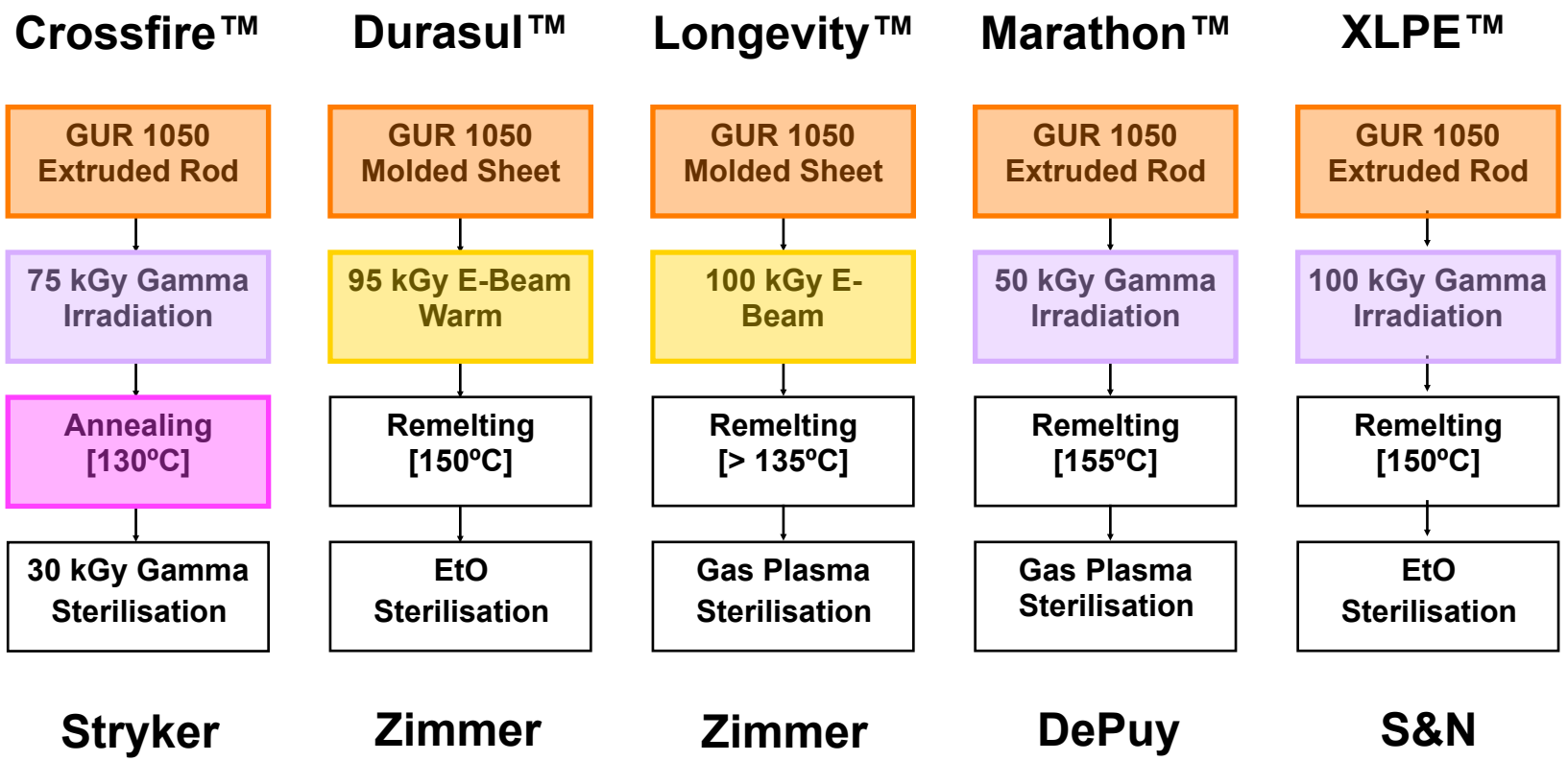

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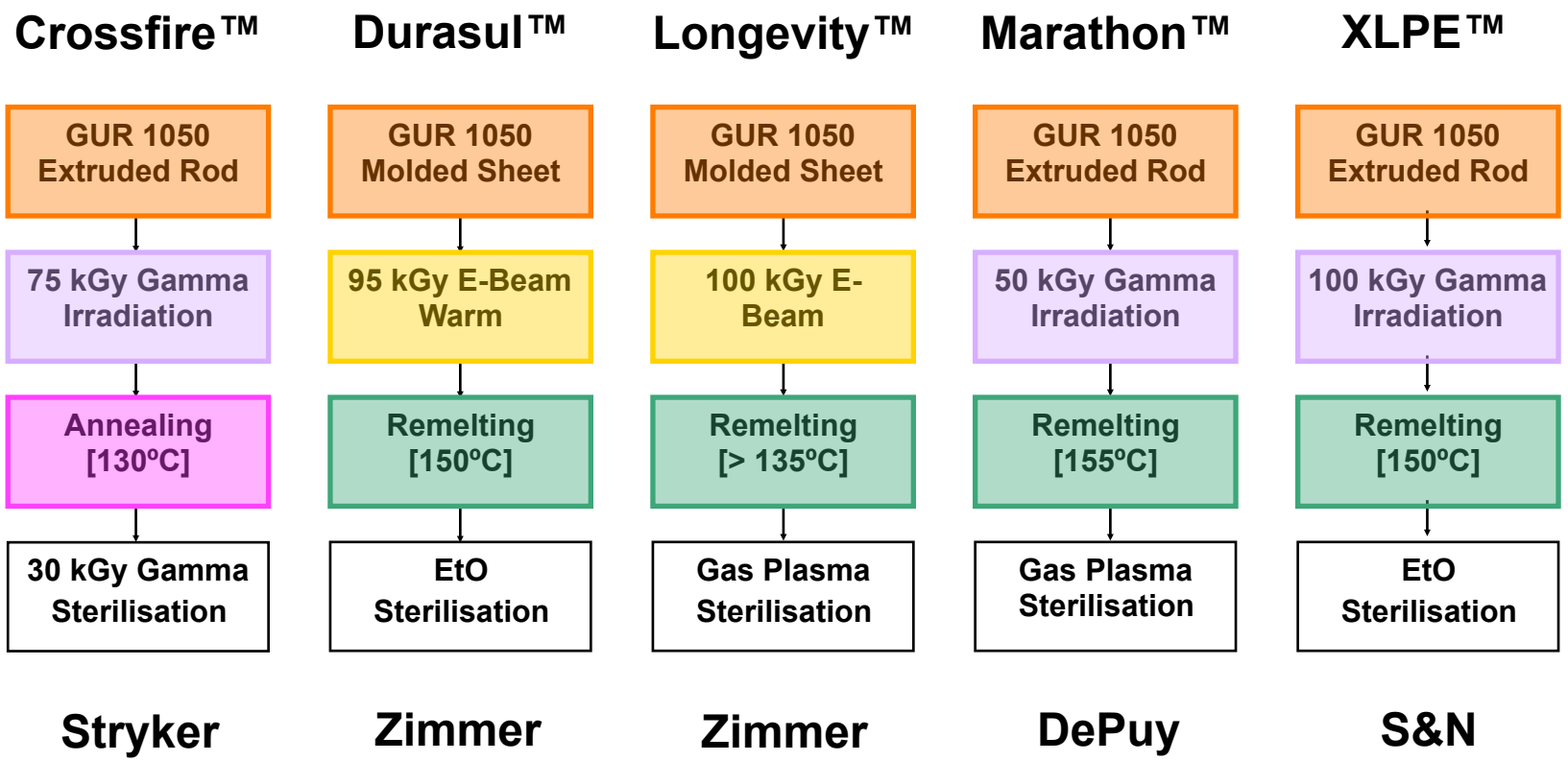

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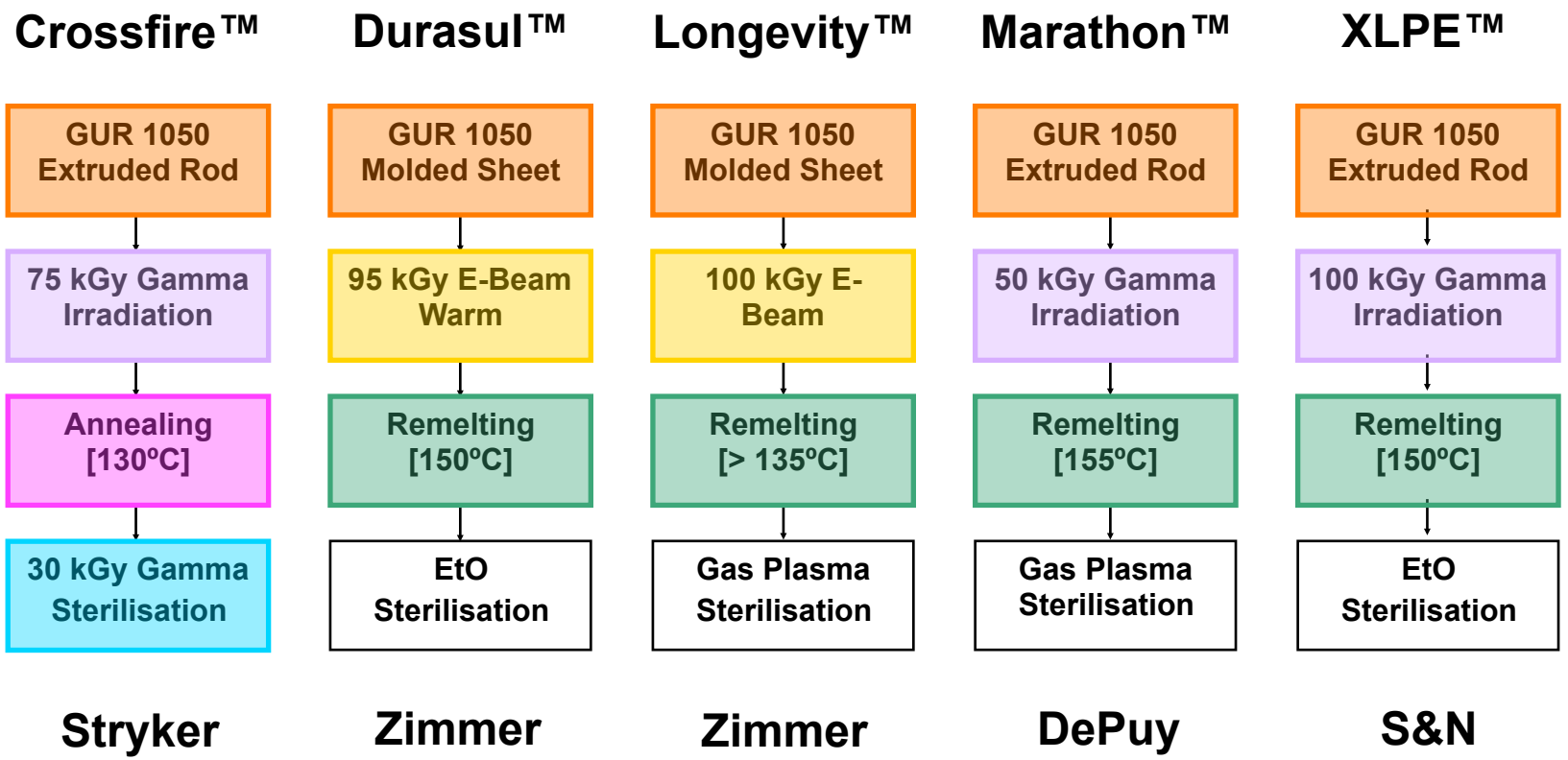

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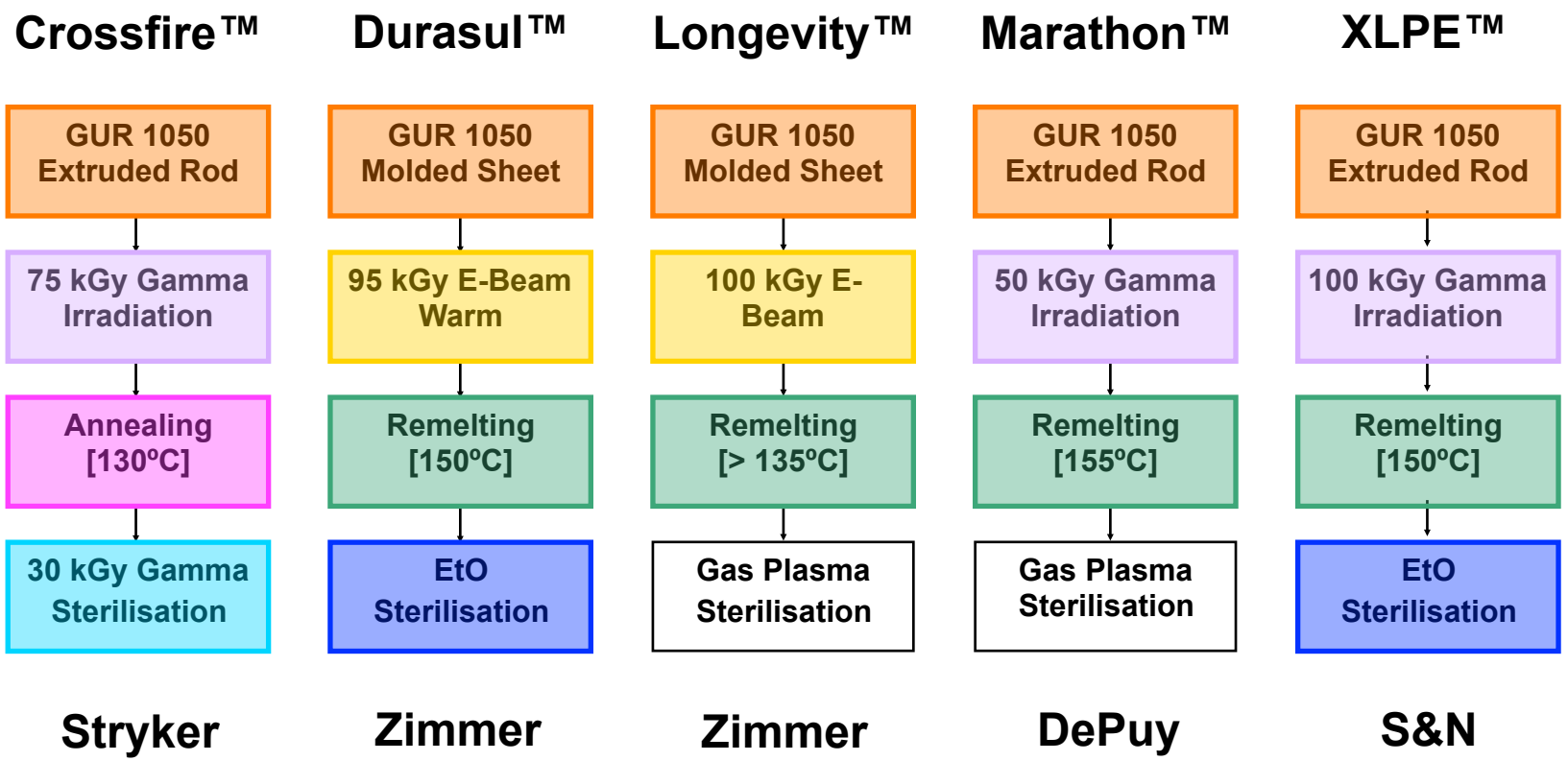

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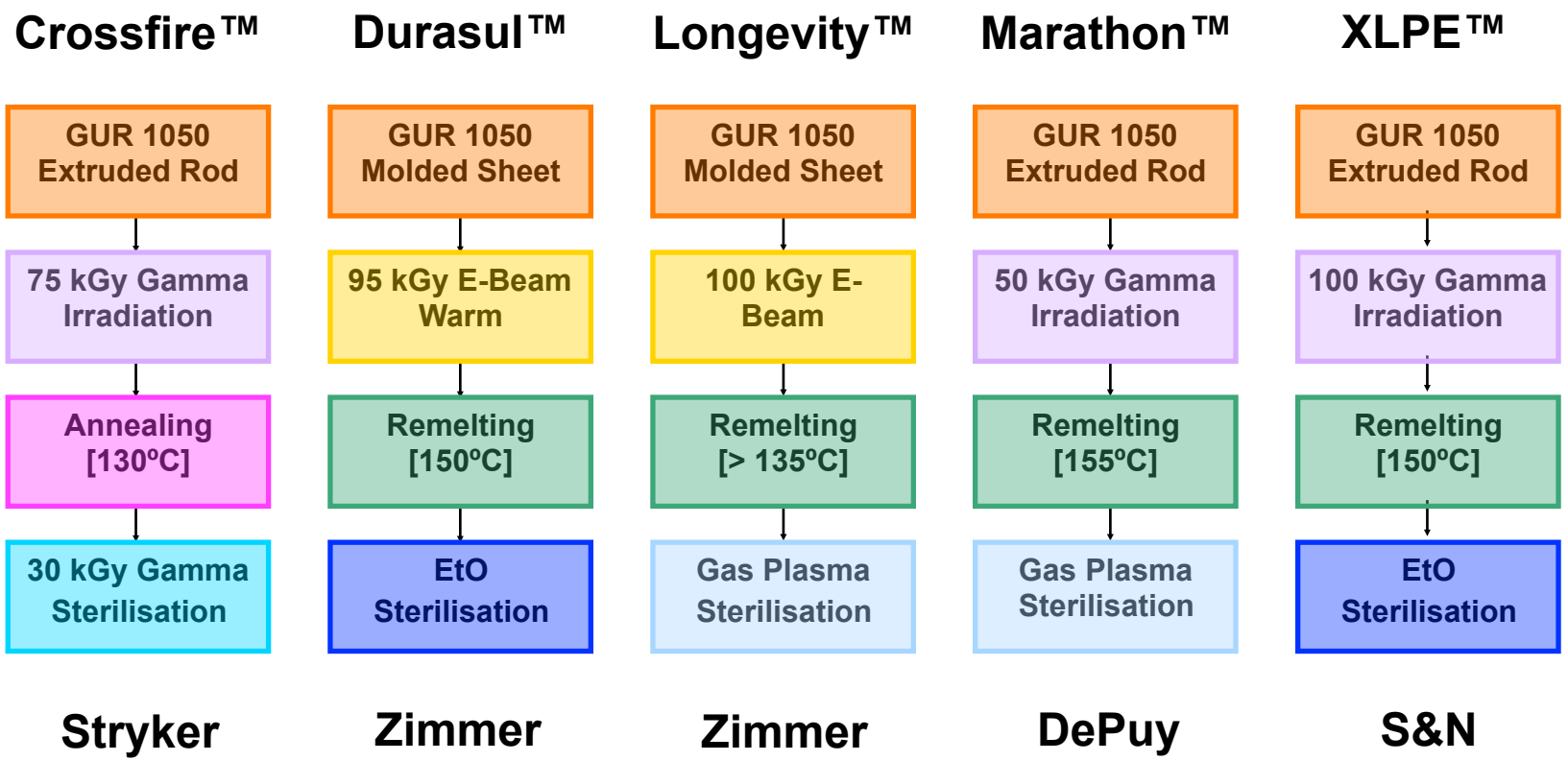

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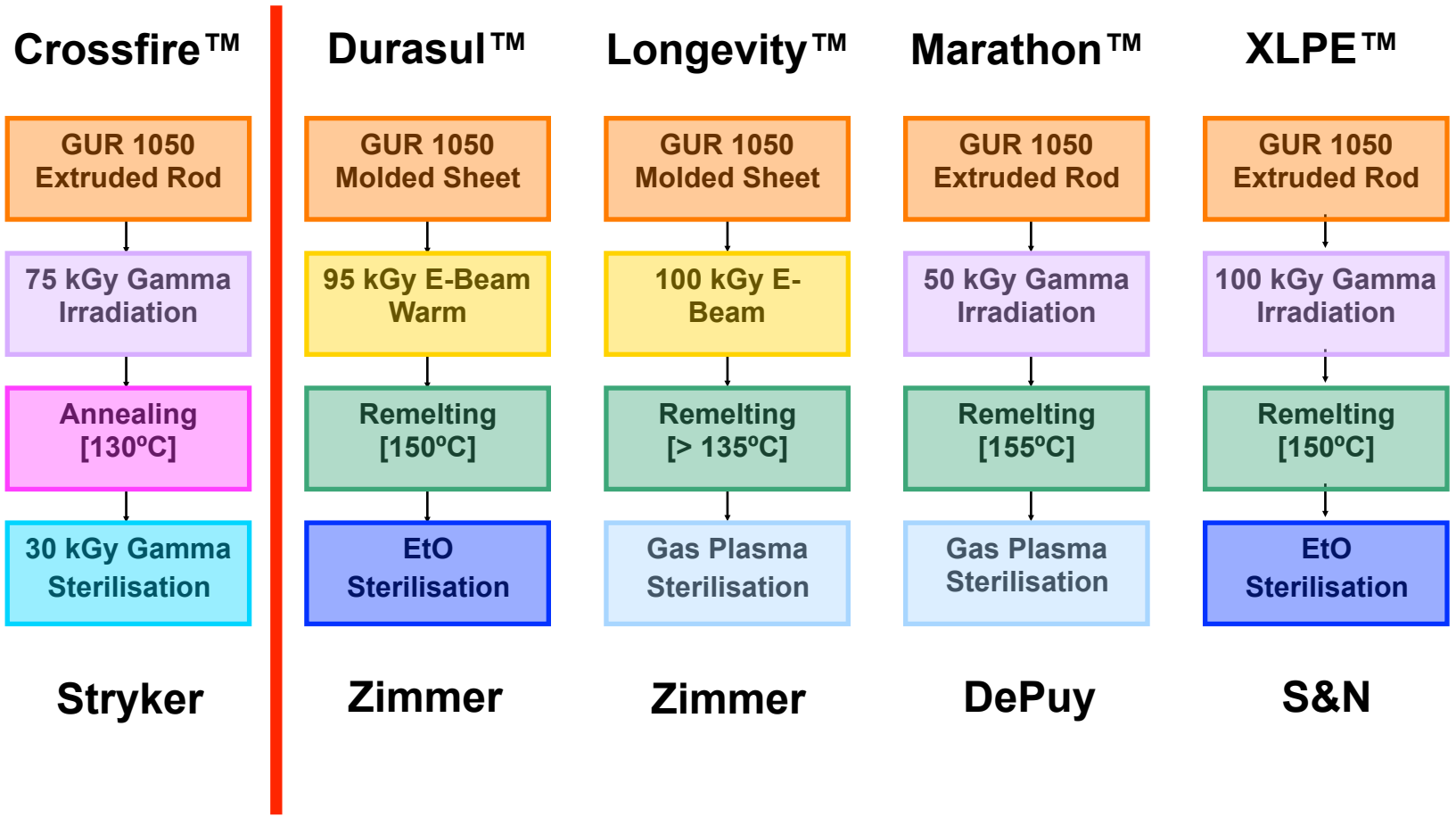

