NATIONAL ACADEMIES *Sciences Engineering Medicine*

Review of Fate, Exposure, and Effects of Sunscreens in Aquatic Environments and Implications for Sunscreen Usage on Human Health

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Mandated by Congressional Act

Statement of Task

An ad hoc committee of the National Academies of Sciences, Engineering, and Medicine will review the state of science on use of sunscreen ingredients that are currently marketed in the United States, their fates and effects in aquatic environments (focusing on U.S. aquatic environments but with consideration of international studies) and the potential public health implications associated with reduced use. For this review, UV filters will be considered broadly in terms of active ingredients and formulations.

Section 1: Review of fates and effects in aquatic environments. This section will be organized to provide information for future application in ecological risk assessment…

Section 2: Implications of potential changes in sunscreen usage on public health. This section will review and summarize the available literature on the use of sunscreen to prevent skin damage in humans from excess exposure to UV in sunlight…

UV filters: the active ingredients in sunscreens (also used in other products)

Committee Approach

"…provide information for future application in ecological risk assessment"

- The committee reviewed available information that could be useful for a risk assessment
- The committee did not conduct a risk assessment for UV filters
- The report includes discussion of data relevance and reliability for ERA

Scope

- 17 UV filters available for use in the United States
- UV filters as used in sunscreens
- Inactive ingredients not in scope
- To be applied to U.S. environments but considering international research

Report Structure and Content

Summary

1 Introduction

2 Introduction to Sunscreens and Their UV Filters

3 Problem Formulation: Sources, Setting, and Ecological Receptors

4 Fate, Transport, and Potential Exposure in the Environment

5 Bioaccumulation and Measured Concentrations of UV Filters in Biota

6 Review of Studies on the Effects of UV Filters in Aquatic Environments

7 Sunscreen, Preventive Health Behaviors, and Implications of Changes in Sunscreen Use for Public Health

Each main chapter contains multiple **findings** and **knowledge gaps**

8 Conclusions and Recommendations

The final chapter contains 7 summary **conclusions** and 2 **recommendations**

Appendixes

Multiple data compilations

UV Filters in the United States

Organic UV Filters	Octisalate
Aminobenzoic acid	Octocrylene
Avobenzone	Oxybenzone
Cinoxate	Padimate O
Dioxybenzone	Sulisobenzone
Ecamsule	Trolamine salicylate
Ensulizole	
Homosalate	**Inorganic UV Filters**
Meradimate	Titanium dioxide (TiO_2)
Octinoxate	Zinc oxide (ZnO)

UV Filters in Consumer Products

- **Sunscreen formulations consist of <u>mixtures</u> of active and inactive ingredients, which influences their effectiveness as sunscreens and may influence their environmental input rate, fate, and toxicity.**
- Usually, an individual UV filter does not provide protection against the entire UVA/B wavelength range.
- Active and inactive ingredients influence effectiveness and cosmetic appeal and thus human usage.
- **Many different products may contribute to the release and detection of UV filters in the environment.**
- More precision in production and use volumes of UV filters specific to their usage in sunscreens would improve ability to clarify the contribution of UV filters from sunscreens compared with other products as a source in the environment and subsequently develop targeted management strategies.

Review of Fate, Exposure, and Effects of Sunscreens in Aquatic Environments

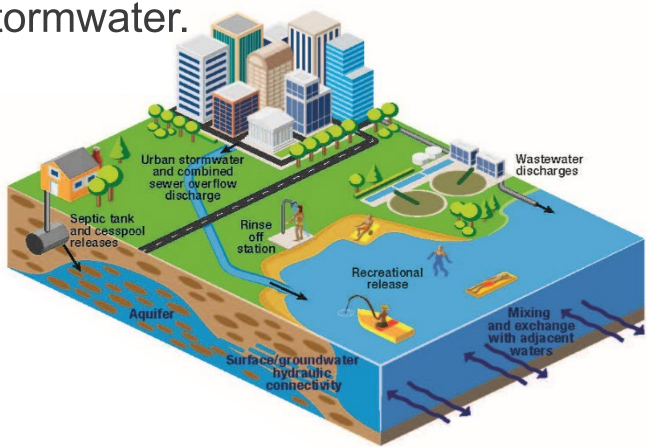
Potential Sources into Aquatic Environments

Direct Release

- Highly variable concentrations of some UV filters have been correlated with the time, location, and intensity of recreational activity
- Other studies have used estimates of rinse-off rates, in combination with the number of swimmers entering the water and sunscreen application rates, to estimate the amounts of UV filters that enter an aquatic system.

