Toxic “Arvin Compounds” Found in PE and PP Geomembranes

Degradation By-products from Antioxidants in Geomembranes Could Threaten Water Quality Safety

By GNA Editor

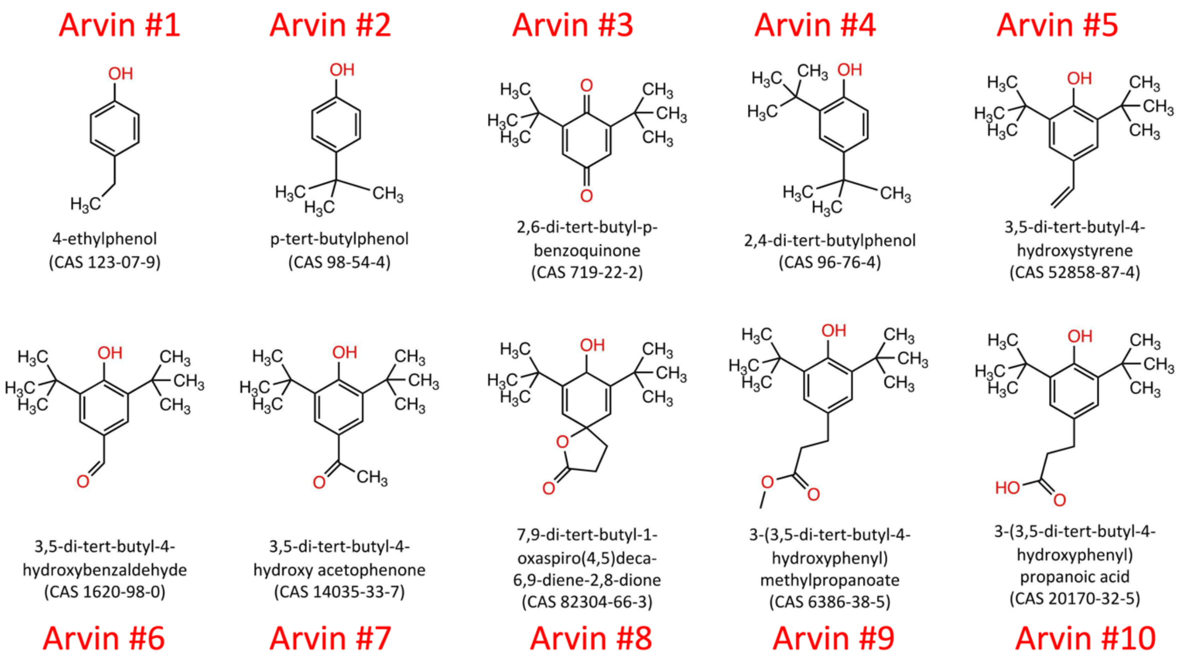
Introduction: The Contaminant Inside Your Containment Liner

Geomembranes made from polyethylene (PE) and polypropylene (PP) are trusted worldwide to line dams, reservoirs, canals, and water tanks—preventing seepage and maintaining water quality. But new research reveals that these very liners may be quietly releasing toxic degradation compounds, known as ***Arvin substances***, as a result of antioxidant breakdown during processing and long-term exposure.

These degradation products—initially discovered by Danish scientist Erik Arvin—have been identified as cytotoxic, genotoxic, and potentially carcinogenic, posing serious risks not only to potable water quality and safety but also to regulatory compliance, especially in drinking water catchments or environmentally sensitive zones such as fish hatchling and fish breeding ponds.

Who is Erik Arvin and Why Does This Matter for Geomembranes?

In a seminal 2000 study, Professor Erik Arvin from the Technical University of Denmark identified a group of migrating organic substances—now dubbed *Arvin substances #1 to #10* (see figure below) - which form as non-intentionally added substances (NIAS) during the degradation of stabilizing antioxidants in polyolefin materials.



These substances have been shown to leach out under heat, oxidative stress, and moisture—all conditions commonly present in field-exposed geomembranes used in drinking water reservoirs, fish ponds, rainwater harvesting pans and freshwater lagoons.