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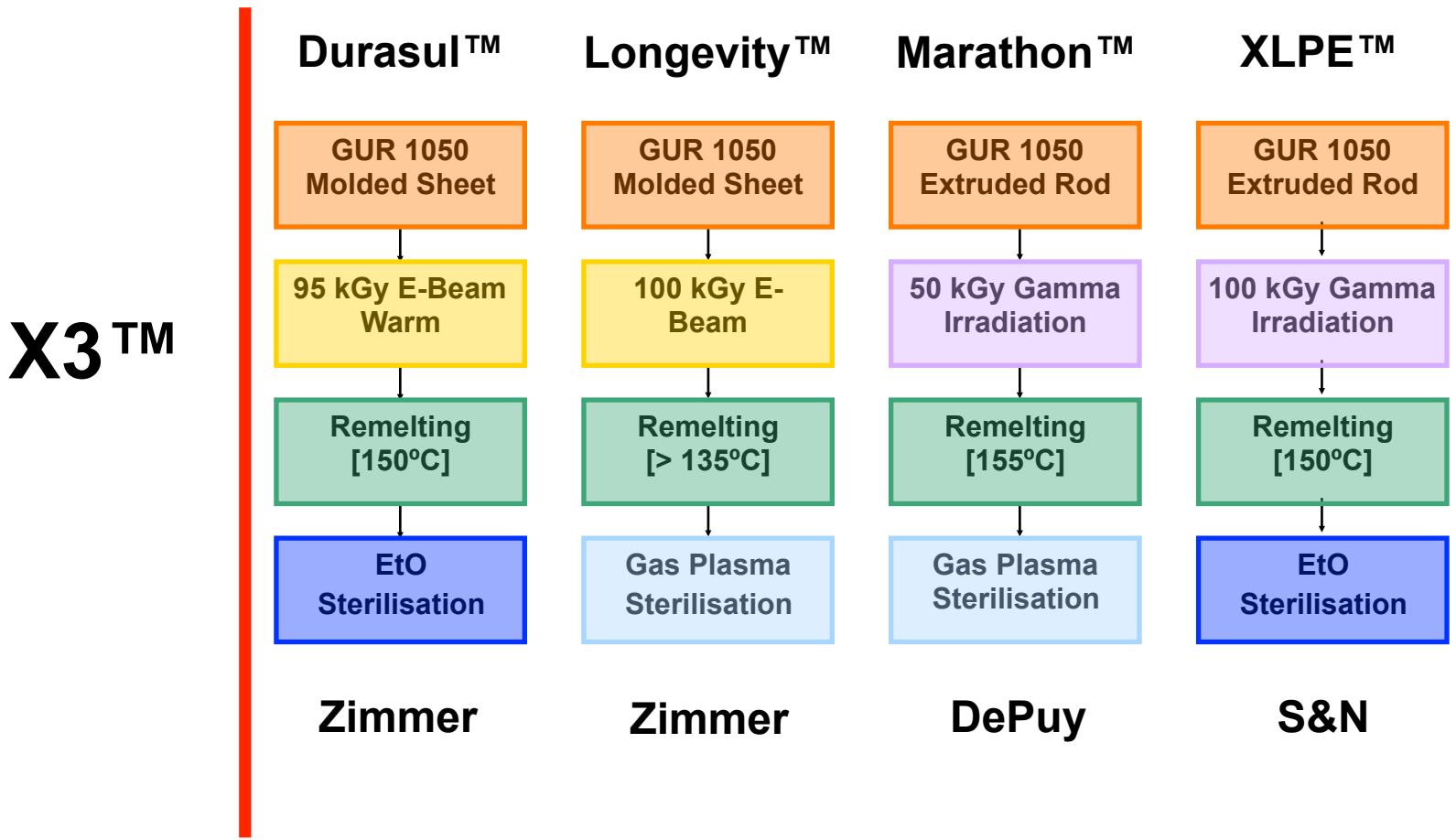

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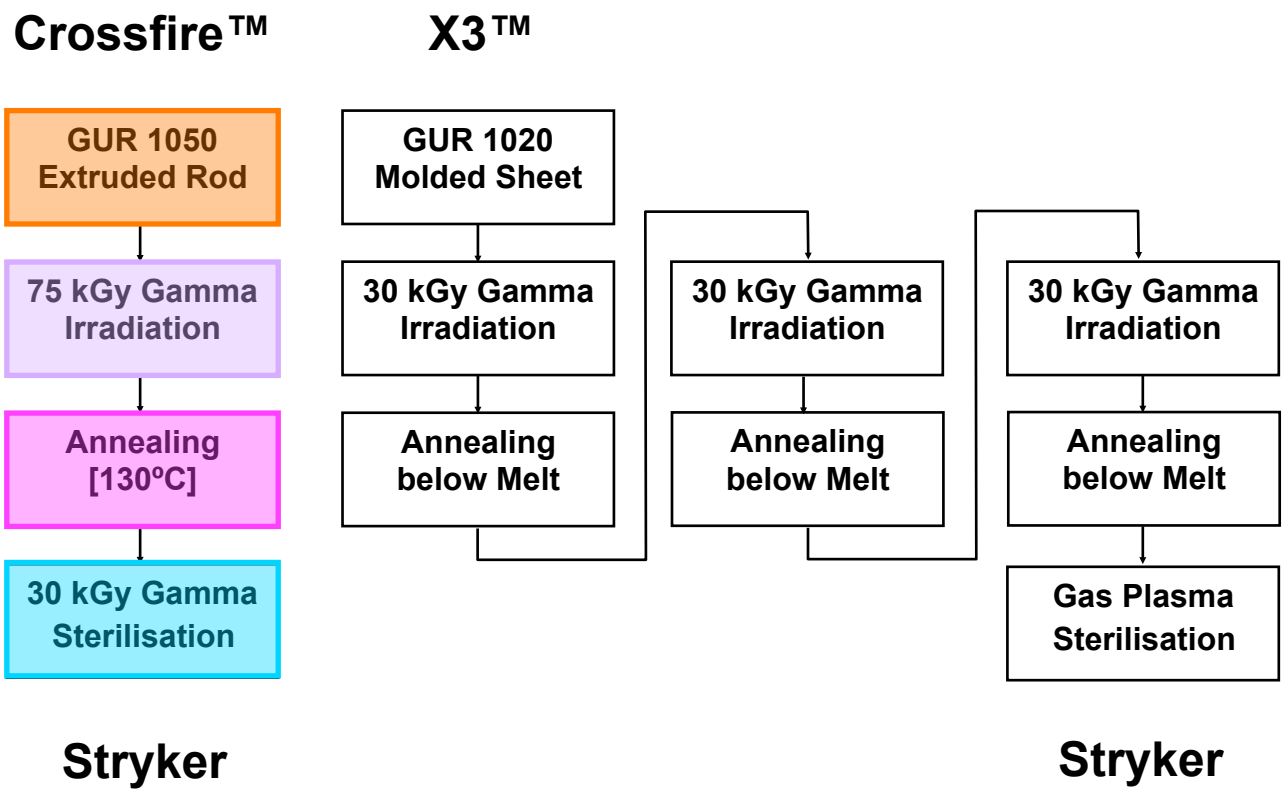

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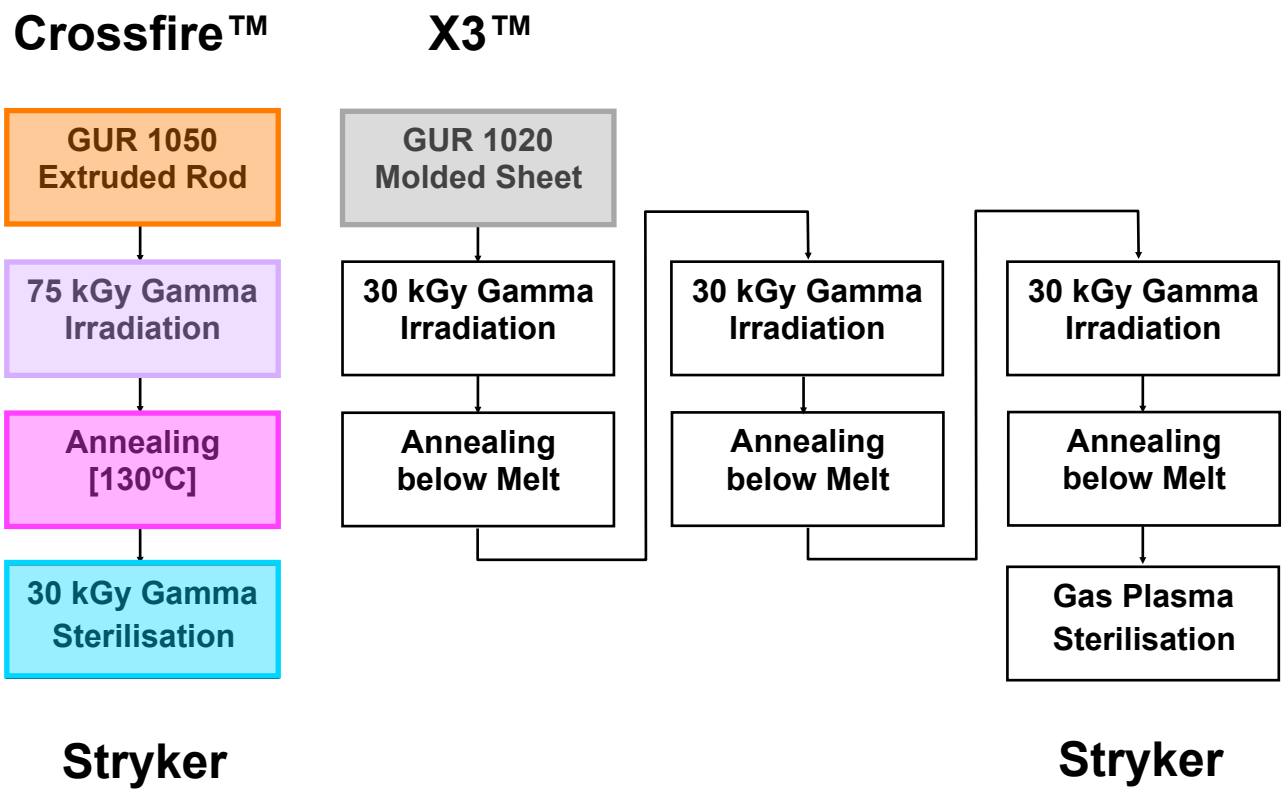

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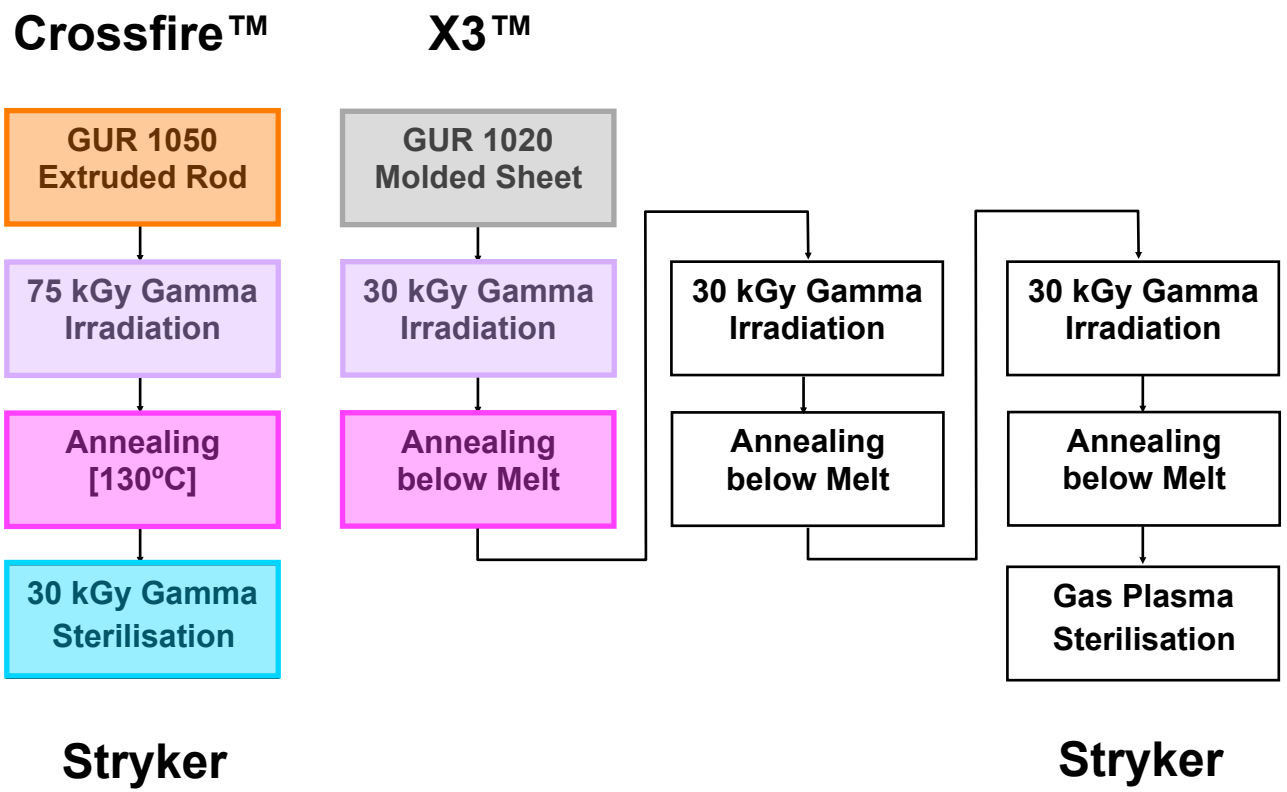

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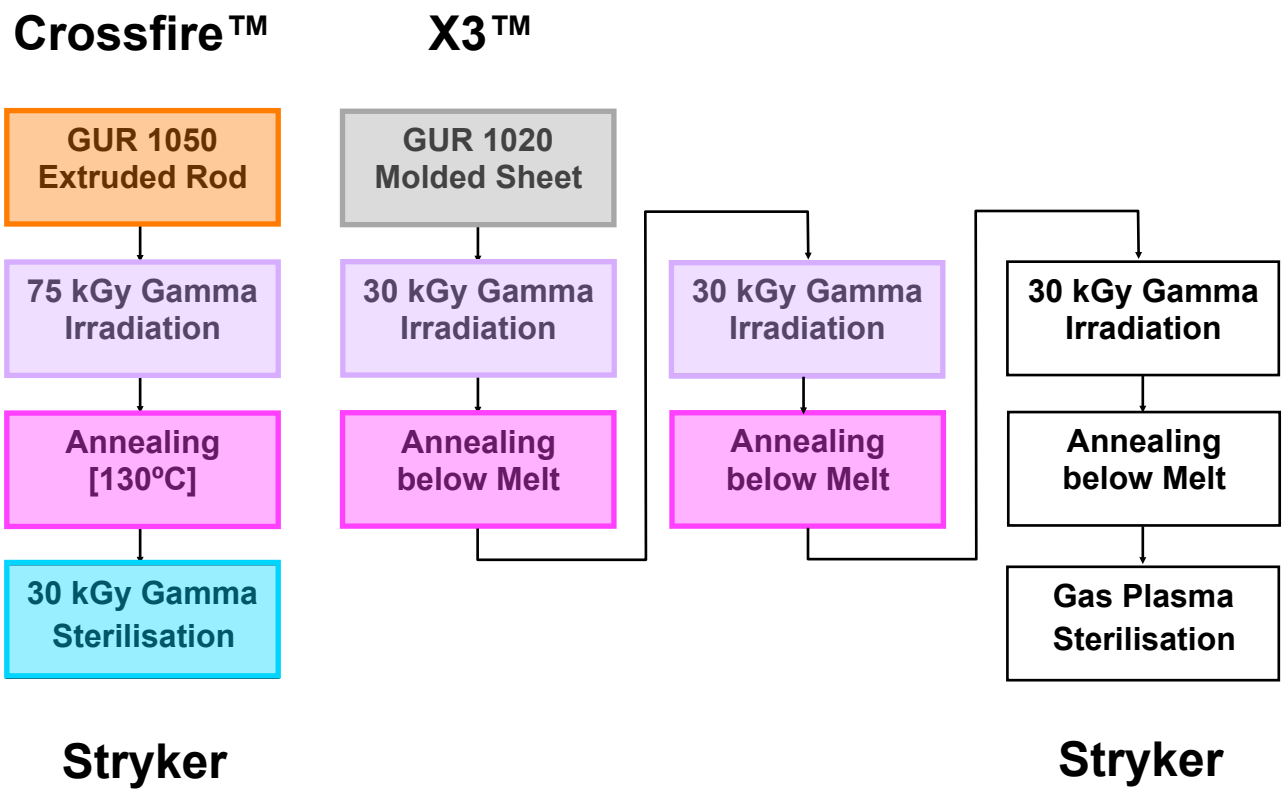

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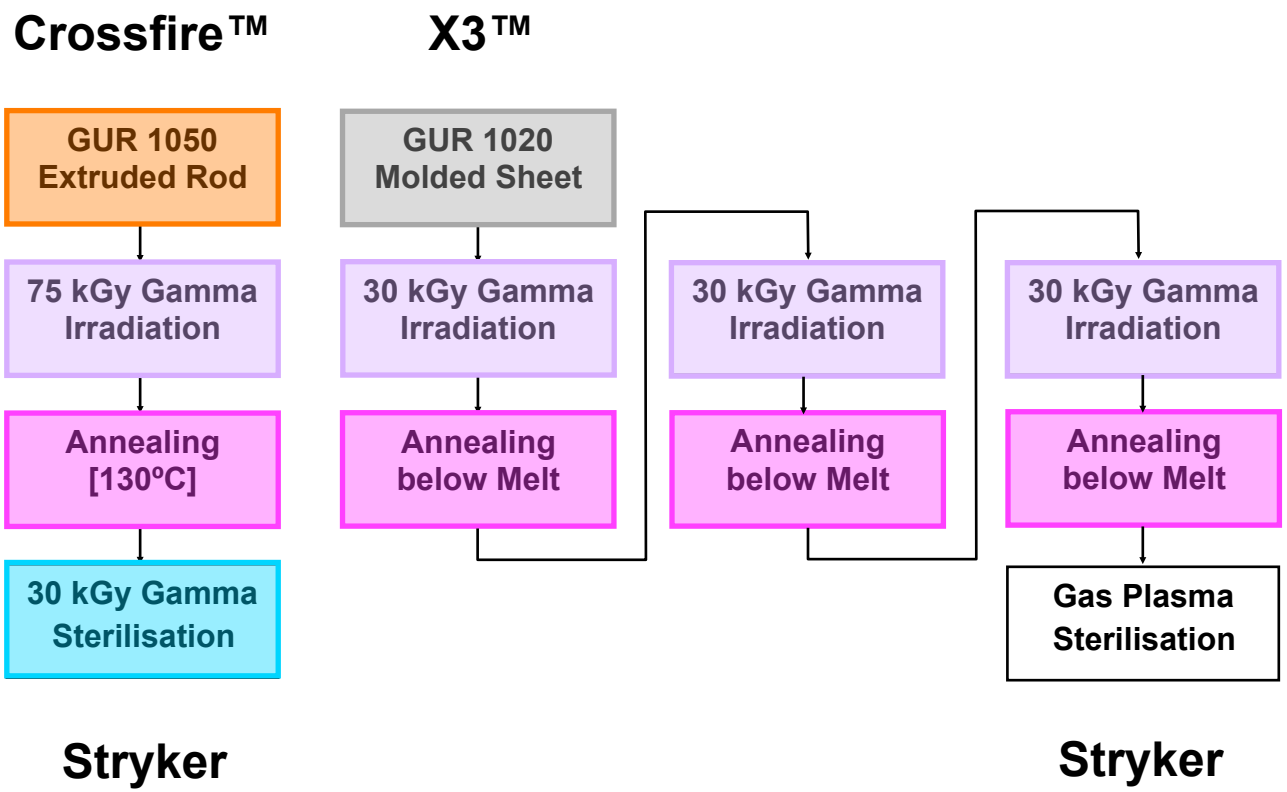

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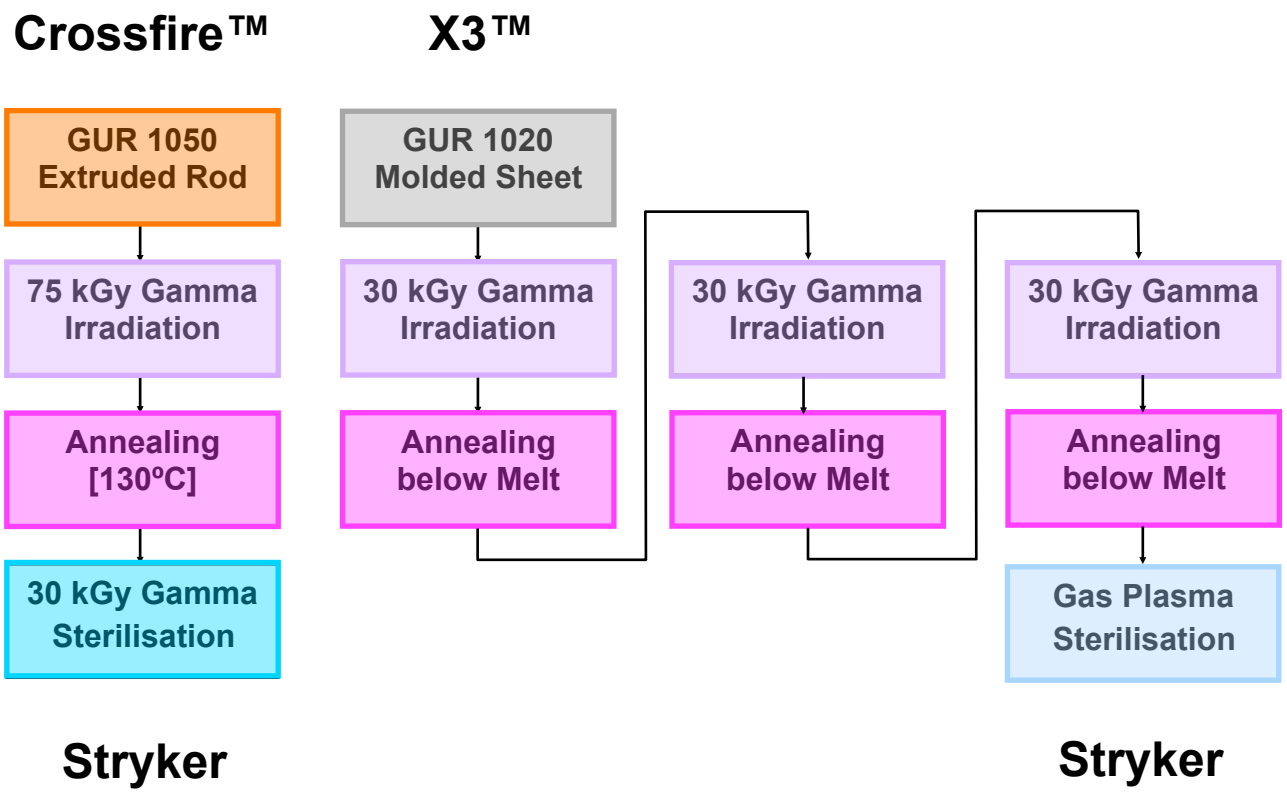

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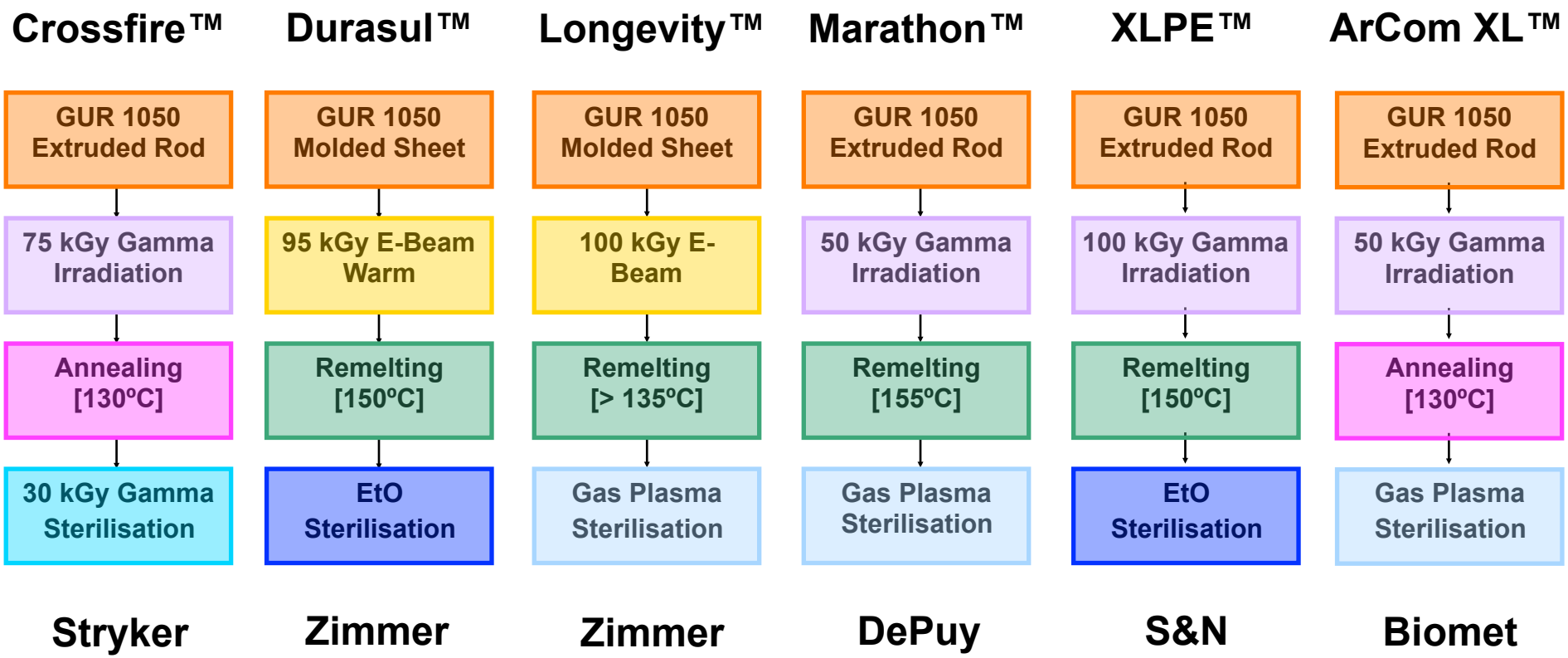