Stormwater & Wastewater

- Information to distinguish UV filters from sunscreens as opposed to other sources in stormwater and wastewater systems was not available.
- Little is known about UV filters in stormwater.



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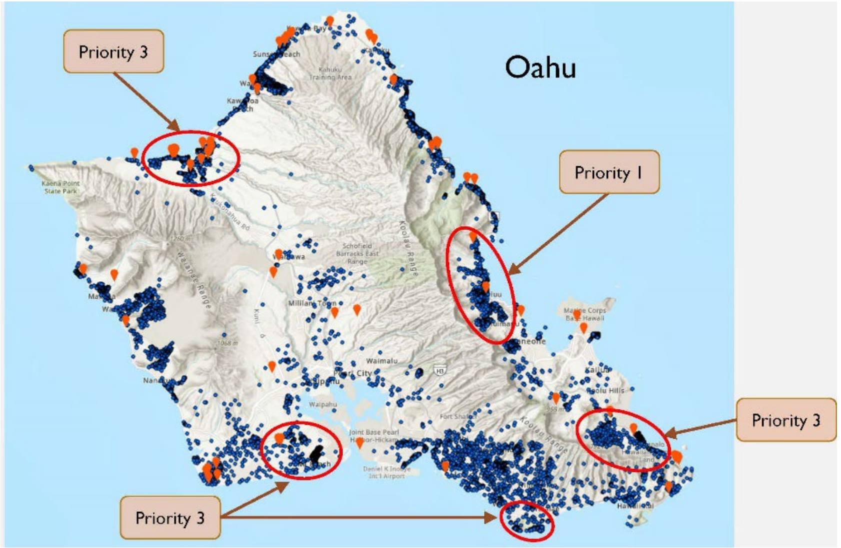
Treatment of UV Filters in Wastewater

- On-site Systems
  - Inorganic UV filters are likely to be retained within on-site systems or removed in leaching fields.
  - There is insufficient research to assess organic UV filter removal.
- Centralized Wastewater Treatment
  - Homosalate, meradimate, octocrylene, octinoxate, octisalate, and padimate O, titanium dioxide, and zinc oxide are most likely to be highly removed from effluent.