The Hidden Role of Antioxidants in Geomembrane Degradation

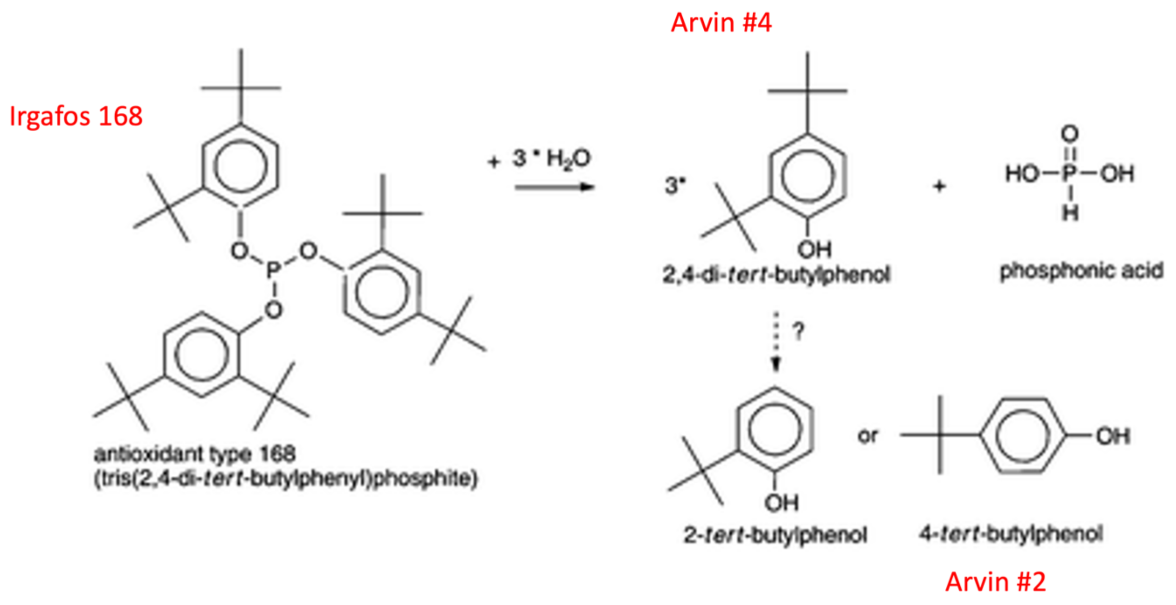
To stabilize PE and PP geomembranes during extrusion and field service, manufacturers routinely incorporate primary (hindered phenol) and secondary (phosphite-based) antioxidants. However, recent research shows that these additives degrade under field conditions, forming harmful by-products that migrate and leach from the geomembrane and into the surrounding soil or water.

It is rather self-evident that these Arvin compounds form in geomembranes during the service life because many studies have shown the Oxidative

Induction Time (OIT) reduces over time which corresponds to the degradation of the antioxidants and stabilizers as they are consumed and converted to these smaller degradation products namely the Arvin substances.