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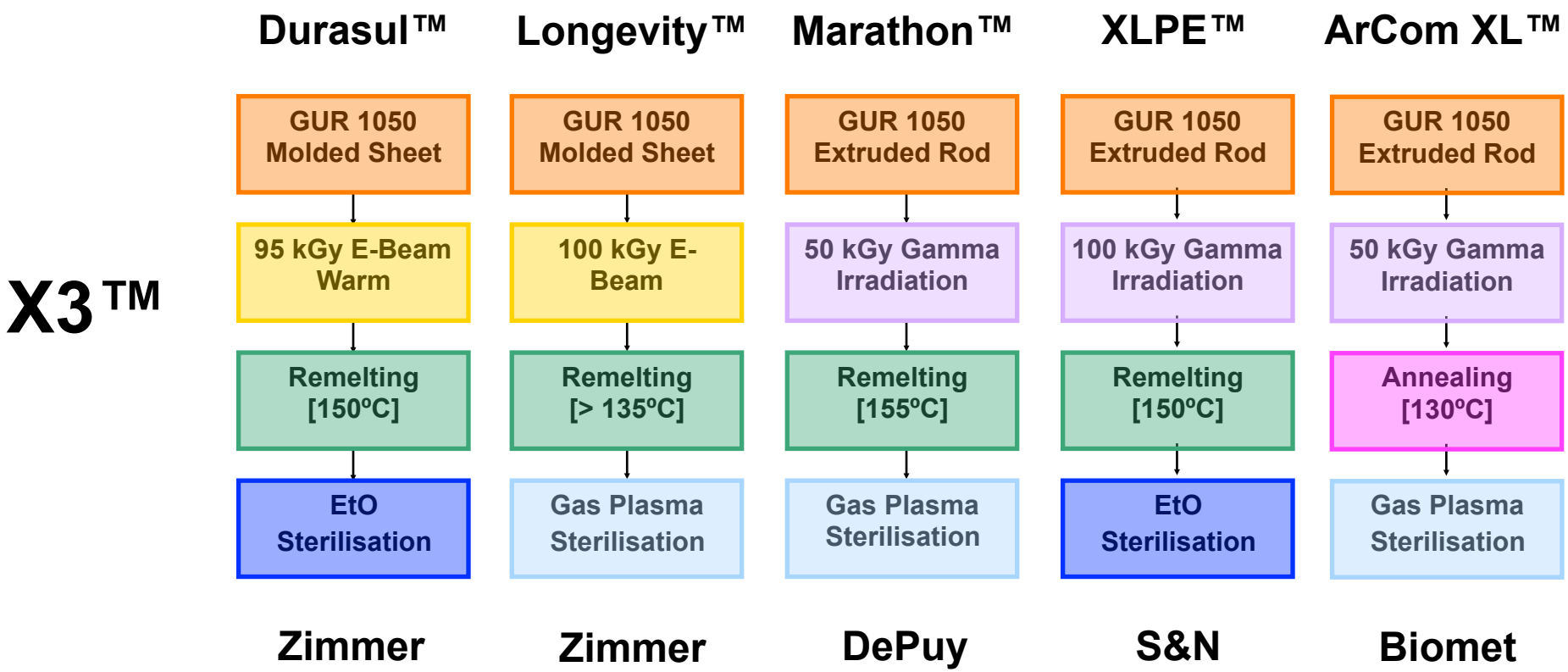

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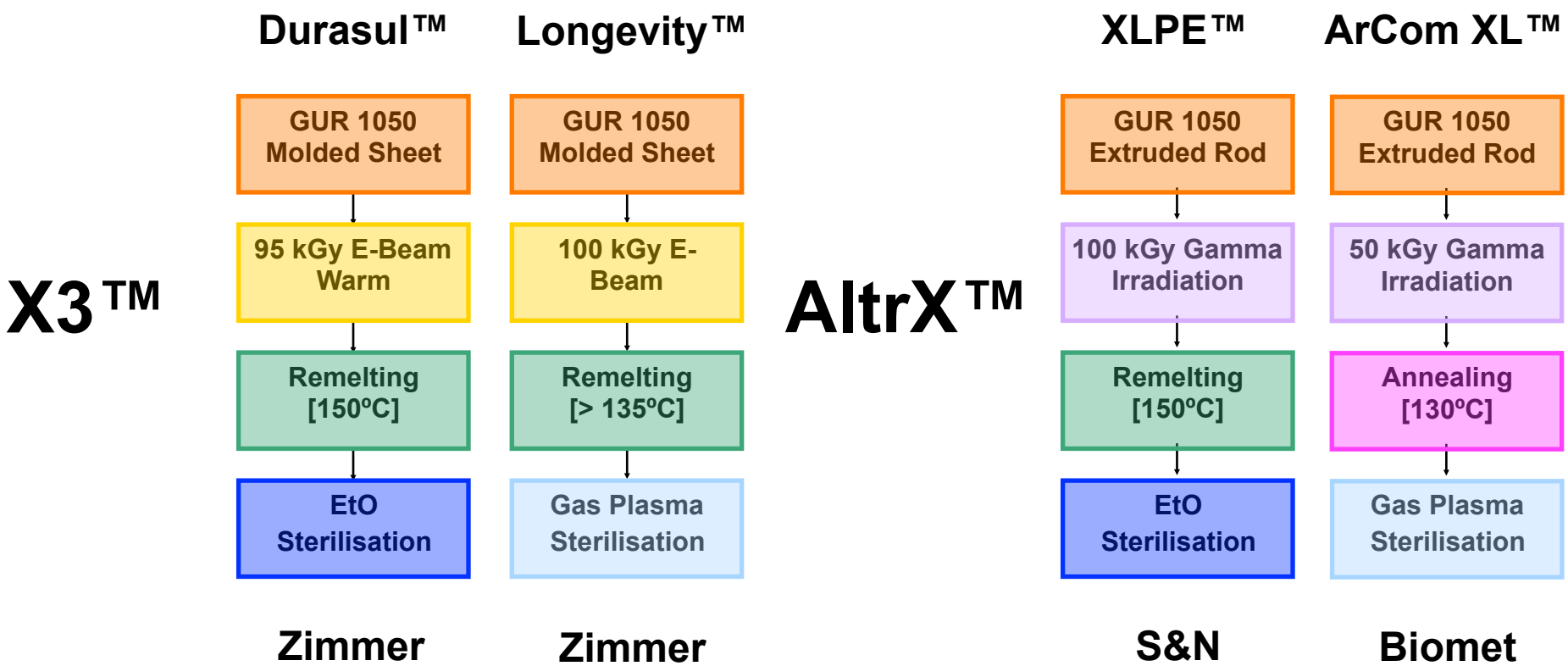

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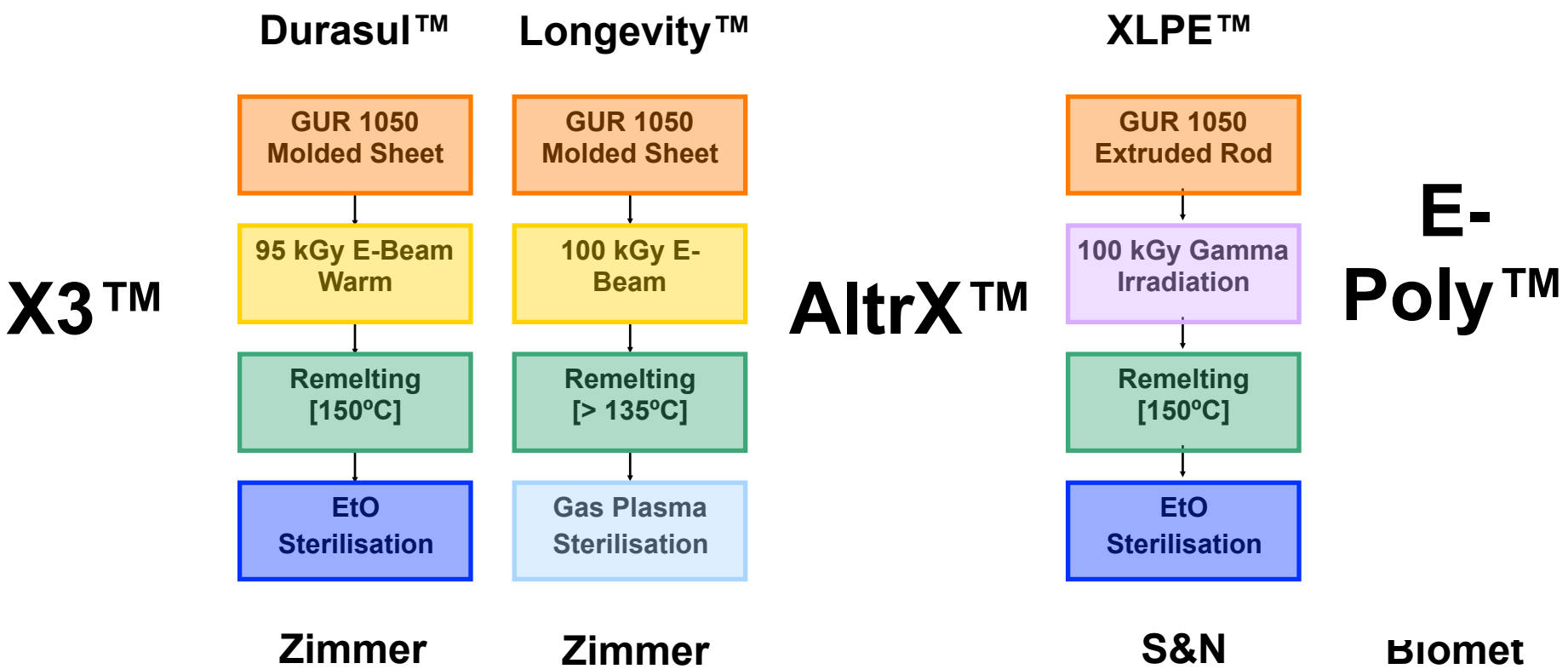

LONGEVITY

GUR 1050
Molded Sheet

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100 kGy E-Beam
Cold Irradiation

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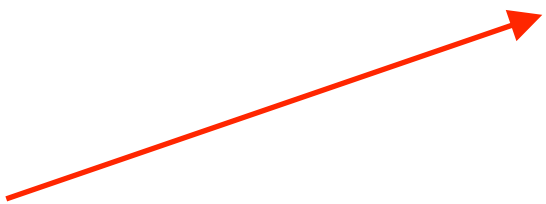
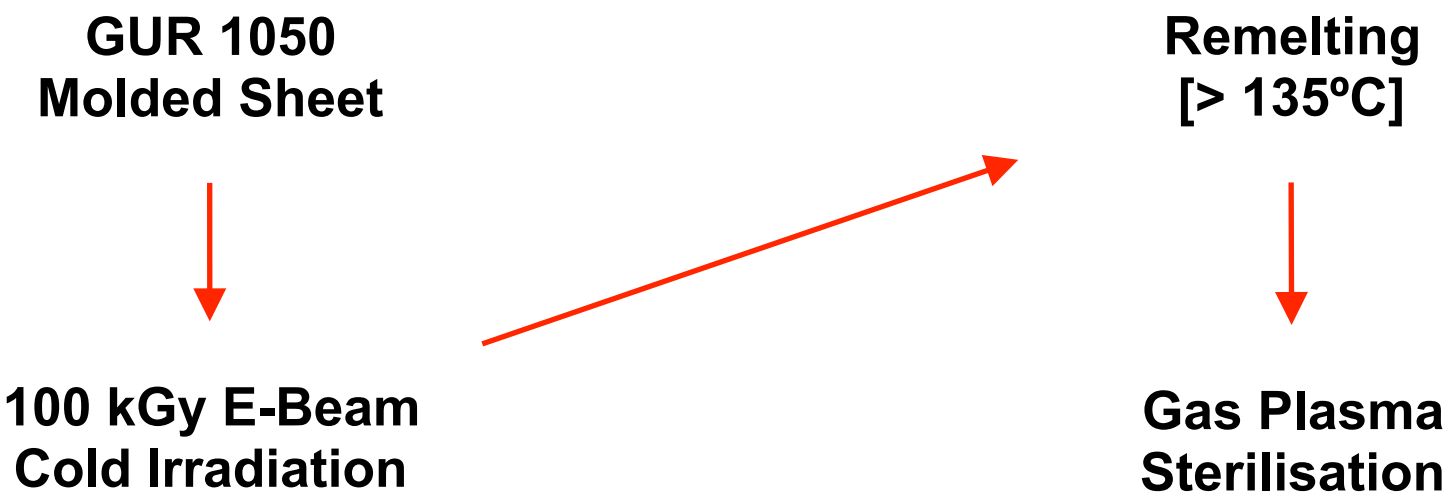


Remelting
[> 135ºC]

LONGEVITY


GUR 1050
Molded Sheet
100 kGy E-Beam
Cold Irradiation
Remelting
[> 135ºC]
Gas Plasma
Sterilisation

MECHANICS OF WEAR

RELATIVE MOTION BETWEEN HEAD

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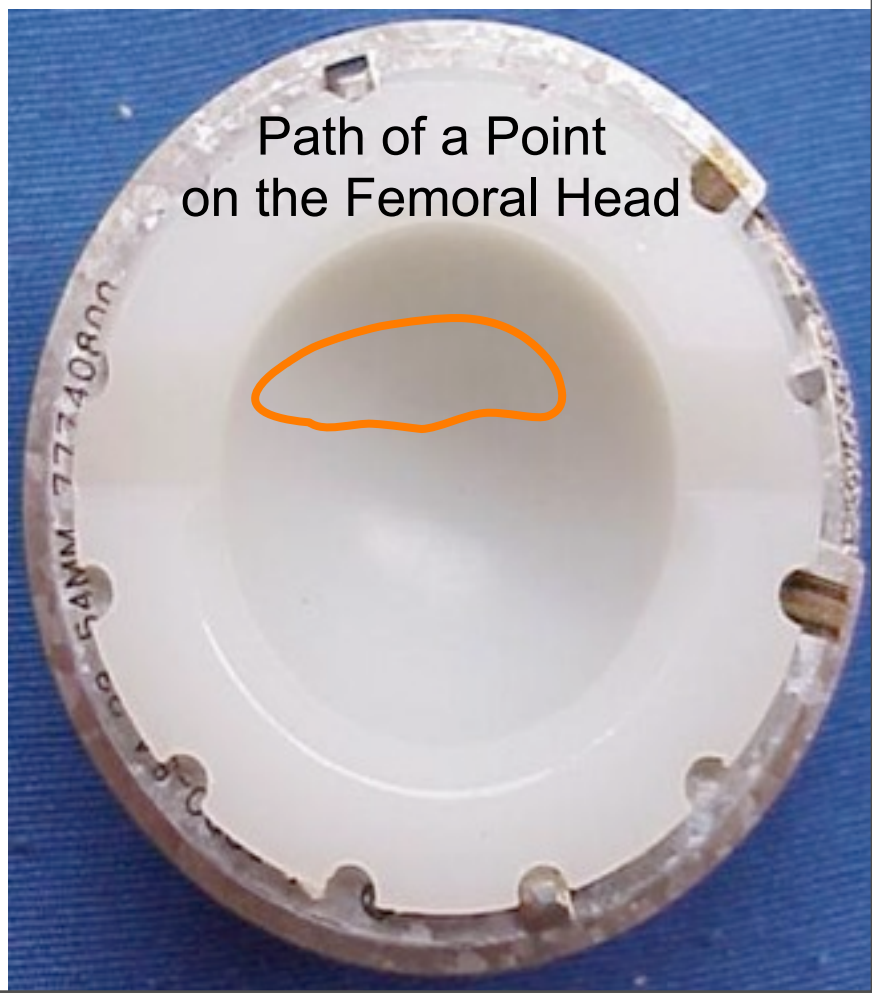

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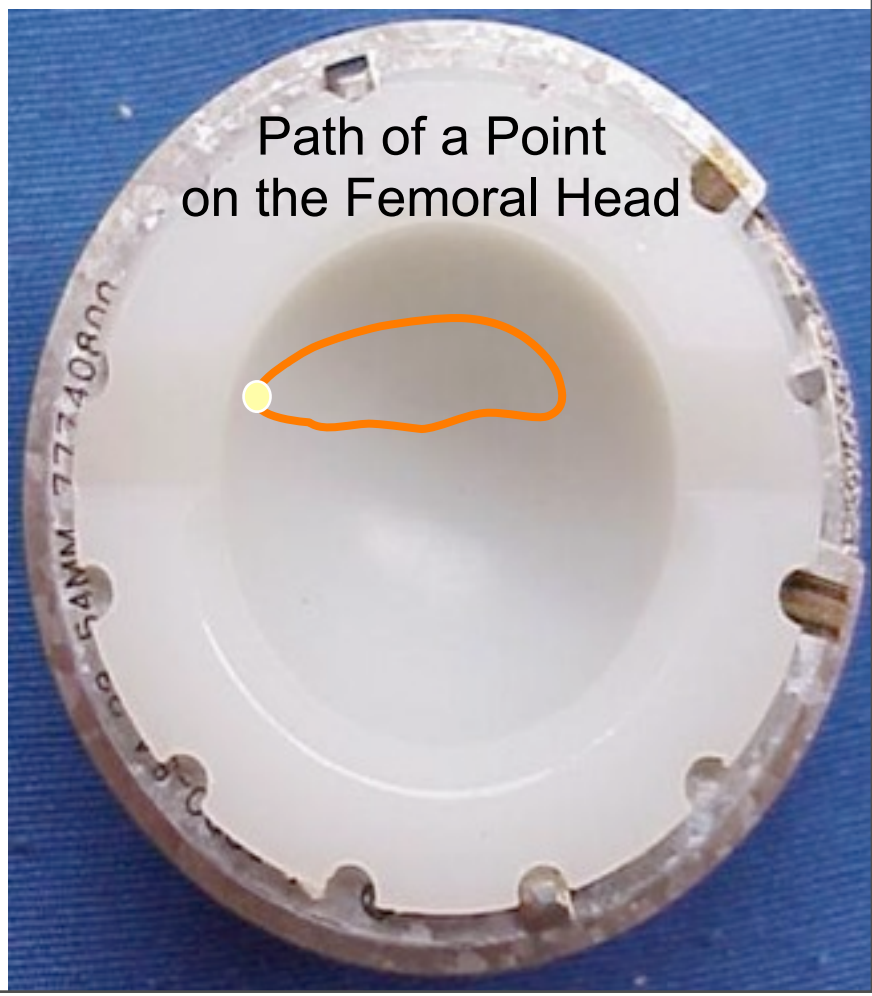

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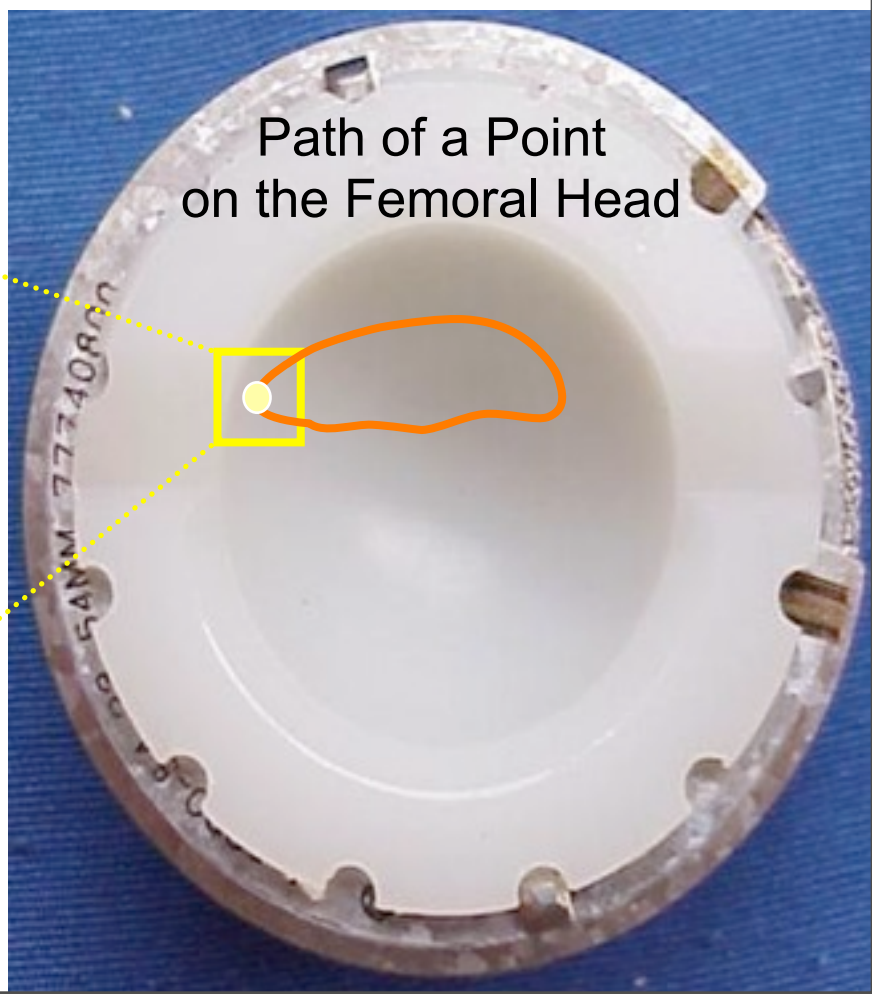

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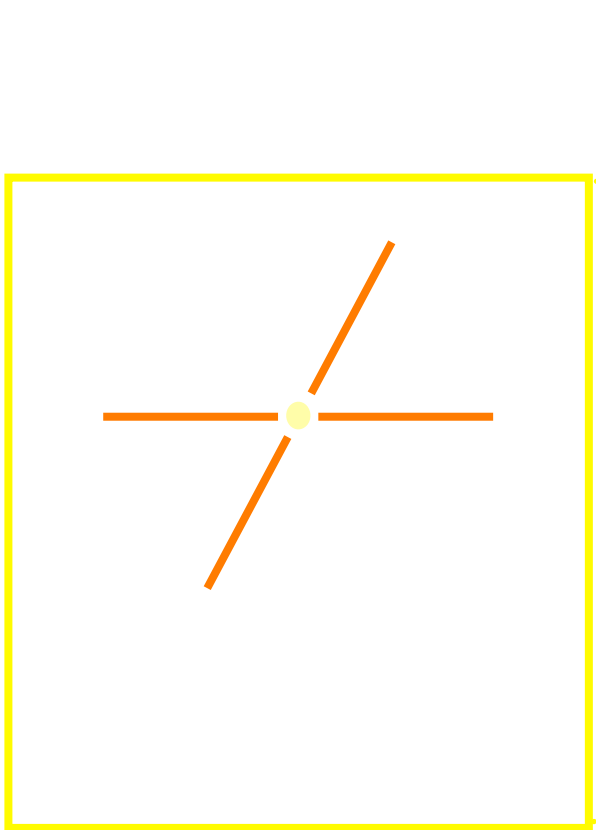