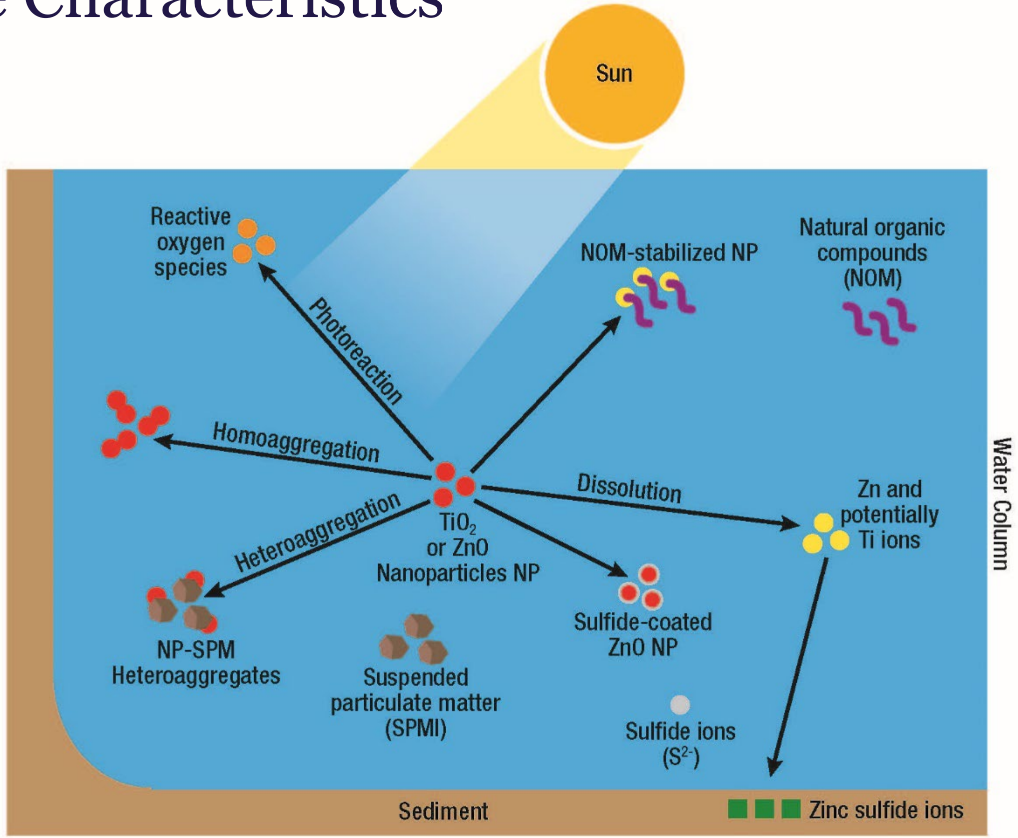


SOURCE: Presentation to Committee by Michael Cummings, Hawaii Department of Health

❖ Disfunctioning treatment systems or untreated wastewater (such as from combined sewer overflows) may result in environmental inputs regardless of removal *potential*.

Inorganic UV Filter Fate Characteristics

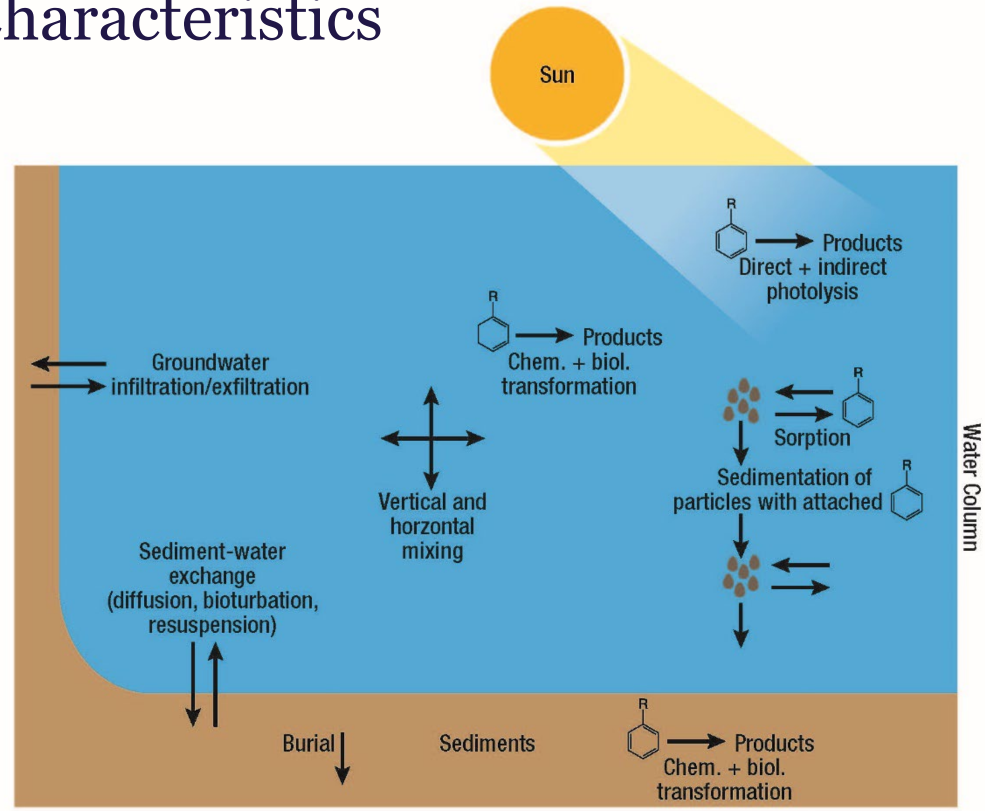
- Aggregation and settling into sediment
- ZnO much more likely to dissolve into ions than TiO_2
  - Dependent on conditions like pH, solids, other ions in water
- Potential reactions with UV radiation and other particles in the water
- Fate can be affected by coatings used in sunscreen formulations



Organic UV Filter Fate Characteristics

Tend to be hydrophobic and thus partition to organic fractions (particles and sediments)

- Exceptions are aminobenzoic acid, ensulizole, trolamine salicylate, and sulisobenzone.
- Oxybenzone is moderately water soluble, with less distinct partitioning.