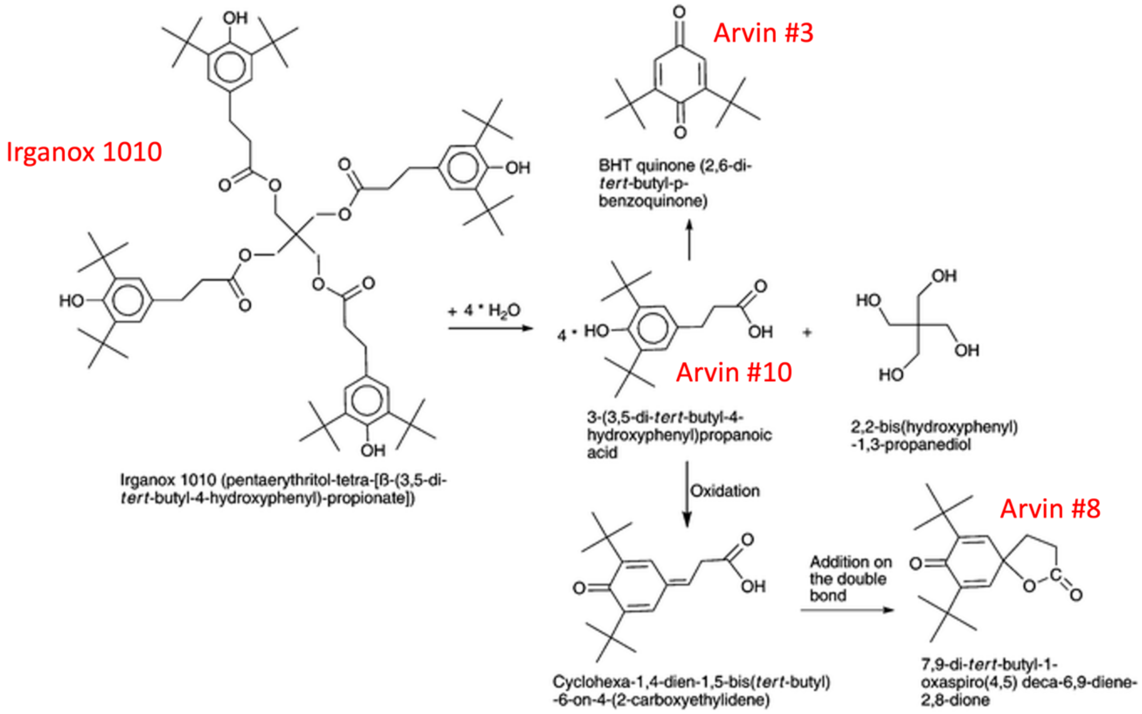
One of the most common secondary antioxidants—tris(2,4-di-tert-butylphenyl) phosphite (CAS No. 31570-04-4) and commonly known as Irgafos 168 - is known to hydrolyze into 2,4-di-tert-butylphenol (Arvin #4), a compound with confirmed genotoxic properties, especially in aquatic environments. It also oxidizes into phosphate esters that persist in the environment and bioaccumulate.

The reaction scheme below shows the Arvin substances formed from Irgafos 168 which is commonly used in all HDPE and PP geomembranes.



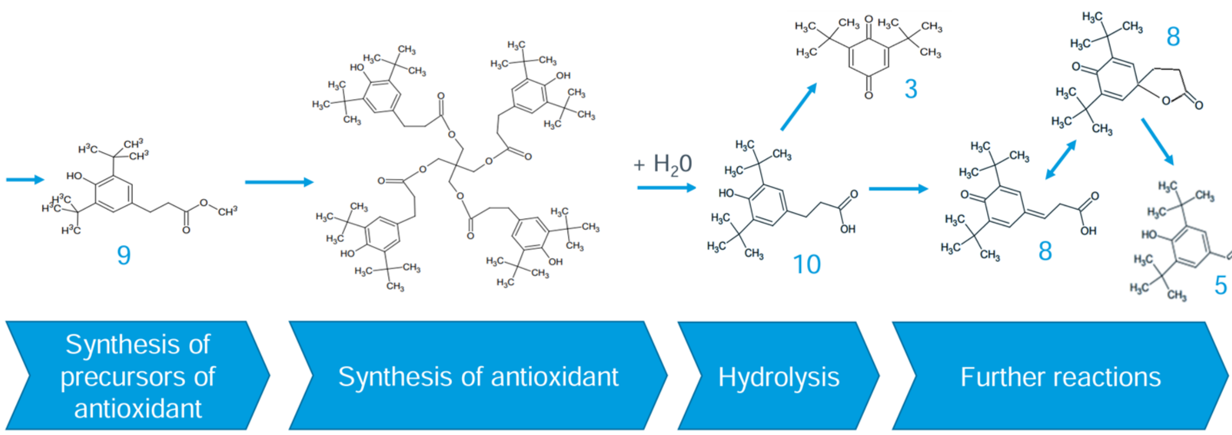
Meanwhile the reaction scheme below shows the Arvin substances formed from Irganox 1010 a hindered phenolic antioxidant which is commonly used in all HDPE and PP geomembranes.

Irganox 1010 forms Arvin #3, #8 and #10 during it degradation reactions.



Interestingly Irganox 1010 is actually manufactured from Arvin #9 (see figure below with reaction scheme).