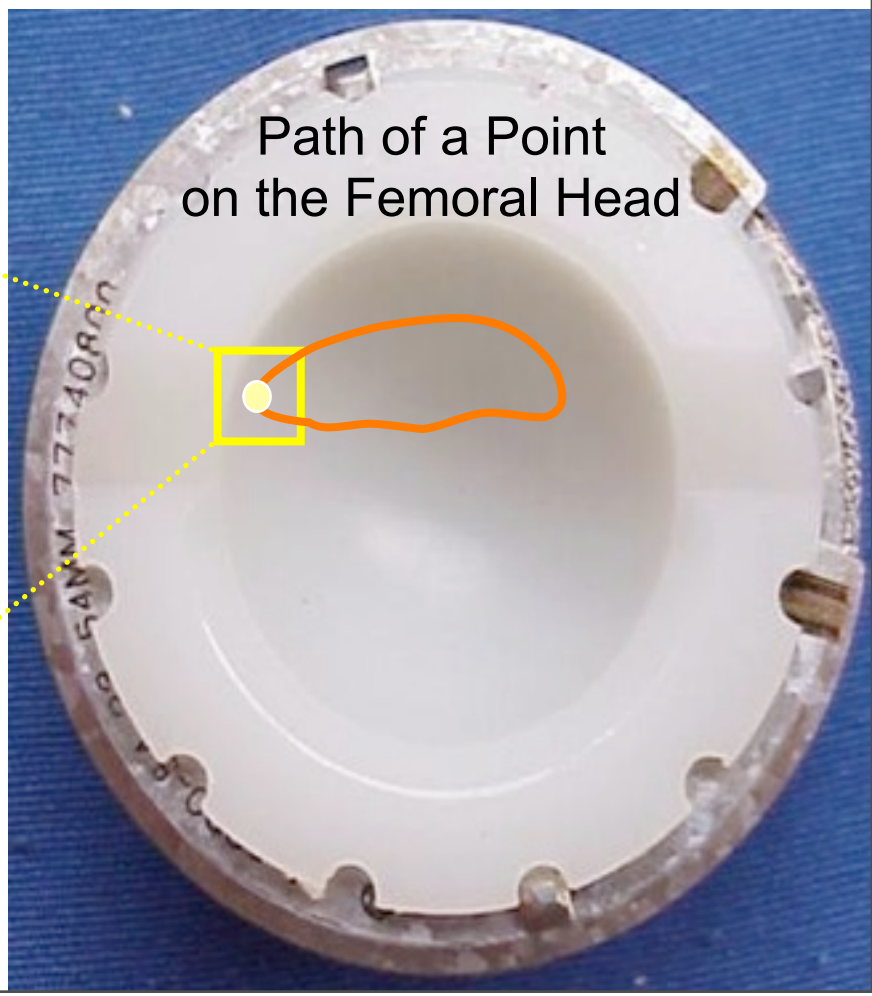

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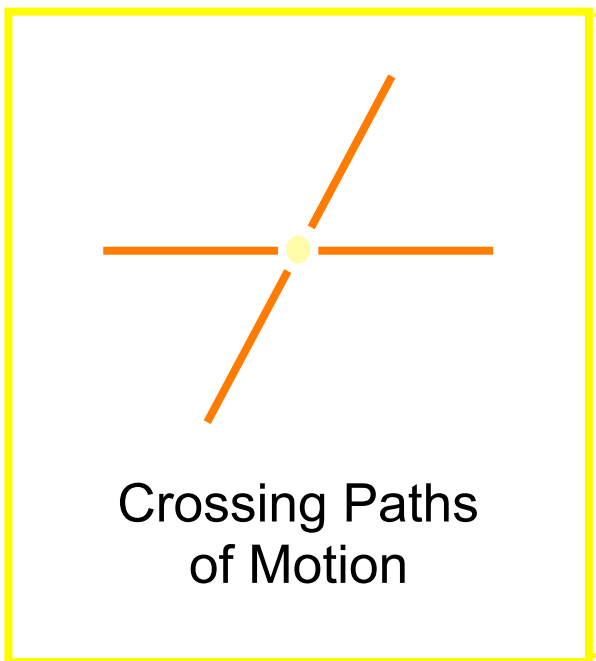

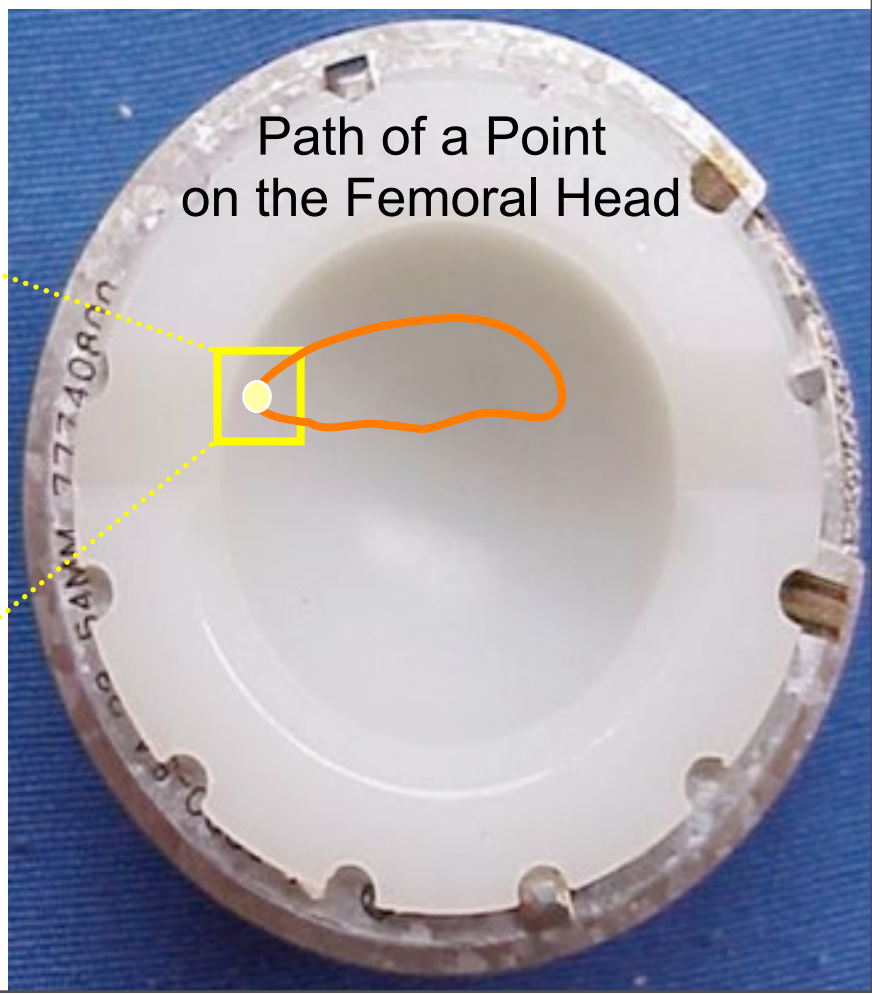

UHMWPE MOLECULAR STRUCTURE AND

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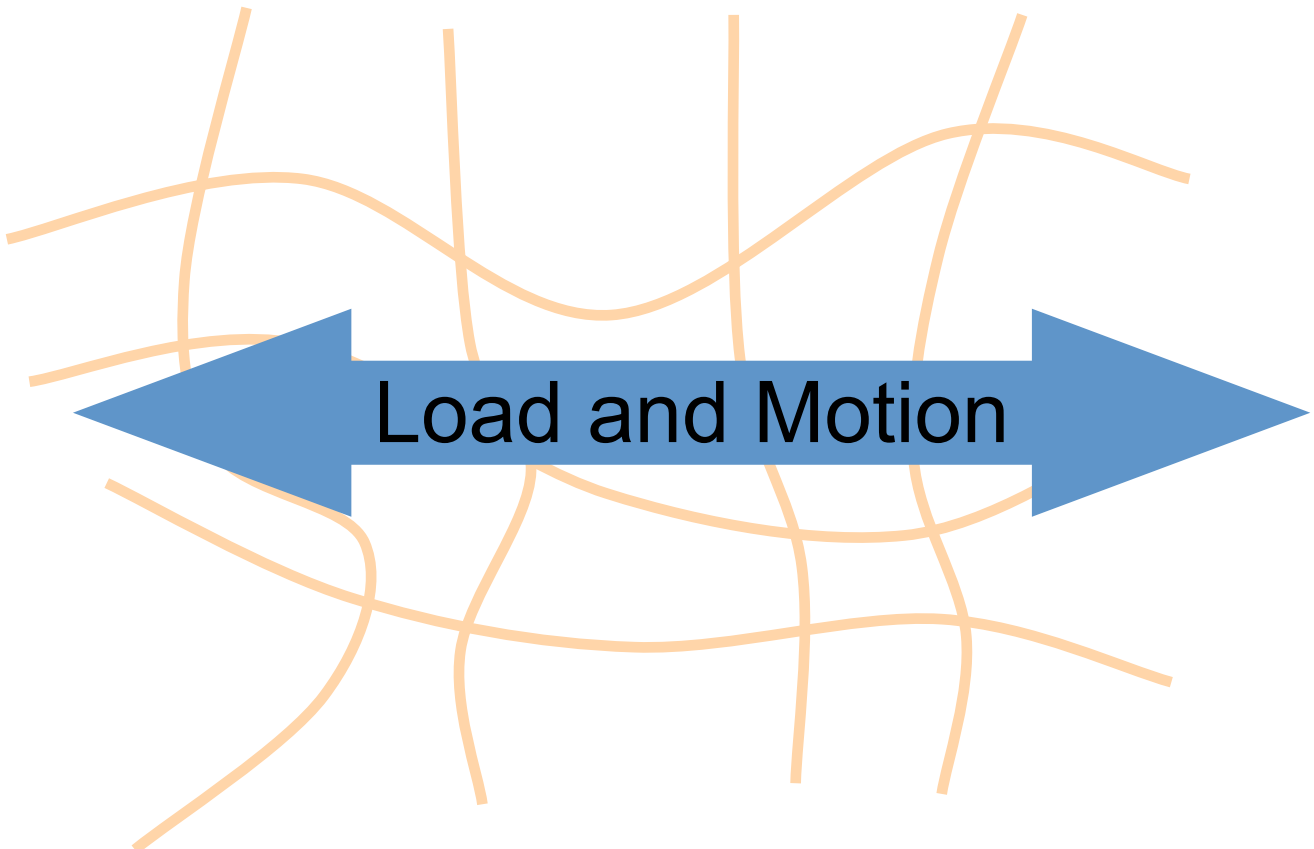

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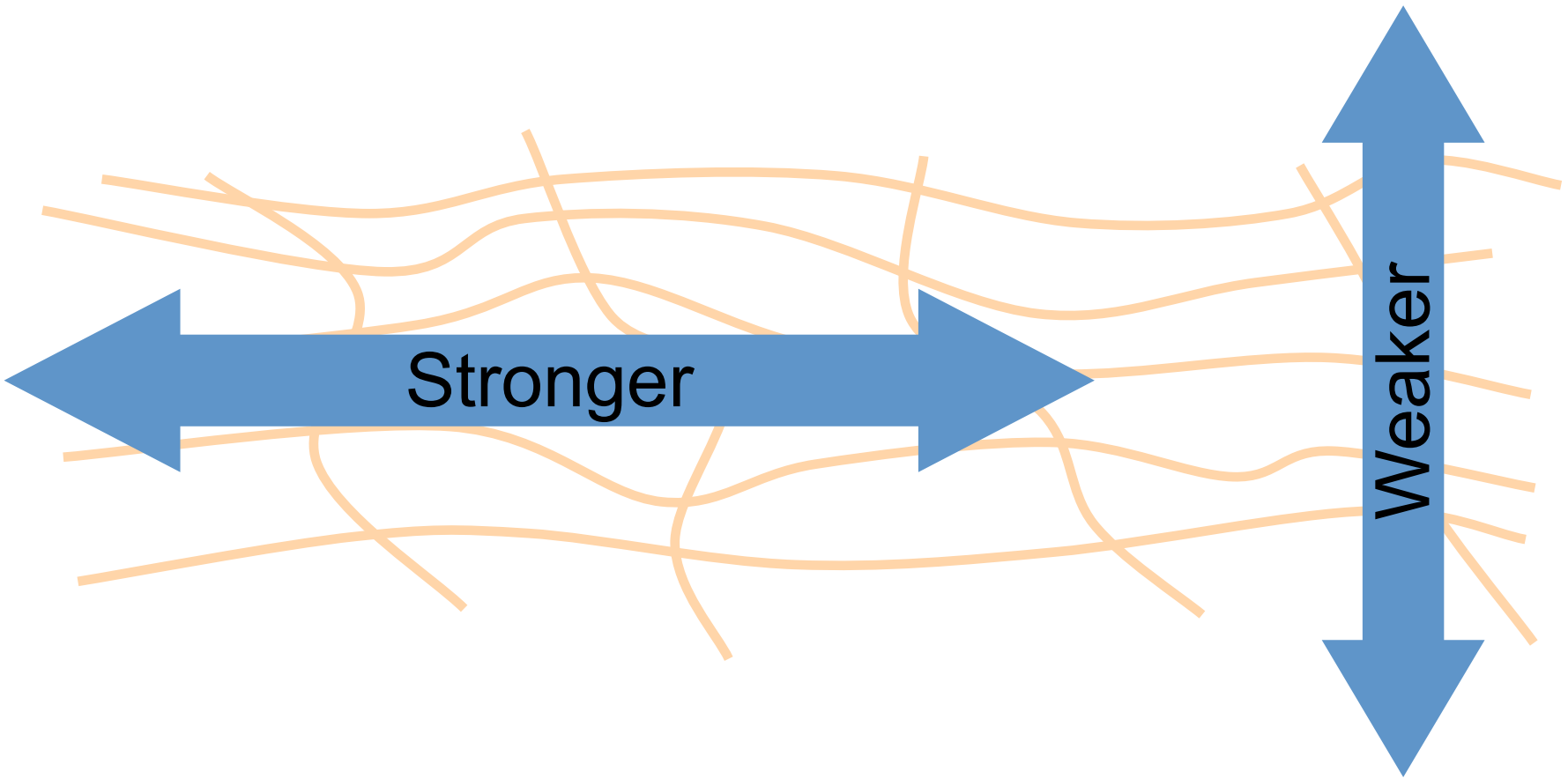

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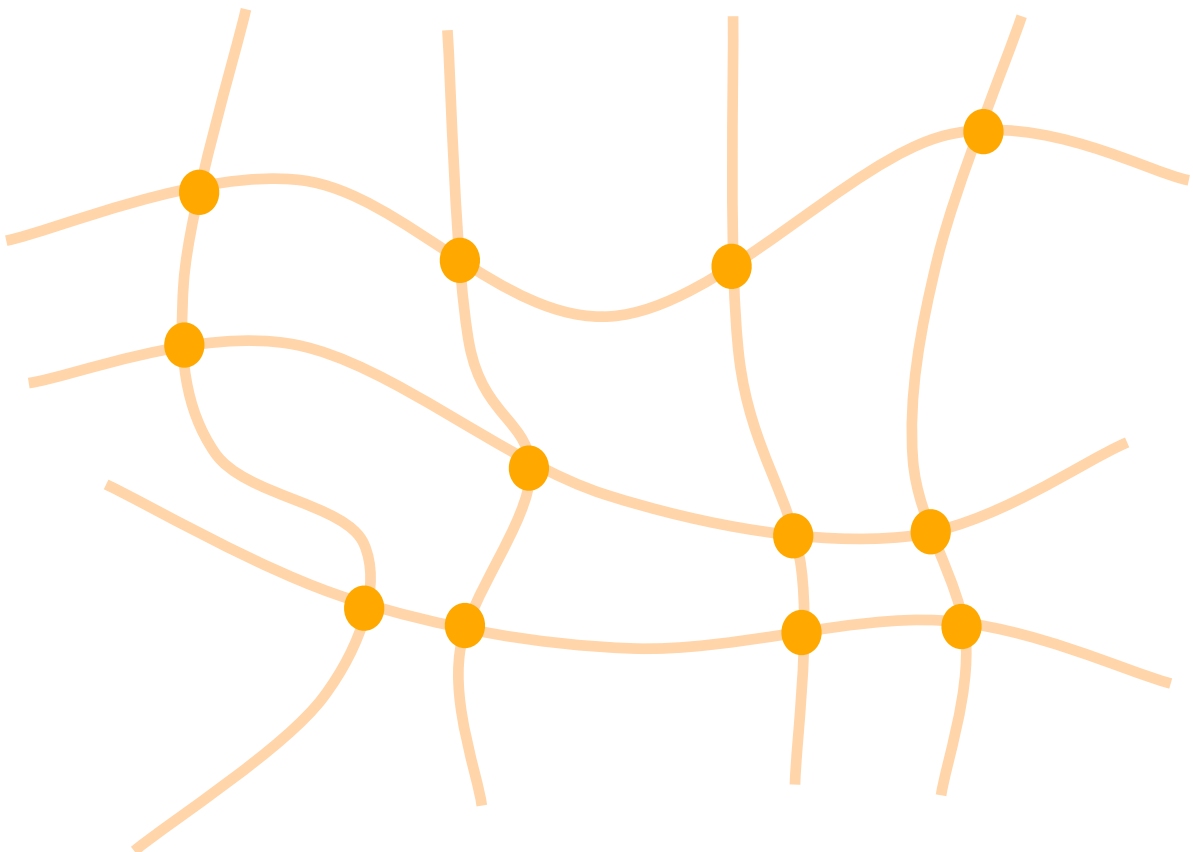

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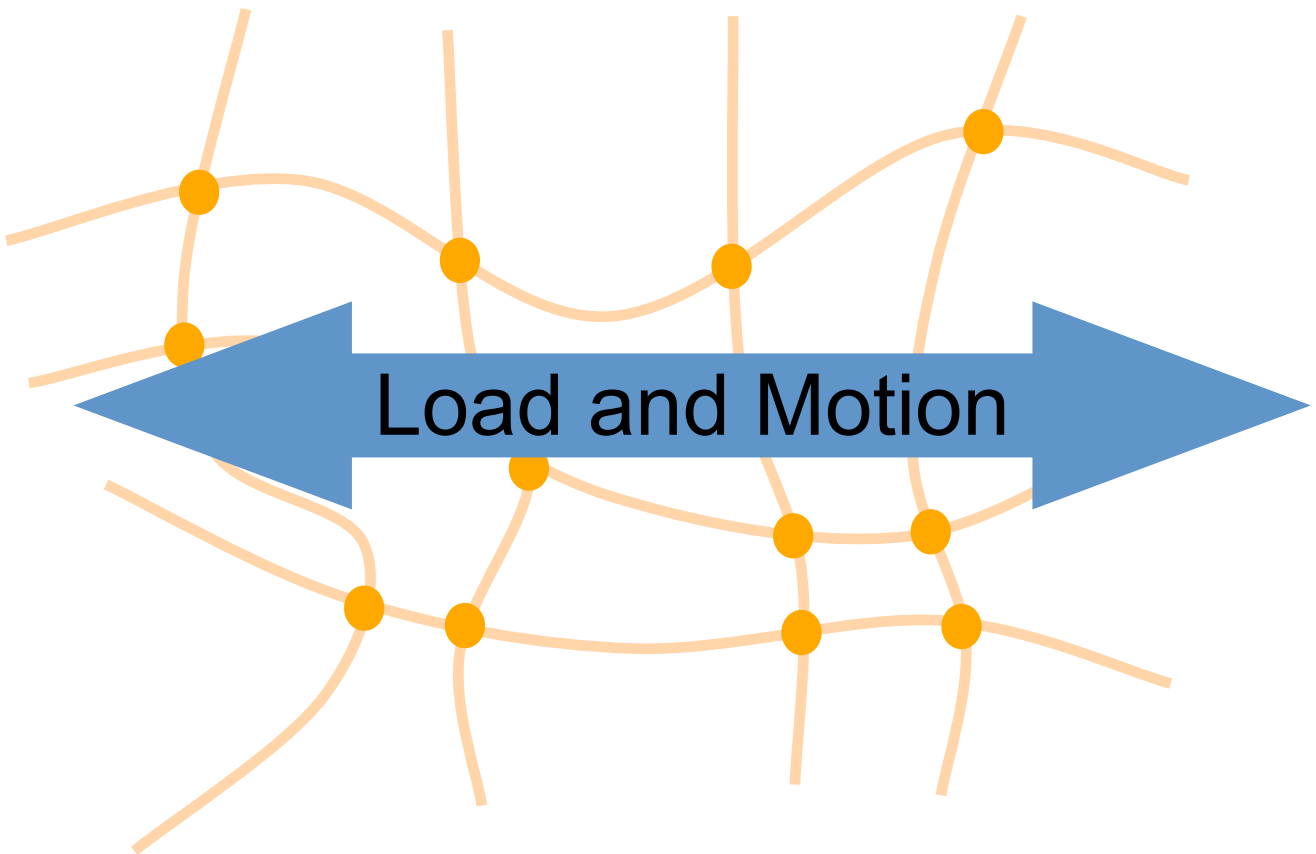

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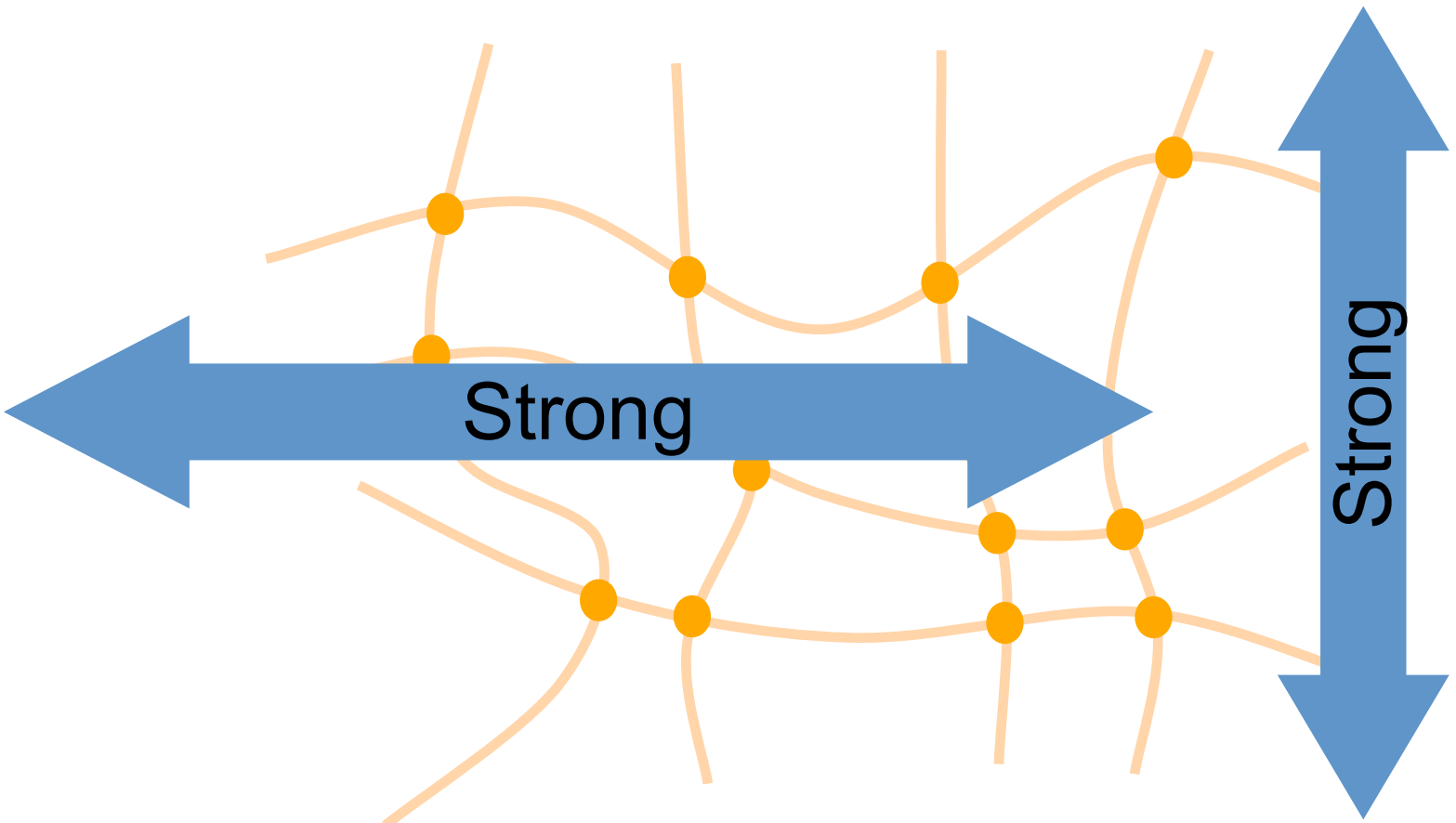
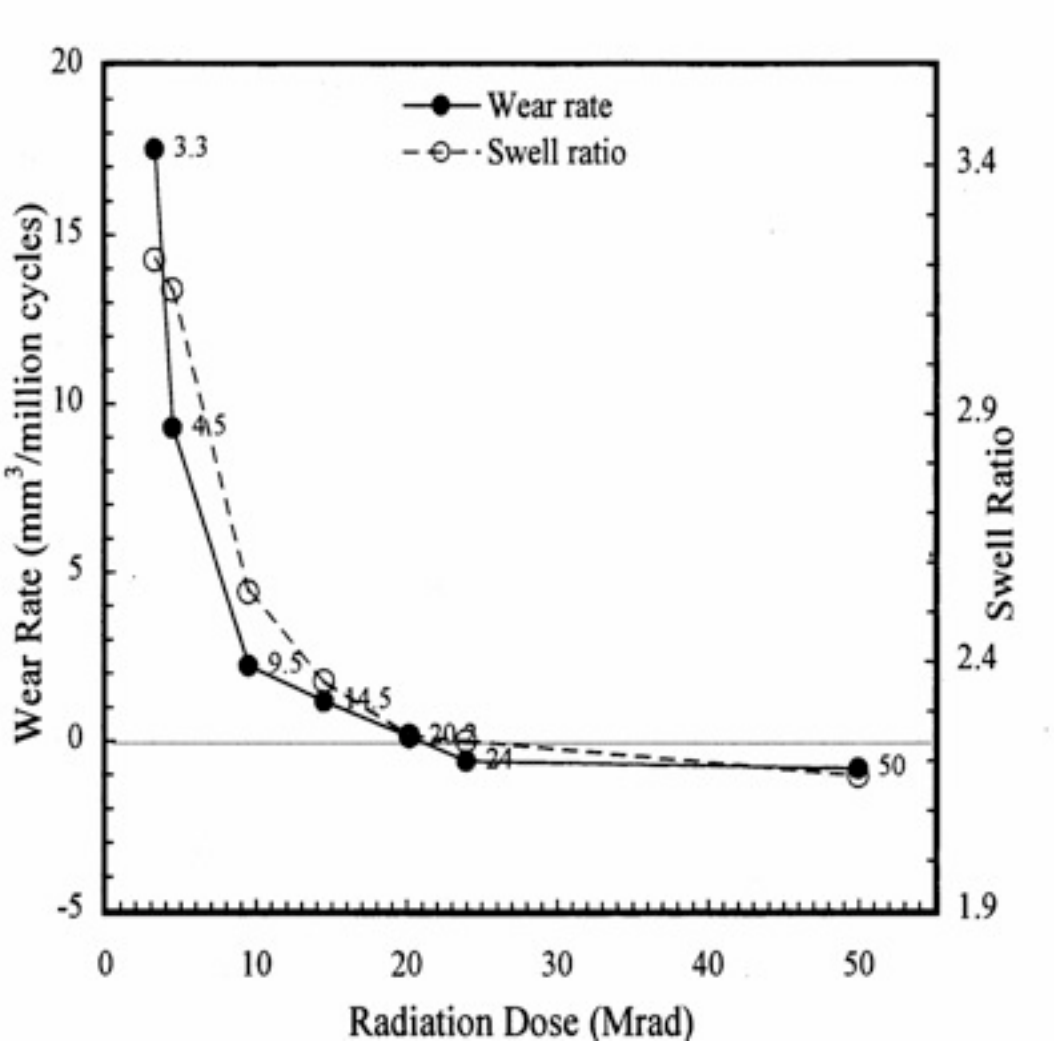