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Persistence: Biodegradability

- Standard tests for biodegradation designed for wastewater
  - Avobenzone, dioxybenzone, octocrylene, ensulizole, and ecamsule are found to be nonbiodegradable (12/15 organic UV filters have been tested)

- Nonstandard tests in environmental media
  - Bulk of research is on oxybenzone and metabolic pathways in fungi and microbes
  - One study each on octocrylene (biotransformation in sediment) and padimate O (high levels of biodegradation)

Persistence: Photostability

- Photochemical half lives are available for 12 UV filters
  - May result in photodegradation or isomerization
  - May be affected by the wavelength(s) of irradiation, irradiation dose, and the presence of additional organic molecules or molecular aggregates

- Avobenzone photostability is highly dependent on the molecular-scale local environment. The influence for other UV filters is unexplored.

- Oxybenzone and sulisobenzone appear to be relatively photostable in laboratory settings.

- Photostability data for UV filters in dilute aqueous environments (without use of solvents) is significantly limited.

Occurrence in Water and Sediment

- Oxybenzone, octocrylene, homosalate, avobenzone, and octinoxate highest measured environmental concentrations in water are in the range of 1 to 10 µg/L, though most measurements for these and all measurements for other organic UV filters are below 1 µg/L.

- Octocrylene and octinoxate have maximum recorded sediment concentration values between 0.1 and 2.4 µg/g dry wt; all other UV filters exhibit maximum recorded concentrations in sediments below 0.1 µg/g dry wt.

- Limited studies are available for inorganic UV filters due to the difficulty separating incremental loadings of Ti and Zn from sunscreens versus other sources.

Patterns of Occurrence

UV filter concentrations appear to be influenced in part by source strength, proximity to source, and water residence time.

Hanauma Bay, Hawaii

Barrier reefs in Florida

Occurrence in Biota and Bioaccumulation

- High quality, laboratory-based bioaccumulation (BAFs) or bioconcentration factors (BCFs) available for avobenzone, octocrylene, octinoxate, oxybenzone, homosalate, padimate O, and titanium dioxide reveal a low to moderate bioaccumulation potential.

- Currently available field studies of tissue concentrations lack comprehensive characterizations of UV filter exposure in water and sediment, leaving interpretation solely as presence and concentration of UV filters in tissues.

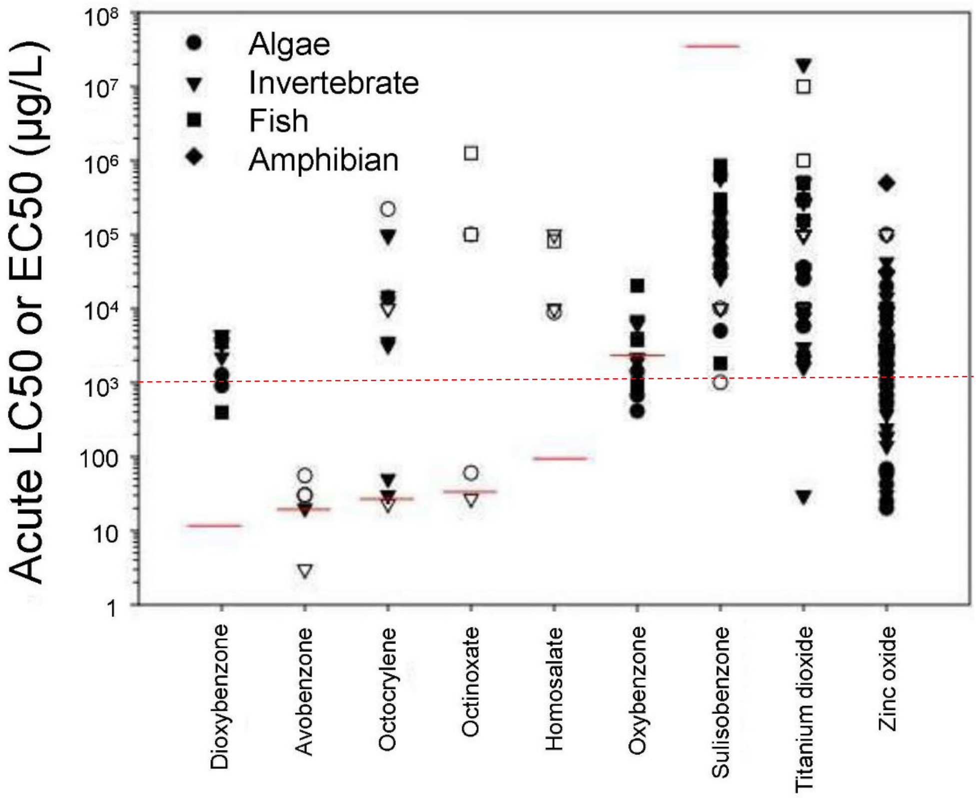
- BAF or BCF studies for the most lipophilic UV filters indicate a low likelihood of trophic magnification, although some have measurable BCFs. However, additional research investigating biomagnification in food webs specifically is warranted.