Reactions of phenolic (Arvin) substances in the lifecycle of one specific antioxidant[1]



1 The scheme above does not show exact chemical reactions with all reaction partners involved – just the phenolic moieties are followed up for better clarity

The synthesis of antioxidant starts already with Arvins

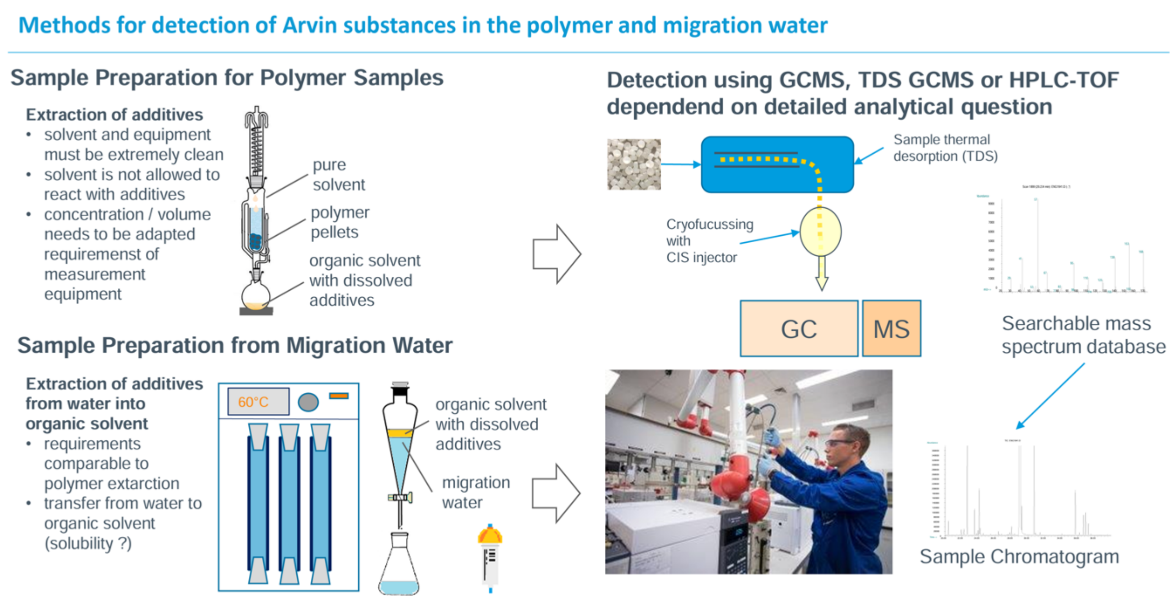
New Research Sends Shockwaves Through the Industry

Two recent scientific papers raise the alarm:

- **"Impact of Antioxidant Purity on Arvin Degradation Products in Polypropylene"** by Jérôme Vachon is a Lead Scientist at SABIC Technology Center in Geleen, Netherlands.
  [SSRN, 2024]
  This study shows that impurities in antioxidant additives significantly affect the quantity and type of Arvin compounds released. Lower-purity stabilizers, often found in recycled or downgraded resins, exacerbate the issue of Arvin compound release.
- **"Review of the Genotoxicity of Arvin Compounds"** by Wolfgang Dekant, Department of Pharmacology and Toxicology, University of Würzburg
  [ScienceDirect, 2024]
  This peer-reviewed article confirms that certain Arvin substances in particular the branched chain alkylphenols Arvin #1, #2, and #4 can cause significant cytotoxicity with implications for both environmental toxicity and drinking water safety in contact with degraded liners.

What Testing Can Detect Arvin Degradation Products?

Advanced analytical testing such as the GC-MS techniques shown below can qualify the level of Arvin compounds both in the polymer geomembranes and in drinking water.



What are the Permitted Levels of Arvin Compounds?

The currently regulated limits for Arvin Compounds are shown in the table below.