WEAR IN-VITRO

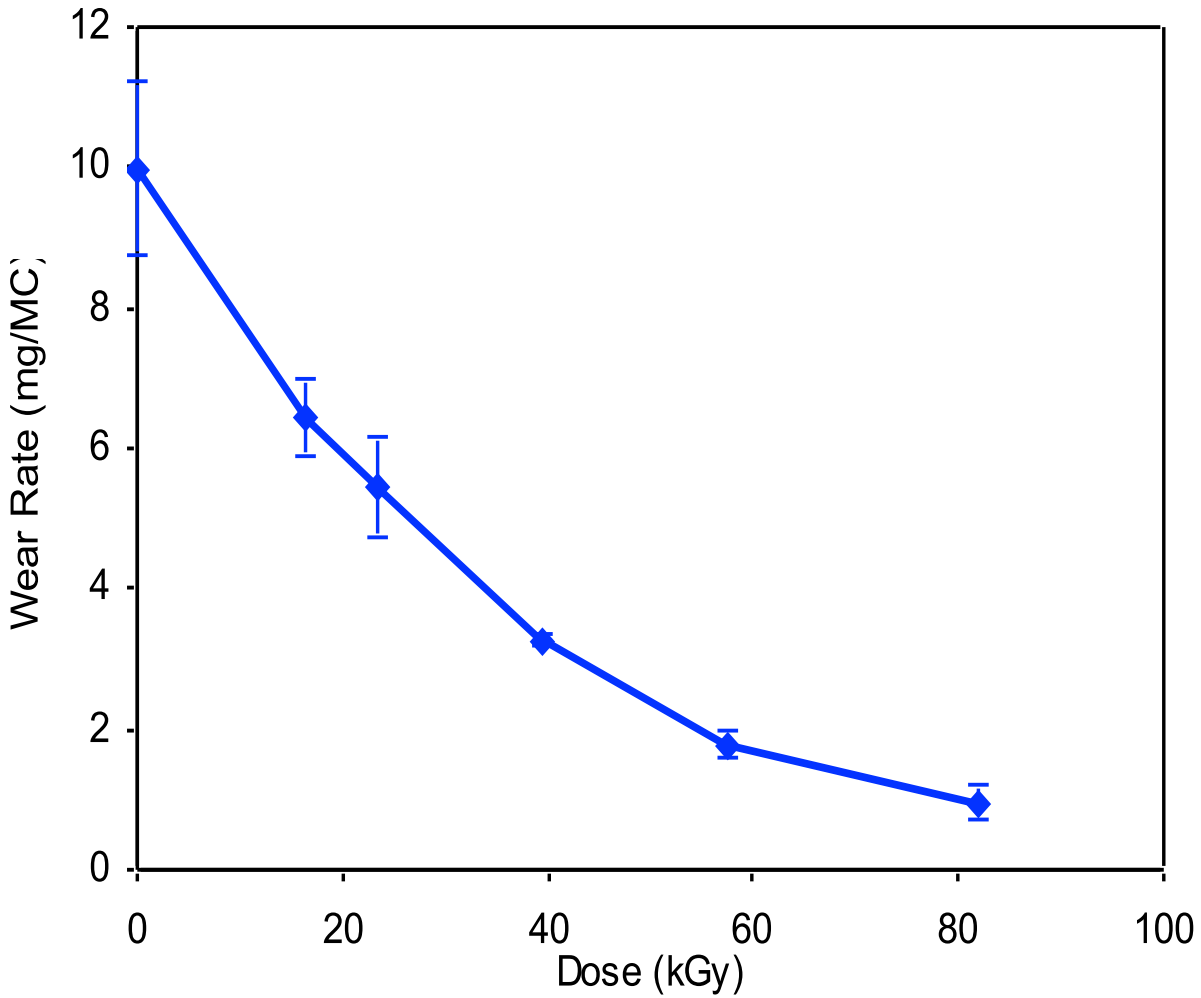
IN-VITRO WEAR ANALYSIS

H. McKellop et al, JOR, 17, 1999, p. 851



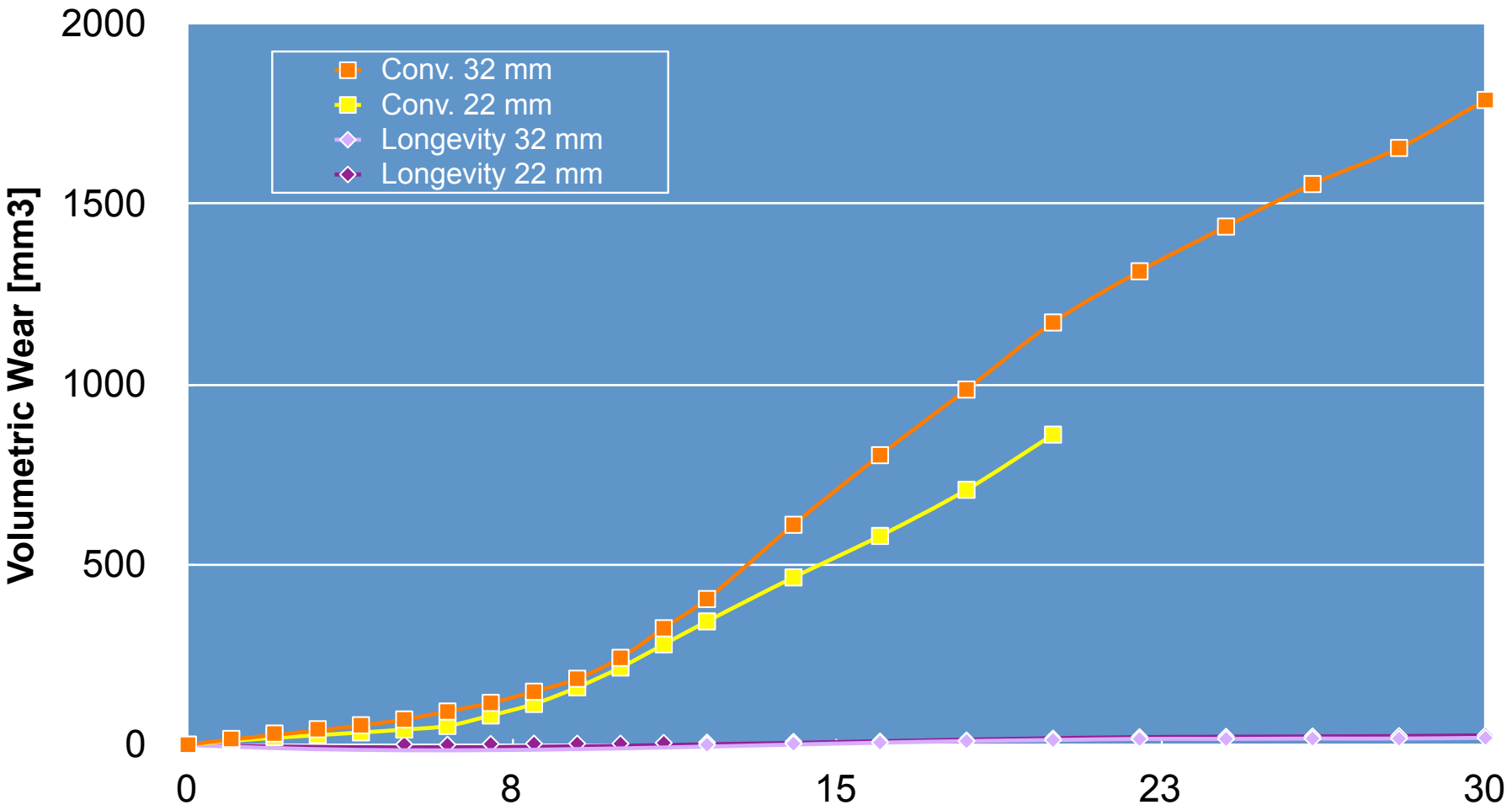
IN-VITRO WEAR ANALYSIS

O.K. Muratoglu et al, World Tribology Forum in Arthroplasty, Hans Huber, 2001, p. 24



HIP SIMULATOR TESTING

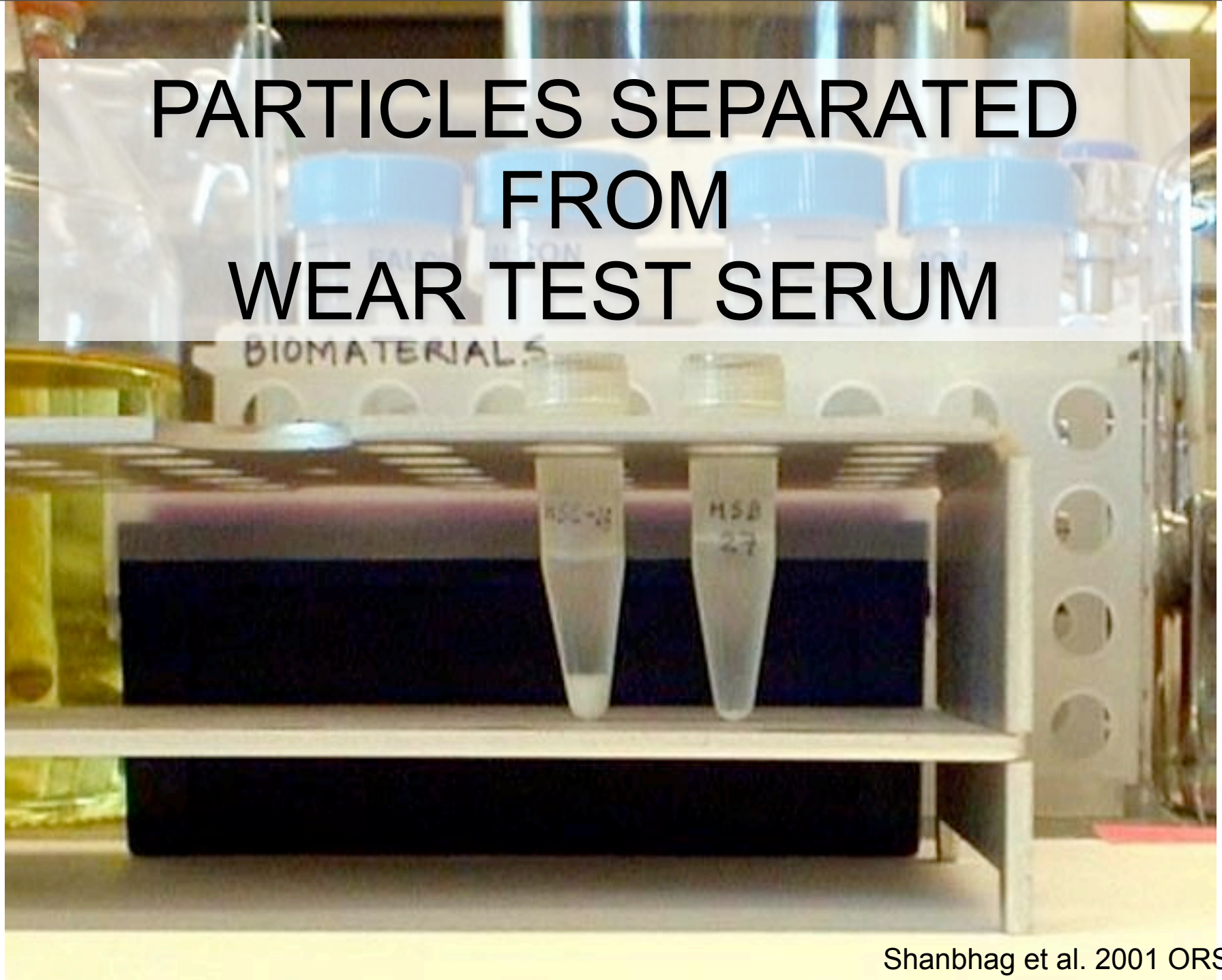
M.P. Laurent et al, SBM, 6th World Congress, 2000, Kamuela, p. 851



IN-VITRO WEAR ANALYSIS

- Mean wear rate of conventional polyethylene:
  - 11.6 ± 0.1 mg/10^6cycles
- Mean wear rate of highly cross-linked polyethylene:
  - Net weight gain
- V. Saikko et al, J Biomed Mater Res (Appl Biomater), 63, 2002, p. 848

PARTICLES SEPARATED FROM WEAR TEST SERUM



Shanbhag et al. 2001 ORS

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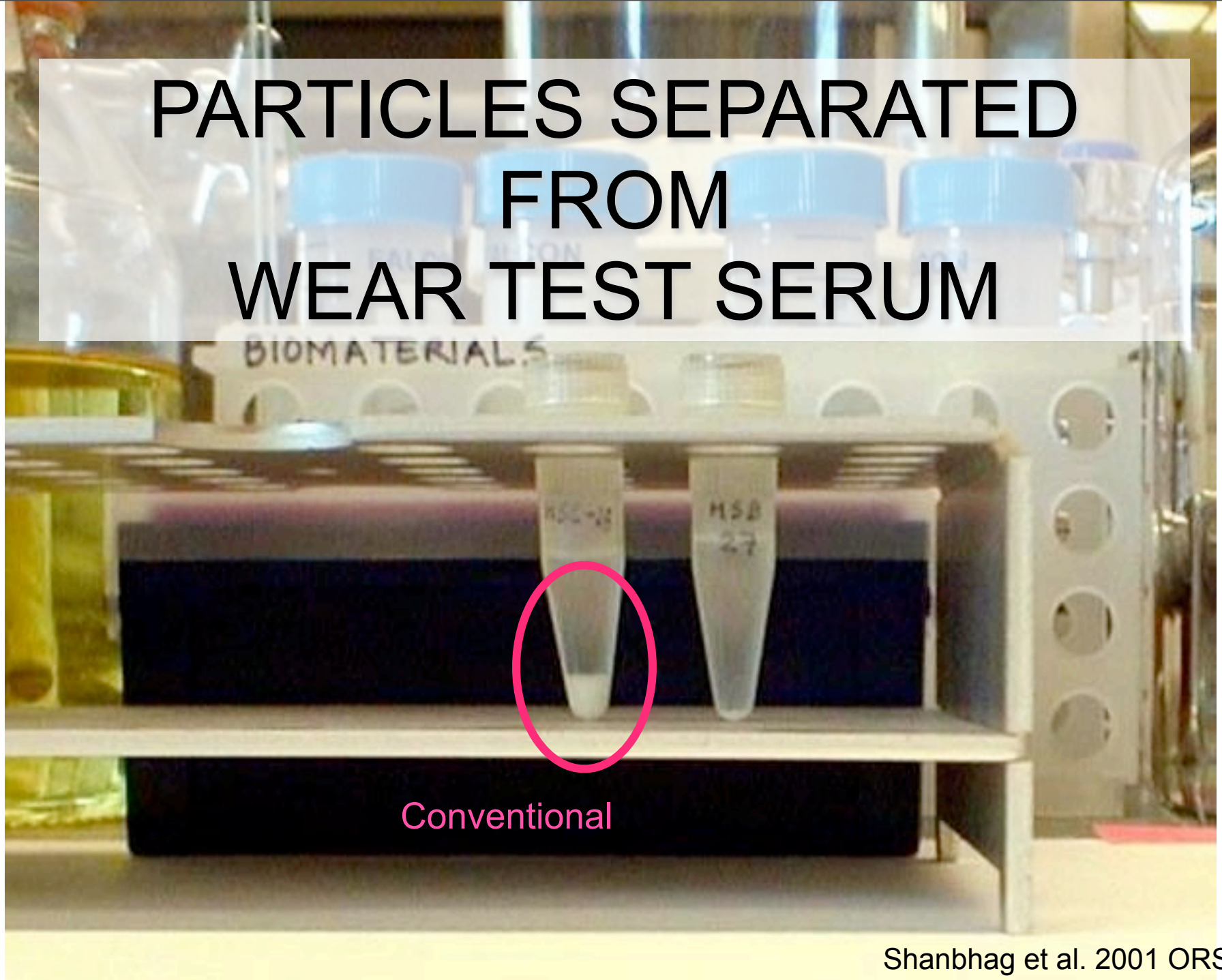

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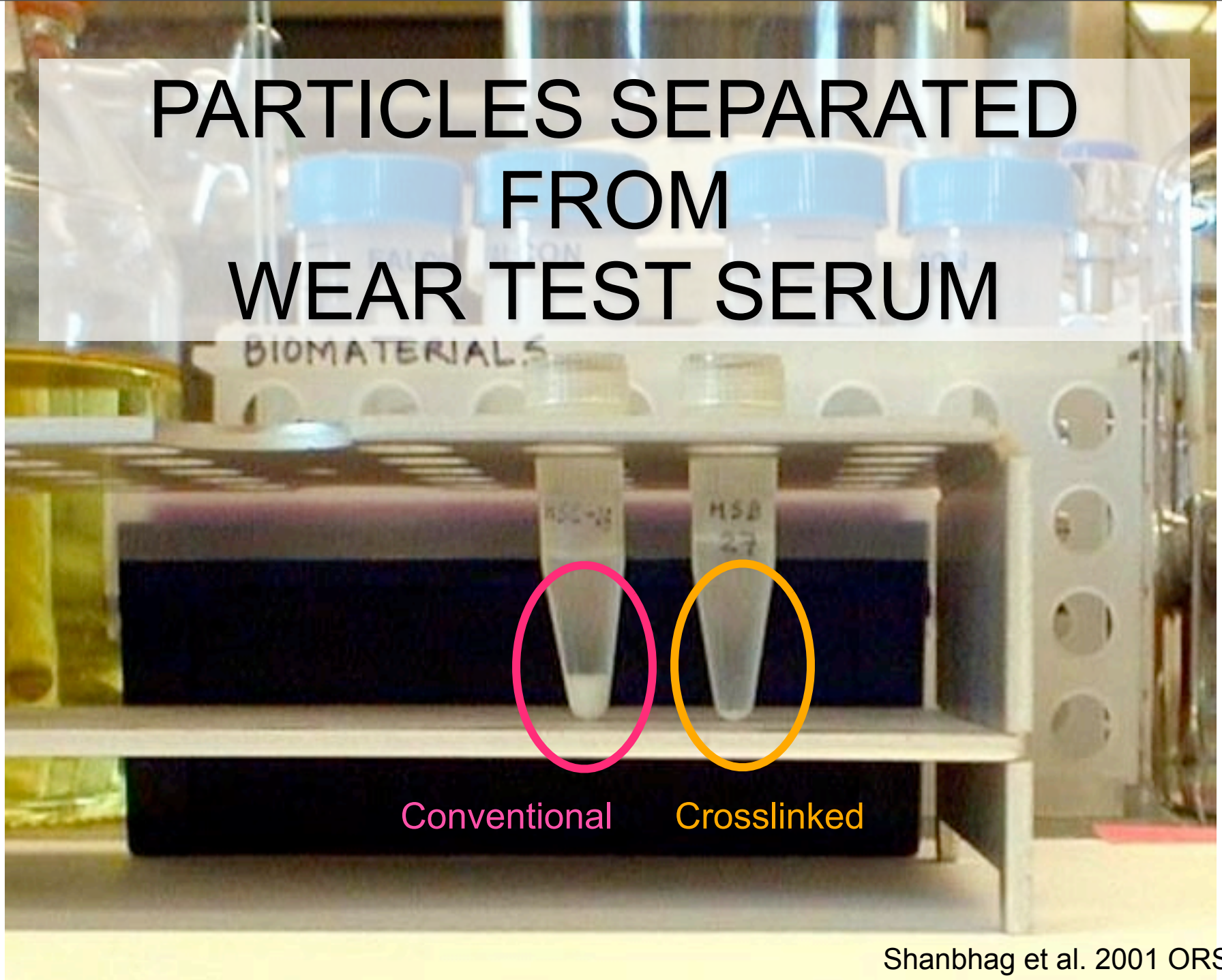
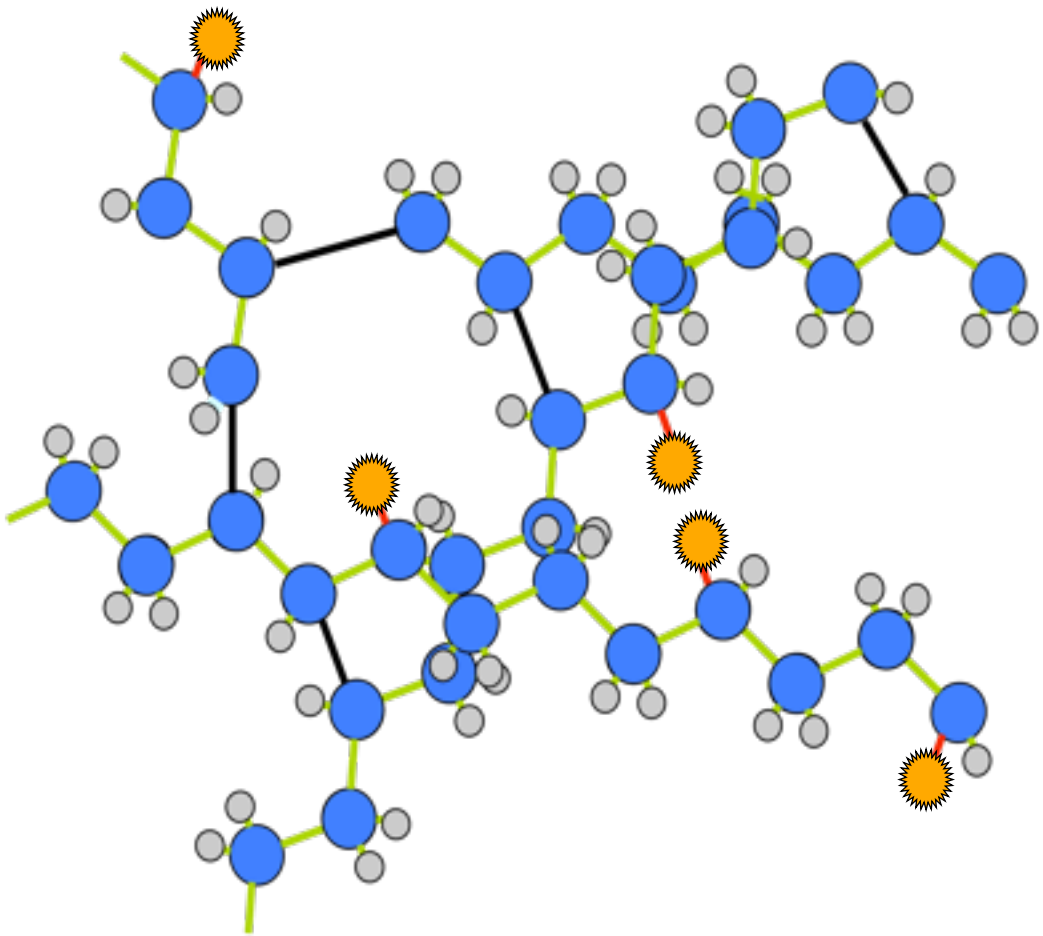