Laboratory Toxicity Testing

- Acute toxicity has been observed under 1,000 μg/L for dioxybenzone, octinoxate, oxybenzone, padimate O, TiO_2 (in the presence of UV radiation), and ZnO and in a few studies for avobenzone and octocrylene.

- Toxicity values typically exceed solubility for the poorly soluble UV filters (solubility under 100 μg/L).

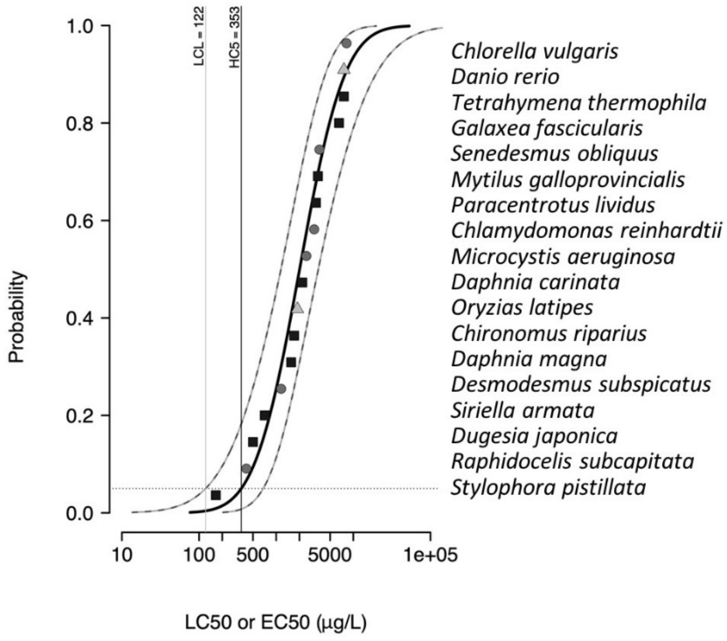
- Chronic studies are limited across all UV filters. They are especially important for the poorly soluble organic UV filters and for the inorganic UV filters



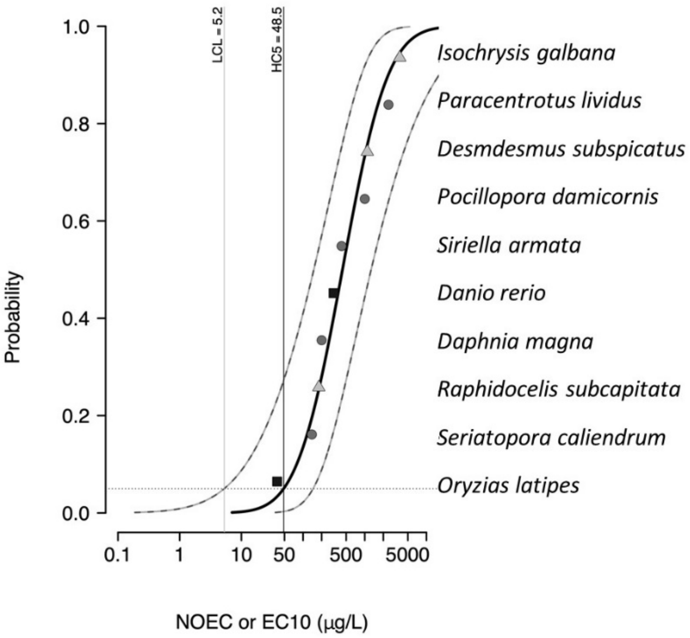
LC/EC50 results that which were unbounded (not < or >) values are displayed with closed (black) symbols whereas greater than (>) values are displayed given as open (white) symbols.

Species Sensitivity Distributions

Oxybenzone Acute



Oxybenzone Chronic



SSDs are also possible for ZnO (acute and chronic) and octinoxate and TiO_2 (acute only)

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Modes of Action

- Informed by *in vivo* and *in vitro* studies of behavior and suborganismal endpoints (genomic, biochemical/biomarker, physiology, and cell-/receptor-based assay systems).