Applied and Upcoming Limits for Arvin Substances

	Denmark[1,2]	UK [DWI][1]	France[3]	EU (Draft)[3]	Comment
	MTC tap [µg/l]	MTC tap [µg/l]	MTC tap [µg/l]	MTC tap [µg/l]	
Arvin 1	0,5		0,1	0,1	
Arvin 2	0,5		2,5	2,5	
Arvin 3	5,0		2,5	2,5	
Arvin 4	5,0		250,0	250,0	
Arvin 5	0,5		0,1	0,1	UBA is working on scientific proof that Arvin 5 is an artefact (created in GC from Arvin 8)
Arvin 6	1,0		2,5	2,5	
Arvin 7	2,0		2,5	2,5	
Arvin 8	1,0	2,5	1,0 or 2,5	2,5	Toxicology study performed on request of Elisana may allow to increase limit New limit of 100 µg/l seems to be possible – under discussion with authorities)
Arvin 9	1,0		50,0	50,0	
Arvin 10					

1 For exterior Pipes
2 For interior pipes < 2µg/l – Sales with Swedish, Netherlands or German drinking water approval possible
3 For chlorinated and not chlorinated water

Geomembrane Applications at Risk

Geomembranes are widely used in sensitive environmental applications, yet the degradation of their antioxidants under common field conditions poses a systemic risk, particularly in:

- Potable Water Tanks
- Drinking water reservoirs lined with PP or HDPE geomembranes
- Aquaculture fish farm lagoons and tanks

Laboratory tests show that these applications can release NIAS into the contained water and underlying soil, contradicting claims of long-term chemical resistance and environmental inertness of geosynthetic liners.

Industry Blind Spots and the Need for Change

Despite decades of reliance on phosphite-type antioxidants and hindered phenolic antioxidants, no international specification exists to limit or monitor Arvin substances in geomembranes.

Both AS/NZS 4020 and NSF/ANSI/CAN 61 are established protocols designed to evaluate the suitability of materials such as plastics and geomembranes for contact with potable water. However, a critical limitation of both standards is that they assess only new, as-manufactured materials, without accounting for the chemical changes that occur during natural ageing and polymer degradation.

These protocols do not simulate long-term exposure to heat, UV, oxidative conditions, or chlorinated water, which are known to cause the breakdown of antioxidant and stabilizer systems within polyolefin-based liners and geomembranes. As a result, they fail to detect or quantify the degradation products and conversion compounds—such as Arvin substances, alkylphenols, and oxidized by-products—that may form over time and migrate into drinking water and into fish rearing ponds.

This gap leaves a significant blind spot in risk assessment, particularly for long-service-life applications where material degradation is inevitable. For comprehensive safety evaluations, supplemental testing that includes accelerated ageing and leachate analysis of aged samples is essential to identify long-term health hazards associated with degraded polymeric components in potable water systems.

Urgent Recommendations for Geosynthetics Stakeholders

1. Ban or Restrict High-Risk Antioxidants in Geomembranes
   Especially those based on alkylphenols or known to degrade into Arvin substances. Note biologically derived antioxidants with similar efficacy to Irganox 1010 have been made from red grape skins (grape mark) see https://www.sciencedirect.com/science/article/pii/S0141391024000223
2. Adopt Field-Ready Testing for NIAS especially in critical applications like potable water reservoirs and fish hatchling ponds.
3. Demand Transparency from Resin Suppliers
   Require disclosure of additive packages and migration data under ASTM/EN conditions.
4. Reassess Use of In-house Regrind
   These may contain degraded antioxidant residues or contaminants that form higher levels of Arvin substances during re-extrusion due to the additional heat history.
5. Incorporate NIAS Risk into Liner Lifetime Modelling
   Especially for 20-50 year projected lifespans, where antioxidant depletion may become critical.

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Conclusion: A Containment Liner Should Not Contain Hidden Risks

Geomembranes are the last line of defence between toxic waste and groundwater. Yet their own stabilizers may be introducing unseen contaminants into the very environments they are meant to protect.

The time has come for the geosynthetics industry to confront the chemical instability of its core materials and move toward non-toxic naturally-derived antioxidant systems, improved quality control, and post-installation monitoring.

In the age of PFAS and microplastics scrutiny, Arvin compounds could become the next regulatory flashpoint—unless decisive action is taken.

References and Further Reading

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