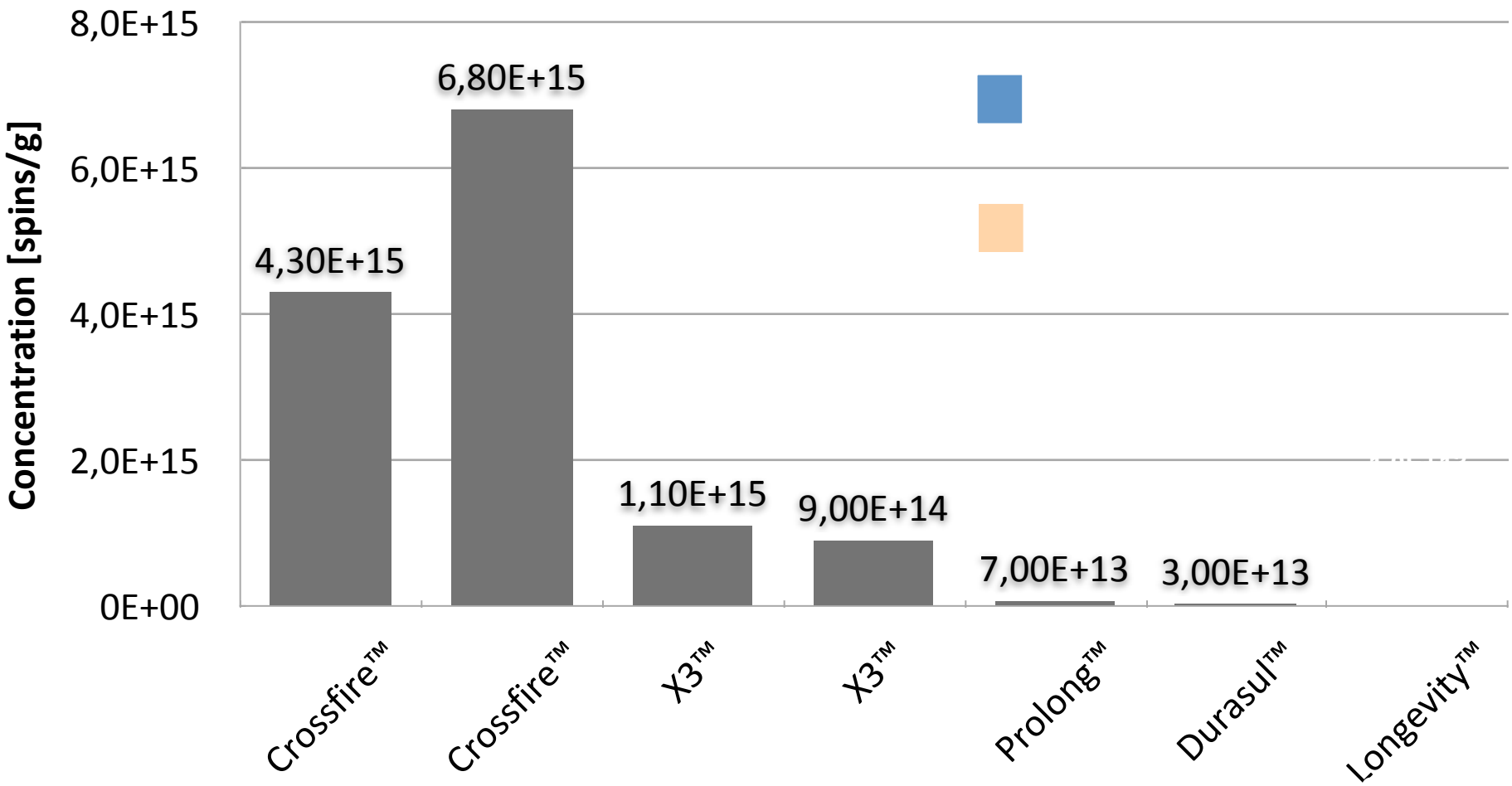
Shanbhag et al. 2001 ORS

FREE RADICALS

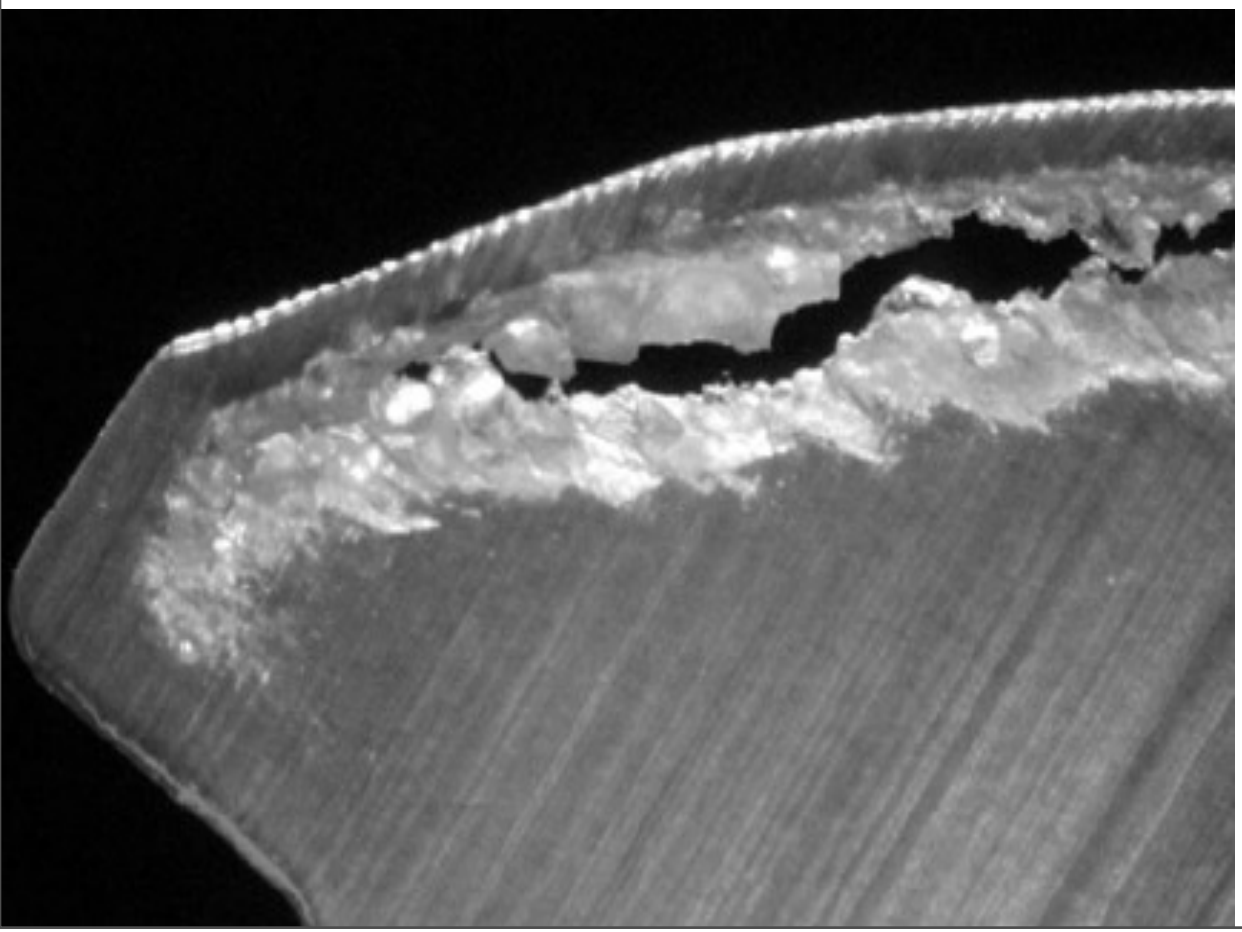
DEVELOPMENT OF HIGHLY CROSS-



CONCENTRATION OF



IN VIVO OXIDATION OF RETRIEVED XL-PE



IN VIVO OXIDATION OF RETRIEVED XL-PE

- “The elevated levels of oxidation and crystallinity measured in the retrieved Crossfire components after less than 3 years of in vivo service are unprecedented.”
- K.K. Wannomae, JOA, 21, 2006, p. 1005

EVALUATION OF OXIDATION AND

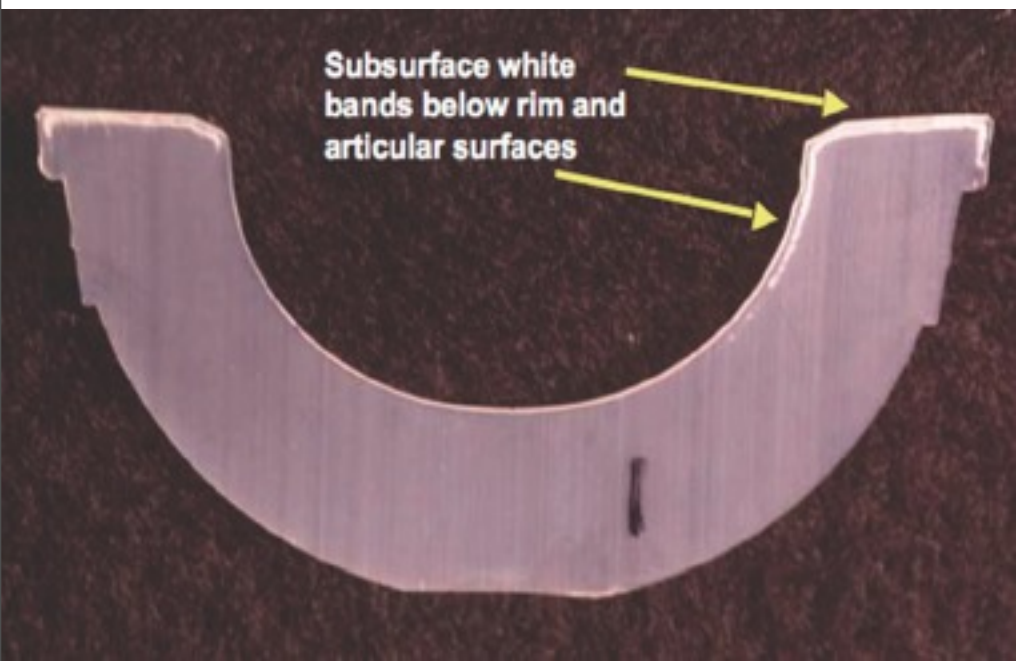
- 12 Crossfire acetabular components (Stryker Orthopaedics, Mahwah, NJ).
- Time in vivo: 0.1 – 5.3 years
- B.H. Currier et al, JBJS 89A, 2007, p. 2023

EVALUATION OF OXIDATION AND

- Retrieved Crossfire acetabular cups with fatigue damage in the form of rim delamination.
- Severe delamination seen after 2.9 years in vivo.

- B.H. Currier et al, JBJS 89A, 2007, p. 2023

EVALUATION OF OXIDATION AND

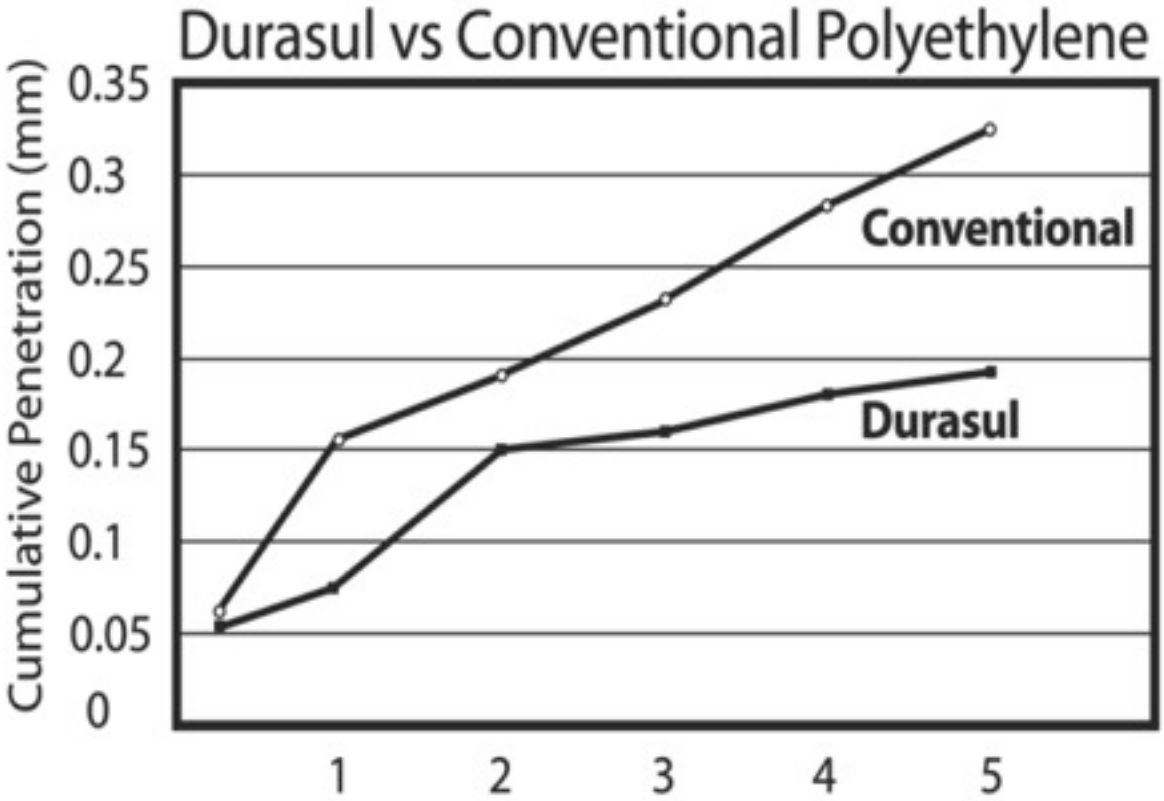


- A thin section of a Crossfire acetabular cup retrieved after 3.3 years in vivo shows a subsurface white band on the rim and the articular surface.

- B.H. Currier et al, JBJS 89A, 2007, p. 2023

HEAD PENETRATION

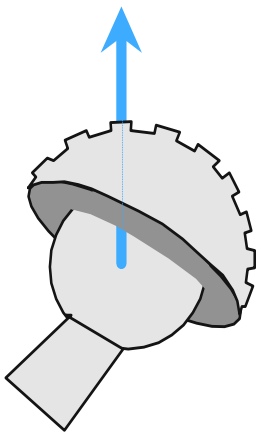
CLINICAL PERFORMANCE OF A DURASUL

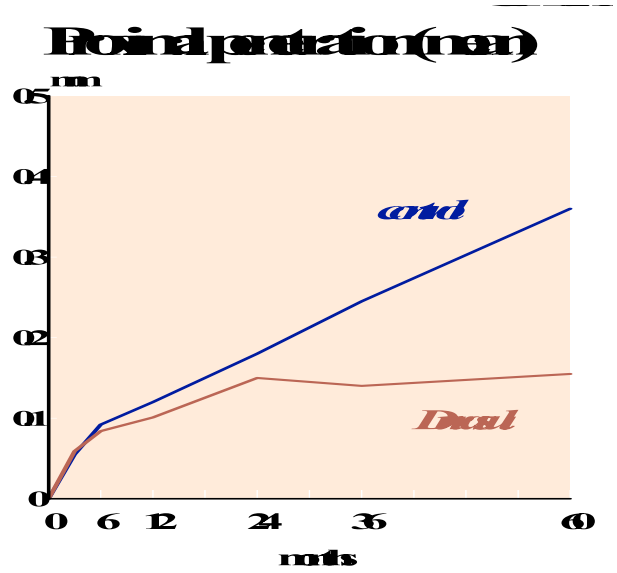


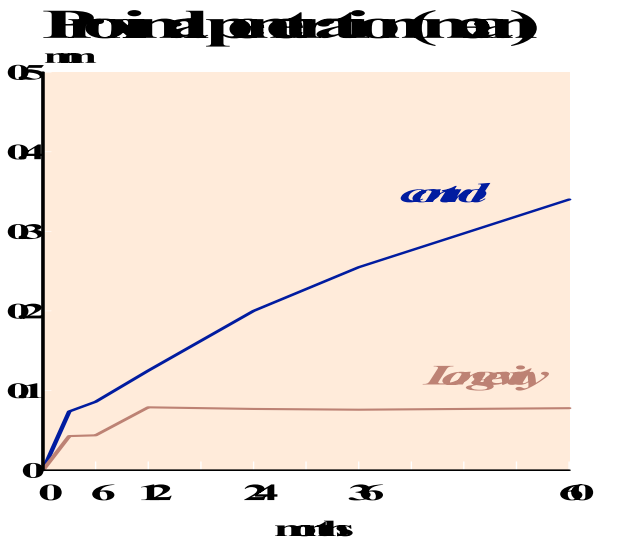
- L.D. Dorr et al, JBJS 87A, 2005, p. 1816

IN-VIVO WEAR ANALYSIS

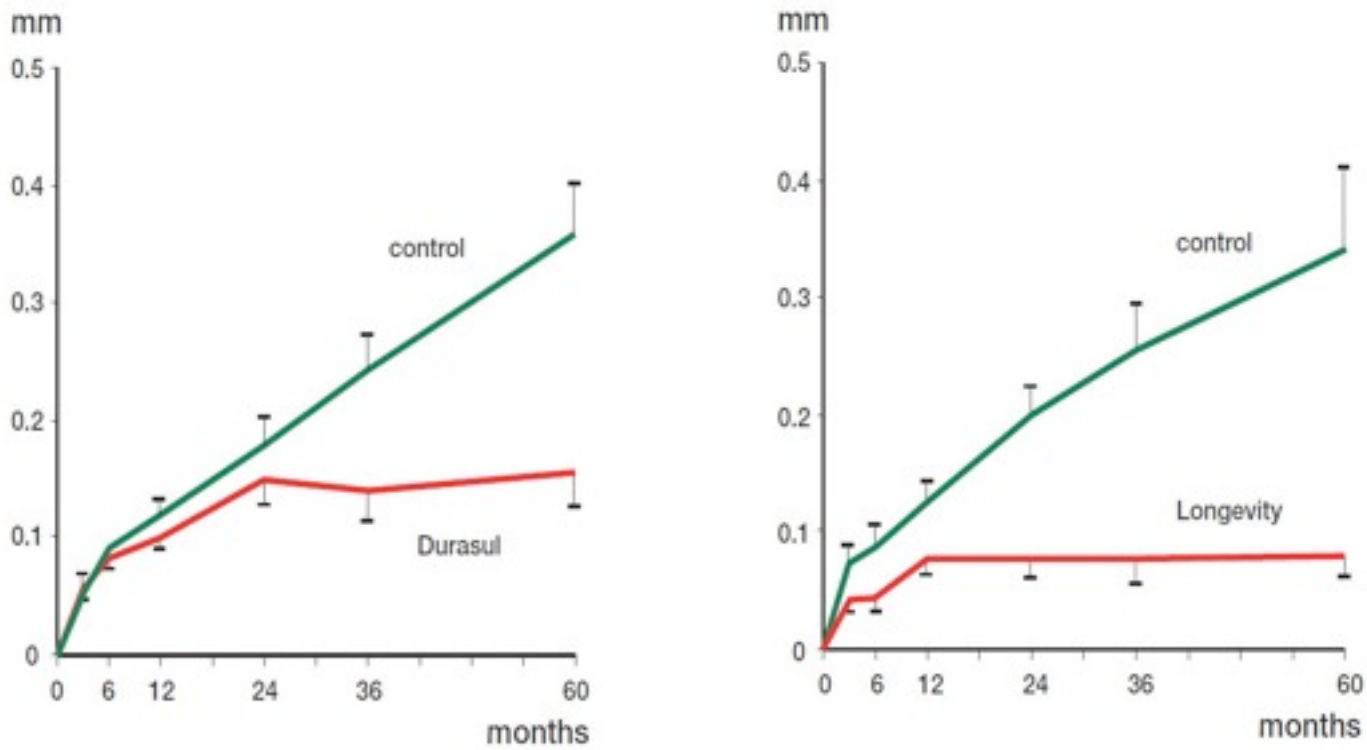
- Five years experience of highly cross-linked polyethylene in cemented and uncemented sockets: Two randomized studies using RadioStereometric Analysis
- G. Digas et al, ORS 2007, Poster 392





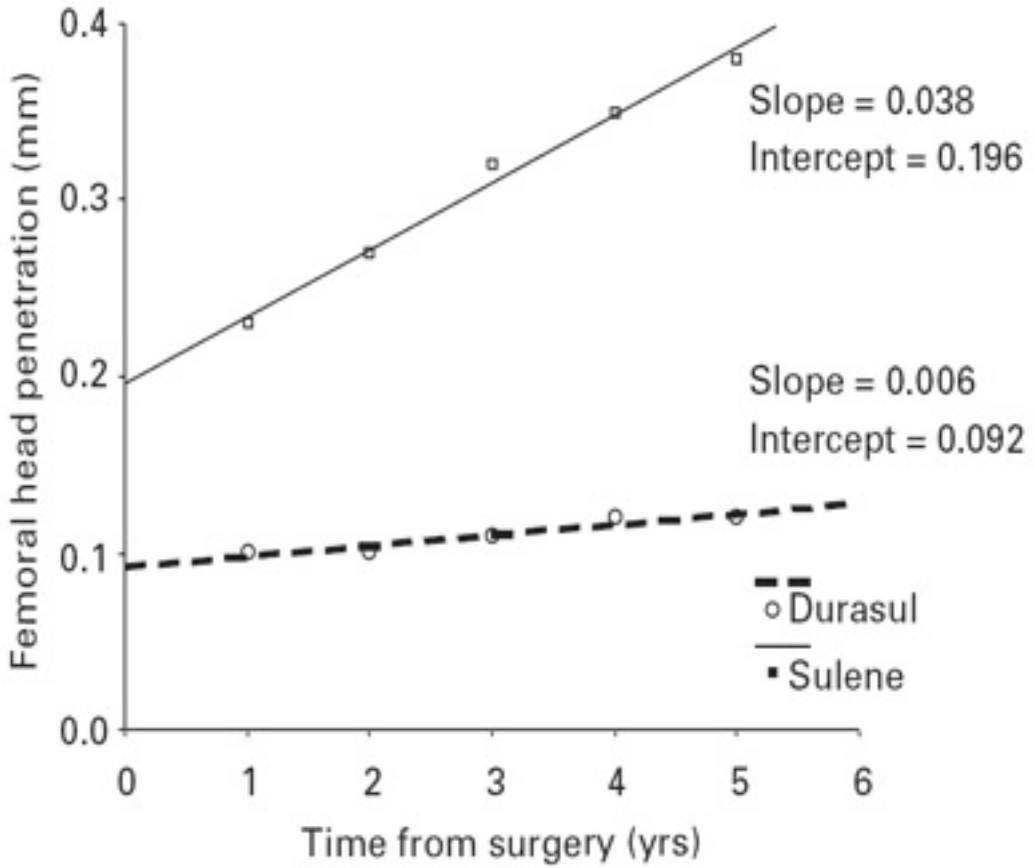


5-YEAR EXPERIENCE OF HIGHLY CROSS-



- G. Digas et al, Acta Orthopaedica, 78, 2007, p. 746

NEW POLYETHYLENES IN TOTAL HIP



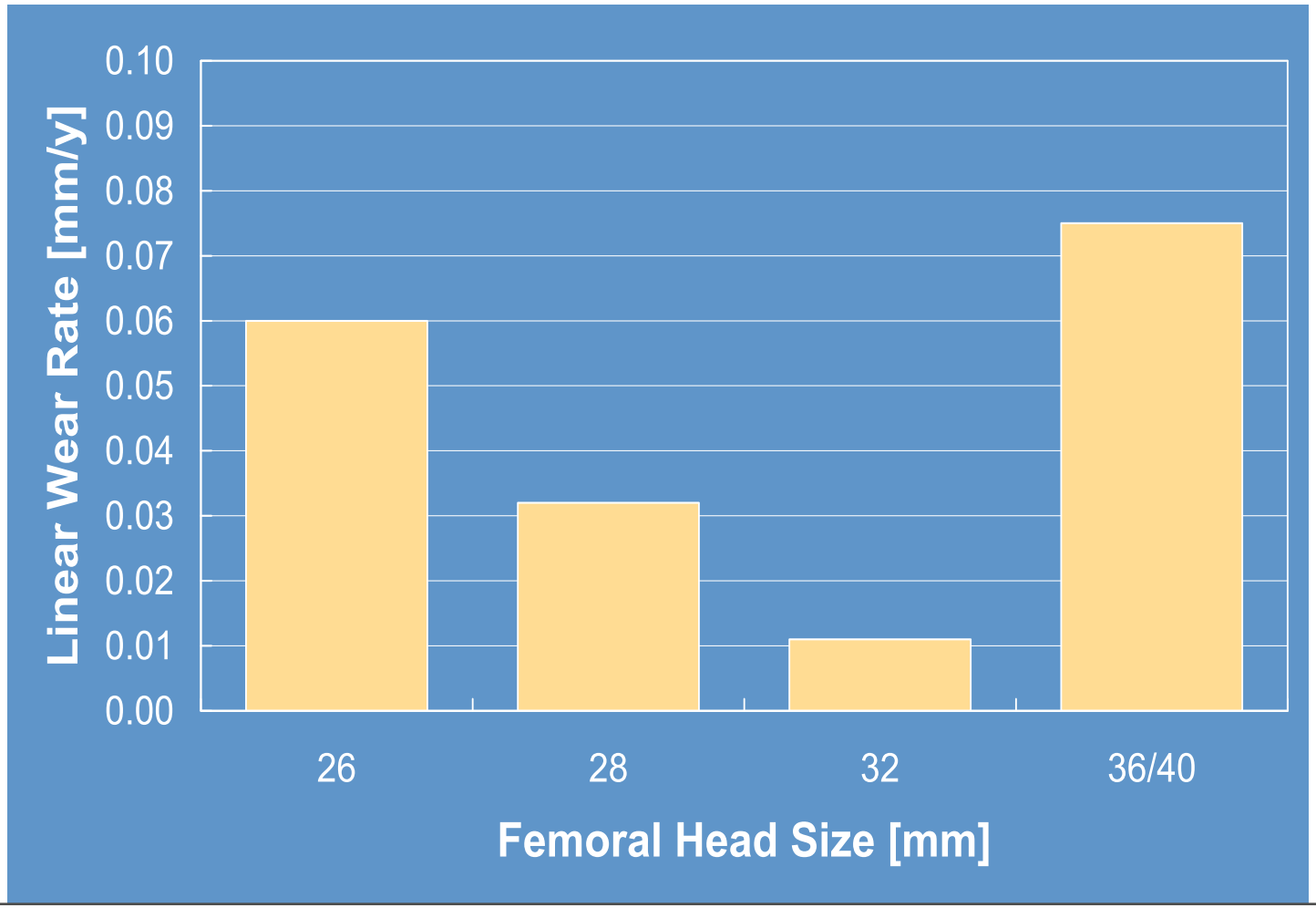
- E. Garcia-Rey et al, JBJS, 90-B, 2008, p. 149

HEAD PENETRATION

FEMORAL HEAD SIZE AND WEAR OF

- 90 patients (102 hips)
  - 14 hips with 26 mm heads
  - 33 hips with 28 mm heads
  - 35 hips with 32 mm heads
  - 20 hips with 36 mm or 40 mm heads
- Wear measurement made by Martell's method
- P.F. Lachiewicz et al, CORR, 467, 2009, p. 3290

FEMORAL HEAD SIZE AND WEAR OF



FEMORAL HEAD SIZE AND WEAR OF

- “Our study may modify the concept that the wear of electron beam XLPE is independent of femoral head size. Although the linear wear rate was not related to the femoral head diameter, there was a greater volumetric wear rate with the larger heads.”
- P.F. Lachiewicz et al, CORR, 467, 2009, p. 3290

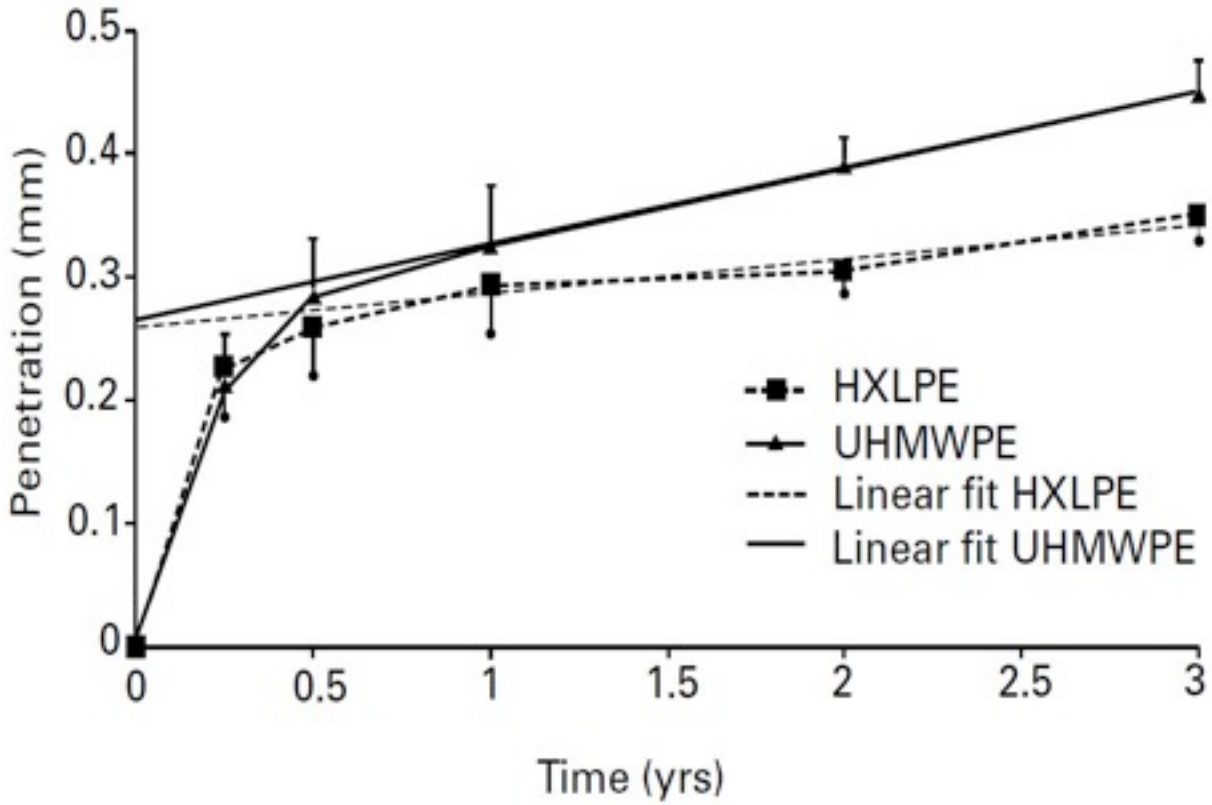
FEMORAL HEAD SIZE AND WEAR OF

- “Pending long-term studies of large head sizes, we advise caution in using larger femoral heads in young or active patients and in those with a low risk of dislocation.”
- P.F. Lachiewicz et al, CORR, 467, 2009, p. 3290

THE CREEP AND WEAR OF HIGHLY

- 54 randomised patients
  - 27 conventional PE
  - 27 Longevity Trilogy liners
- Wear measurement made by RSA
- Minimum follow-up: 3 years
- S. Glyn-Jones et al, JBJS, 90B, 2008, p. 556

THE CREEP AND WEAR OF HIGHLY

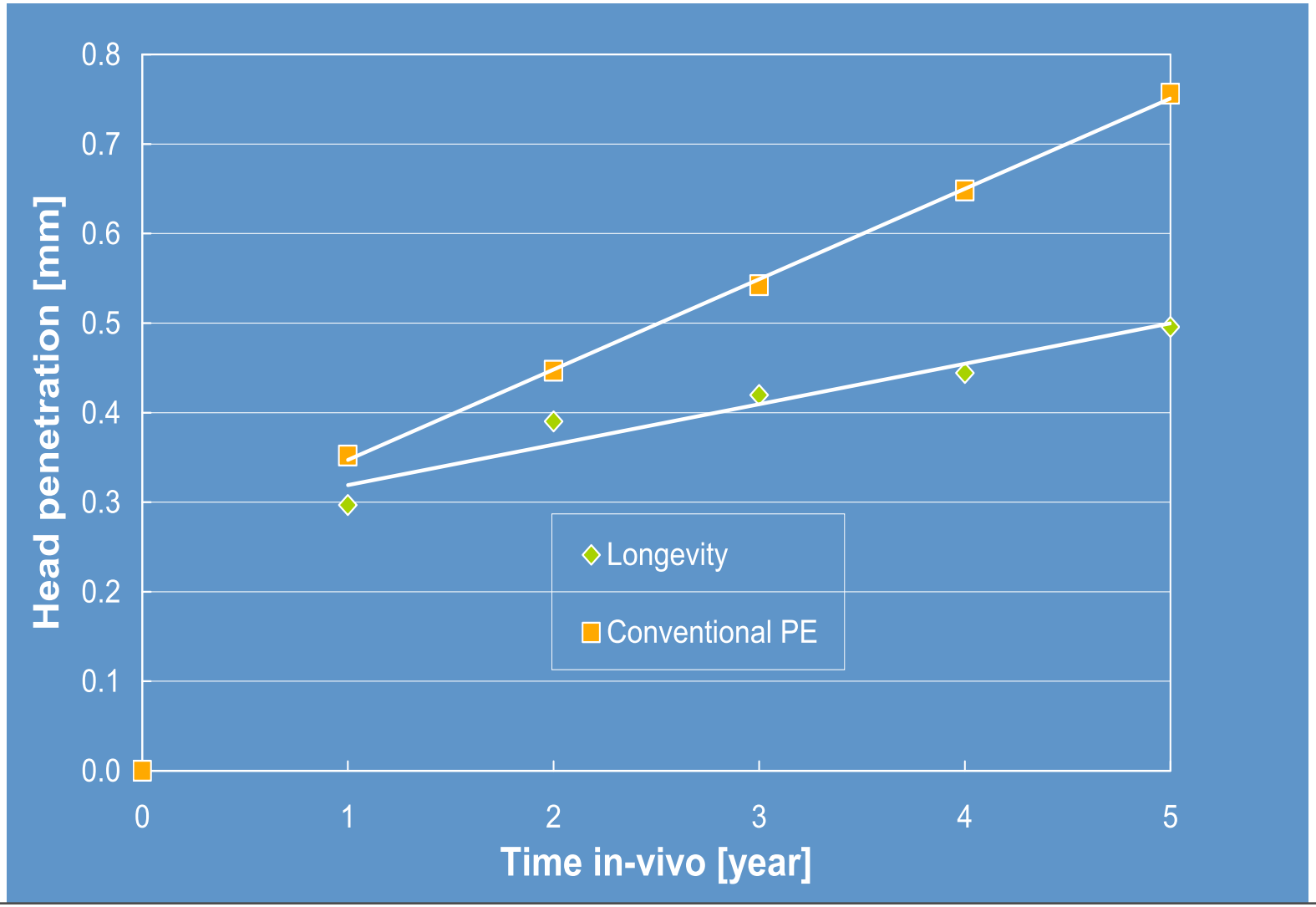


- S. Glyn-Jones et al, JBJS, 90B, 2008, p. 556

WEAR IN CONVENTIONAL AND HIGHLY

- 110 THAs on 102 patients
- 80 matched THAs (age and BMI)
  - 20 conventional PE
  - 60 Longevity Trilogy liners
- Two-dimensional head penetration
- Minimum follow-up: 5 years
- C. Olyslaegers et al, JOA, 23, 2008, p. 489

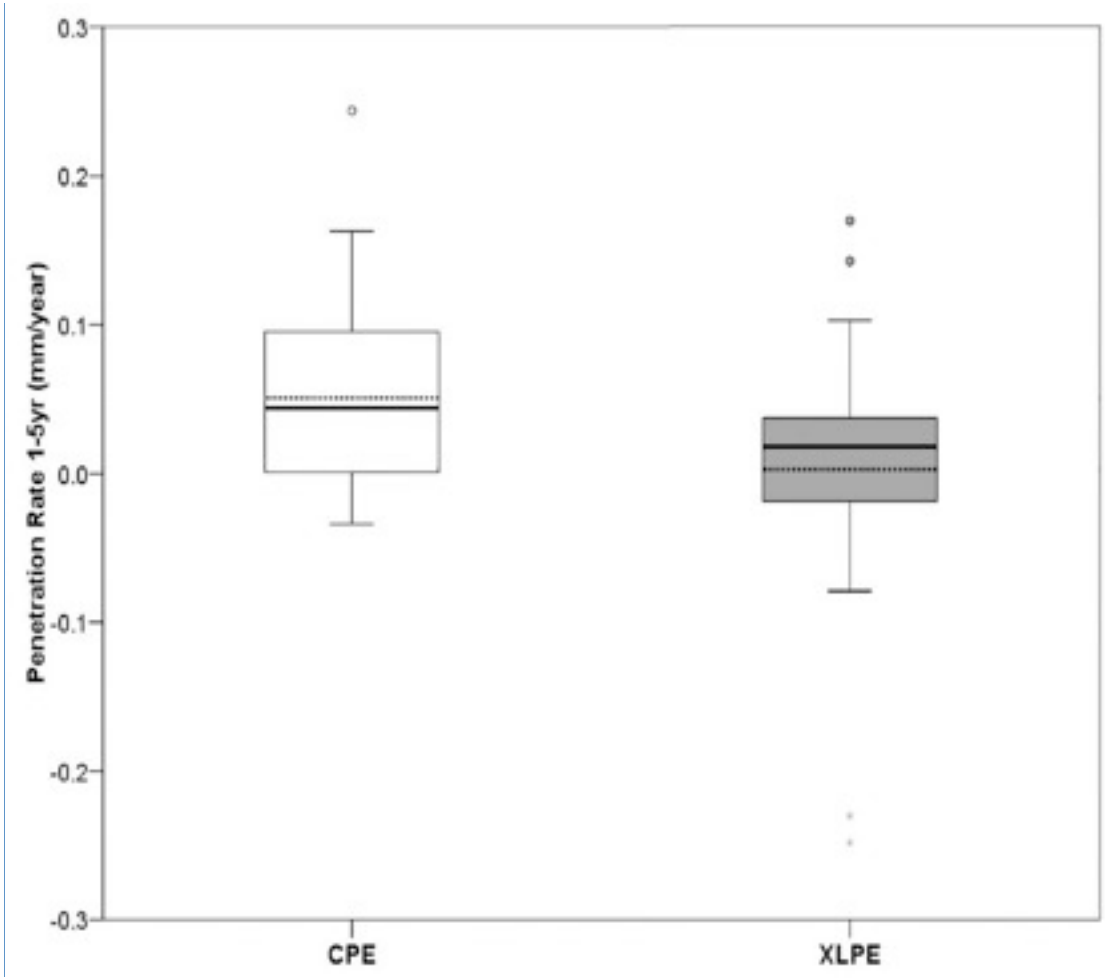
WEAR IN CONVENTIONAL AND HIGHLY CROSS-LINKED PE CUPS



WEAR RATE OF HIGHLY CROSS-LINKED

- 100 consecutive patients
  - 50 conventional PE
  - 50 Longevity Trilogy liners
- Analysis made by the Hip Analysis Suite software
- Minimum follow-up: 5.62 years
- R.W. McCalden et al, JBJS, 91A, 2009, p. 773

WEAR RATE OF HIGHLY CROSS-LINKED



- Penetration rate:
  - CPE: 51 µm/yr
  - XLPE: 3 µm/yr
- The penetration rates differed significantly between the polyethylene groups (p = 0.006).
- R.W. McCalden et al, JBJS, 91A, 2009, p. 773

WEAR IS REDUCED IN THA PERFORMED

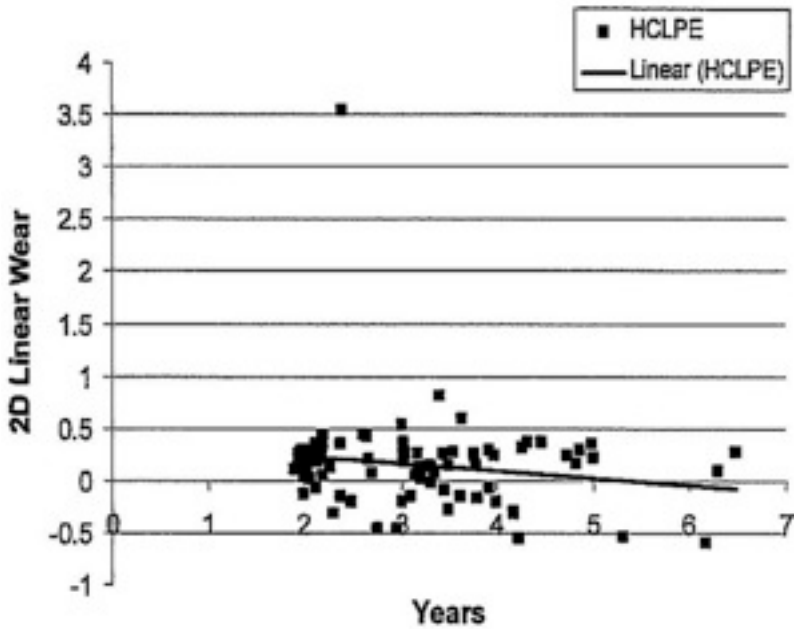
- “Our matched-pair study of 82 hips in young patients at a mean of 5 years (4 - 8 years) follow-up revealed lower wear of HCLPE liners in comparison to CPE liners, with fewer patients having calcar resorption and periprosthetic osteolysis.”
- B. Beksaç et al, CORR, 467, 2009, p. 1765

THA WITH HIGHLY CROSS-LINKED

- 70 THAs on 64 patients
- Average age: 41 years (19 – 50 years)
- Longevity liners
- Martell measurement technique
- Average follow-up: 4 years (2.4 – 6.5 years)
- D.S. Shia et al, CORR, 467, 2009, p. 2059

THA WITH HIGHLY CROSS-LINKED

- "With the bedding-in phenomenon excluded, the wear rate was -0.036 mm per year, representing undetectable wear at this follow-up."



THA WITH HIGHLY CROSS-LINKED

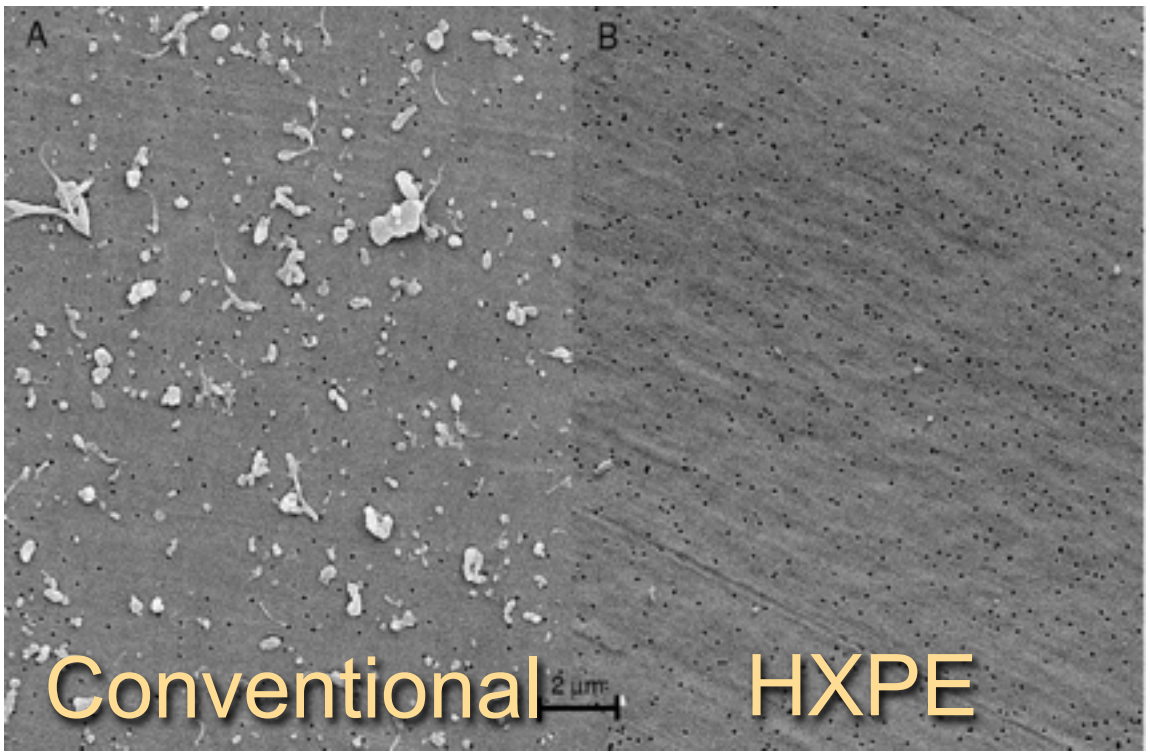
- “We found the early wear rates of this HCLPE in a young patient population are comparable to published data for older populations. In addition, the polyethylene wear rate that we determined was less than that of previously reported conventional polyethylene historic controls. Finally, no patient underwent revision, had evidence of accelerated wear, or had evidence of early failure during the follow-up period.”
- D.S. Shia et al, CORR, 467, 2009, p. 2059

PARTICLES

CHARACTERIZATION OF A

- Wear particles were extracted from the serum lubricant after 30 Mc for both the conventional and the HXPE materials
- Equivalent circle diameter (ECD):
  - Conventional PE: 0.229 ± 0.123 µm
  - Longevity™: 0.159 ± 0.051 µm
  - This difference in being statistically significant
- M. Laurent et al, JOA, 23, 2008, p. 751

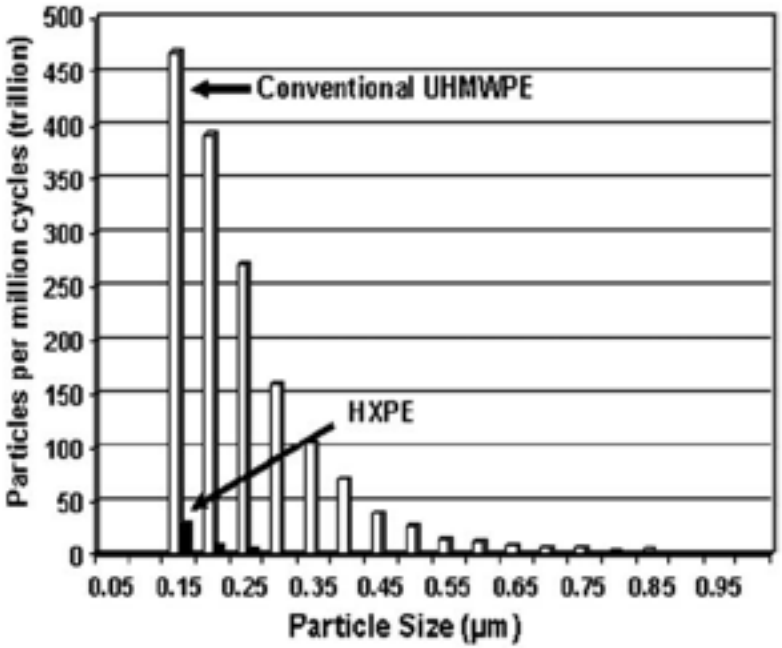
CHARACTERIZATION OF A



- M. Laurent et al, JOA, 23, 2008, p. 751

CHARACTERIZATION OF A

- “The relative number of particles within all particle size ranges generated per million wear cycles was substantially lower for the HXPE than for the conventional material.”



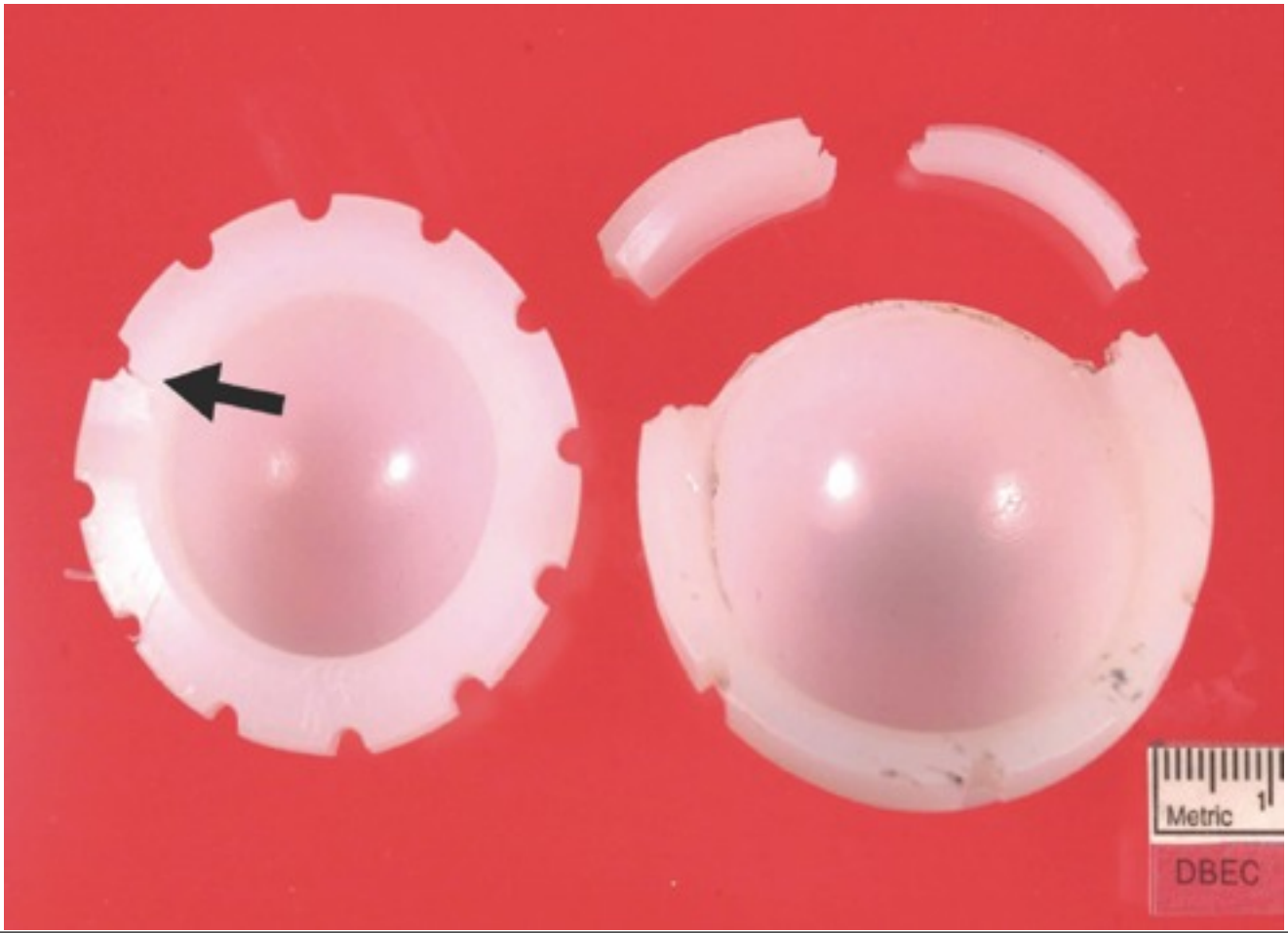
FAILURES

FRACTURE OF LONGEVITY™ INSERTS

RIM CRACKING OF THE CROSS-LINKED

- „We reviewed a series of retrieved acetabular liners with a fracture of the superior rim to assess the factors that played a role in their failure.“
- S.S. Tower et al, JBJS 89A, 2007, p. 2212

RIM CRACKING OF THE CROSS-LINKED



RIM CRACKING OF THE CROSS-LINKED

- All the liners have a high abduction angle (higher than 60º).
- None of the retrieved liners had measurable oxidation.
- S.S. Tower et al, JBJS 89A, 2007, p. 2212

RIM CRACKING OF THE CROSS-LINKED

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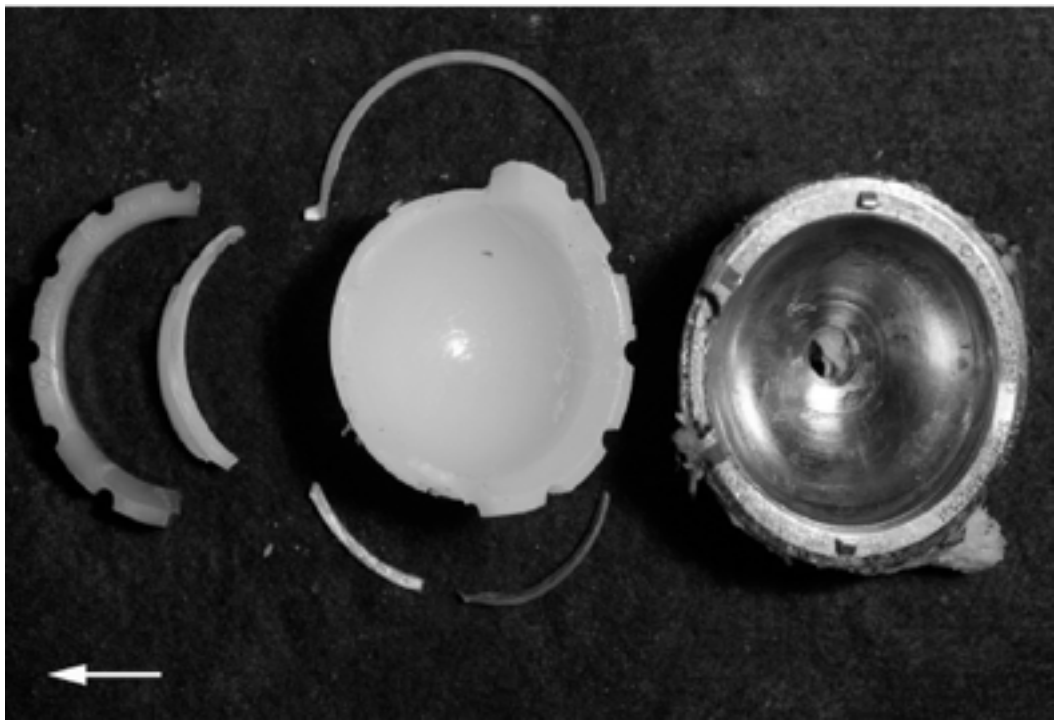
RIM CRACKING OF THE CROSS-LINKED

- All the liners have a high abduction angle (higher than 60º).
- None of the retrieved liners had measurable oxidation.

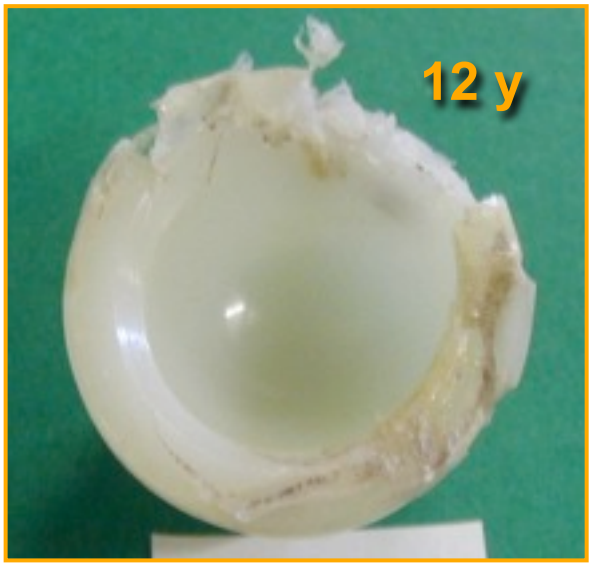
EARLY FAILURE OF A CROSS-LINKED

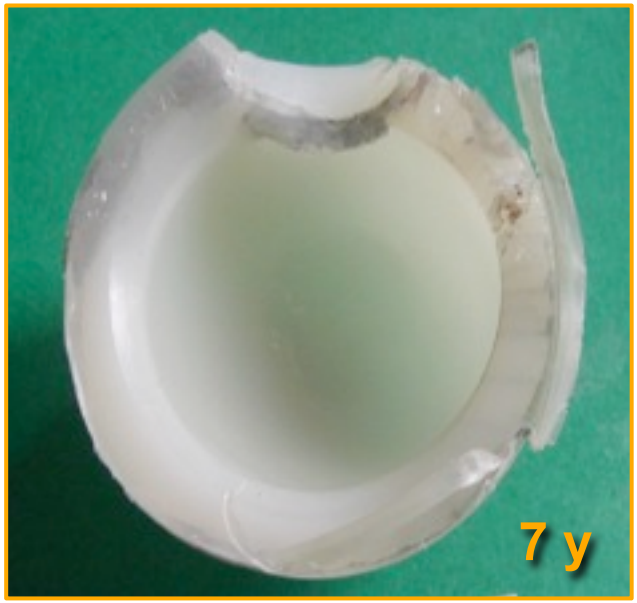
- „We report the catastrophic failure of a highly cross-linked acetabular liner with less than three years of service.“

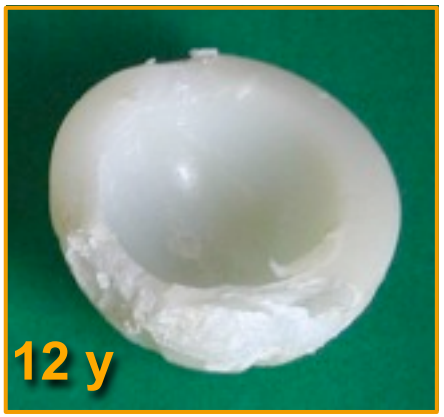


FAILURES

Retrieved conventionnal UHMWPE Prof. L. Costa - University of Torino

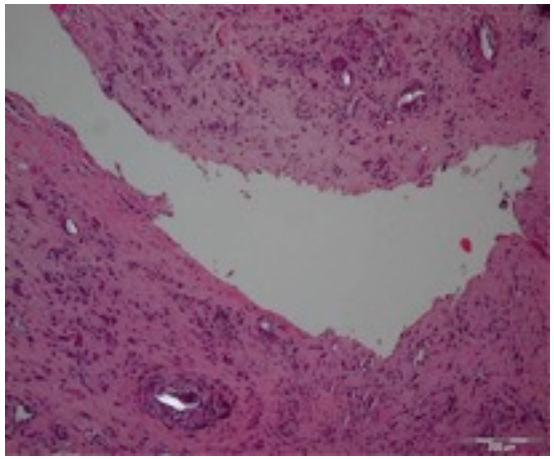
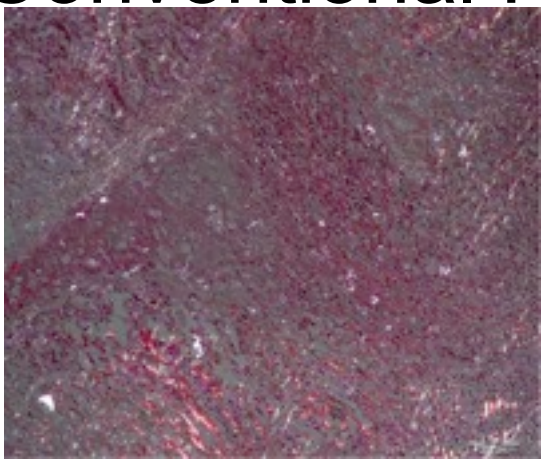
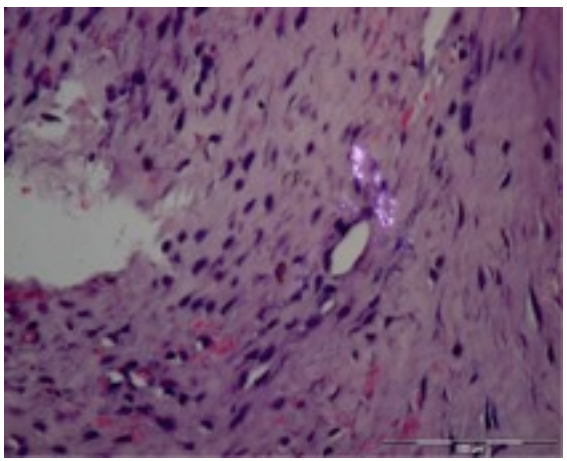
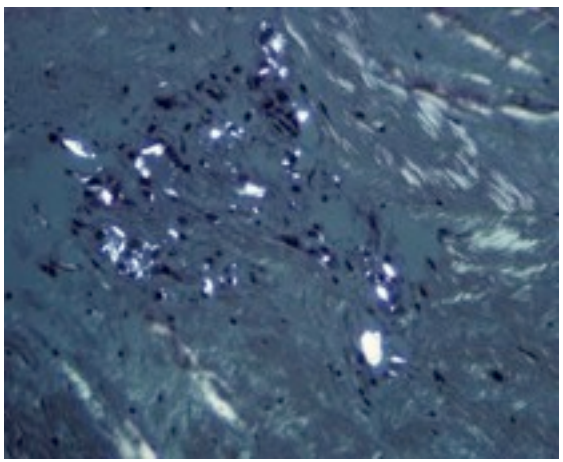






PARTICLES

NO OR EXTREMELY LOW WEAR DEBRIS

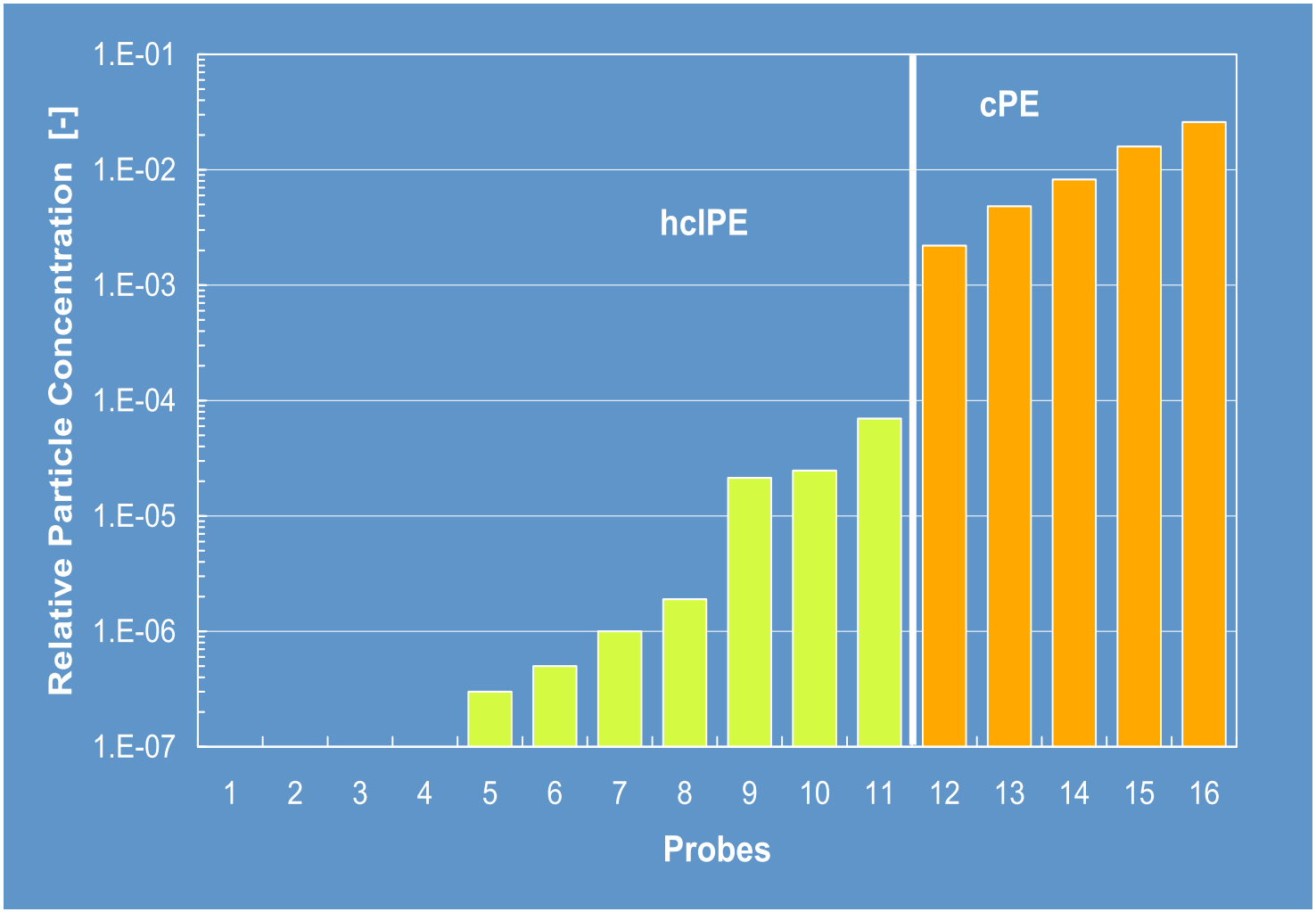
	Durasul	Conventional PE
10x		
40x		

- H.G. Willert et al, SBM, 2006, poster 542

NO OR EXTREMELY LOW WEAR DEBRIS

- “The relative particle concentration for XL-PE ranged between $0.3 \cdot 10^{-6}$ and $69.9 \cdot 10^{-6}$ (median: $0.5 \cdot 10^{-6}$).”
- “In the PE cases, the relative particle concentration ranged between $1.06 \cdot 10^{-3}$ and $25.91 \cdot 10^{-3}$ (median: $8.25 \cdot 10^{-3}$).”
- “This difference is statistically highly significant (Mann-Whitney U test / p = 0.0005).”
- H.G. Willert et al, SBM, 2006, poster 542

NO OR EXTREMELY LOW WEAR DEBRIS



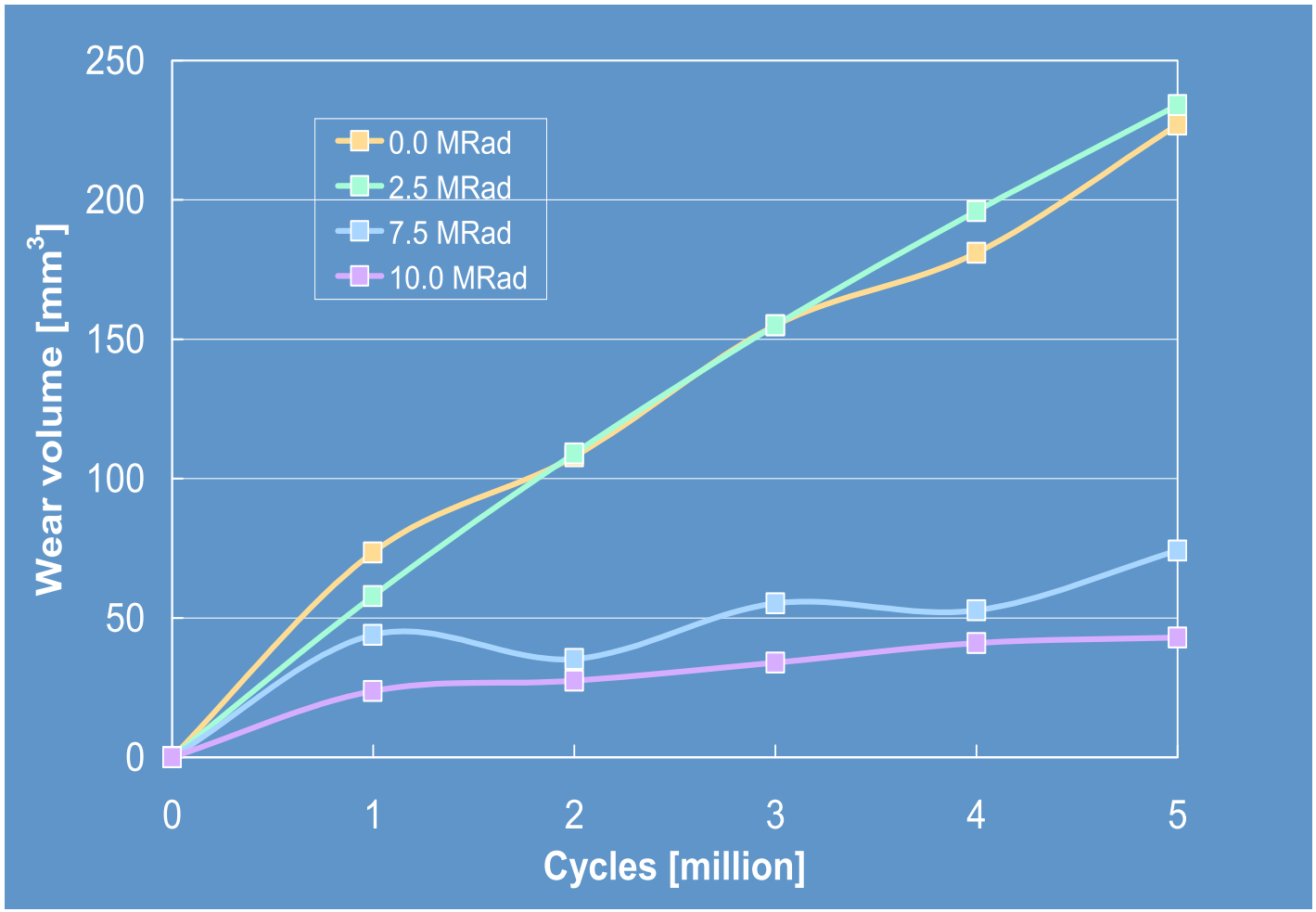
- H.G. Willert et al, SBM, 2006, poster 542

FUNCTIONAL

WEAR AND BIOLOGICAL ACTIVITY OF XLPE

- GUR 1050 polyethylene
- 7.5 and 10.0 MRad gamma irradiation
- Re-melting at 155ºC for 24 hours in N_2
- 25% new-born calf serum
- PROSIM hip simulator – 5 million cycles
- A.L. Galvin et al, IMechE – Part H, 221, 2007, p. 1

WEAR AND BIOLOGICAL ACTIVITY OF XLPE



WEAR AND BIOLOGICAL ACTIVITY OF XLPE

- “All four materials had very similar Specific Biological Activities (SBA) and there were no statistically significant differences between them.”
- 0.0 MRad: 0.96 7.5 MRad: 0.90
  2.5 MRad: 0.89 10.0
  MRad: 0.86
- A.L. Galvin et al, IMechE – Part H, 221, 2007, p. 1

WEAR AND BIOLOGICAL ACTIVITY OF XLPE

- “However, there was a considerable difference in the Functional Biological Activities (FBA) of the particles. The 10.0 MRad highly cross-linked materials gave the lowest FBA due to their lower wear volume.”
- A.L. Galvin et al, IMechE – Part H, 221, 2007, p. 1