- Evidence is accumulating that oxidative stress, genotoxicity, neurotoxic, and endocrine modulation modes of action are present among UV filters.

- Adverse Outcome Pathways are needed to link suborganismal effects to population-relevant responses.

Other Impacts

- Threatened and Endangered Species:
  - Can be extrapolated from impacts to surrogate species and potential for exposure
  - The only effects data available for a listed aquatic species is for calicoblast cells for two threatened Caribbean coral species, *A. cervicornis* and *O. annularis* in an *in vitro* cell culture exposure to oxybenzone (Downs et al., 2016)

- Communities and Ecosystems: Limited studies on key communities (microbial, macroinvertebrate, coral), nutrient cycling, organic matter decomposition rates, and primary production.

Mixtures and Multiple Stressors

Climate change, pollution, overfishing, habitat destruction all contribute to impaired health of aquatic ecosystems.

- Causal Analysis: Methods to attribute the contribution of a single stressor to observed impairment.

- Cumulative and Interacting Effects:
  - Methods for evaluating cumulative risk, such as based on common modes of action, can be applied to evaluating mixtures of UV filters or combinations of UV filters and other chemical contaminants.
  - Cumulative and interacting effects UV filters and environmental variables like temperature, salinity, and UV light have been seen in some studies and can be considered as context in a risk assessment.
- Increasing temperature is highlighted by the committee as a predominant stressor on its own and a known interacting stressor with chemical contaminants.

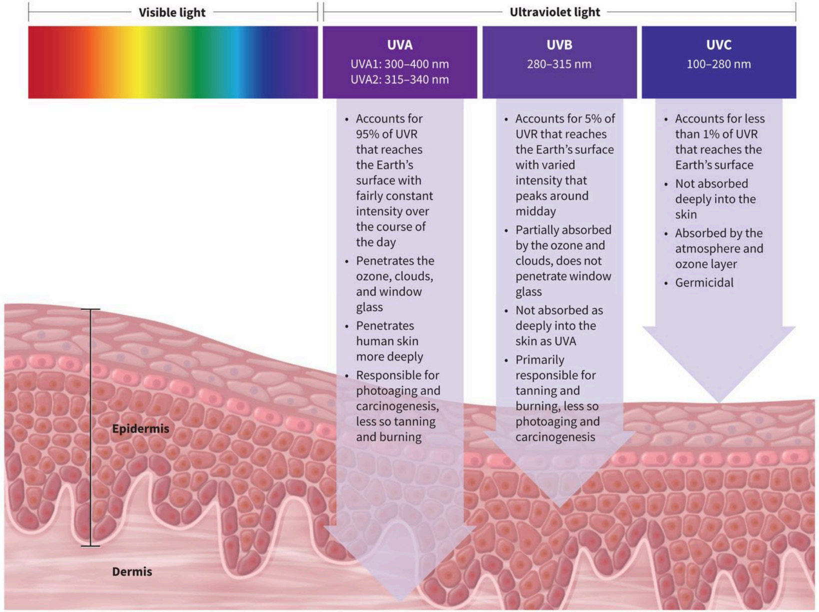
Implications for Sunscreen Usage on Human Health

UV Radiation, Skin Damage, and Sunscreen

- Exposure to UVR causes sunburn and photoaging in human skin and is a risk factor for the development of skin cancers, both keratinocyte carcinomas and melanomas.

- Consistent use of broad spectrum, SPF 30 sunscreen when outdoors reduces the risk of developing skin cancer (keratinocyte carcinomas and melanomas), photoaging, and sunburn.

- Most studies conducted on fair-skinned populations.



Sunscreen Usage

- Only about a third of the U.S. population uses sunscreen regularly, though use is higher during outdoor activities and at the beach (between 70 percent and 80 percent).

- Even when sunscreen is used, dosage (i.e., amount applied and rate of reapplication) usually does not meet recommendations for optimal effectiveness.

- Sunscreen preferences are primarily driven by perceived effectiveness (e.g., SPF) and cosmetic preferences (e.g., skin feel, scents, and appearance on skin). These features can be influenced by UV filters and other ingredients in sunscreen.

Impacts of Potential Changes in Sunscreen Usage

- Scenarios likely to lead to negative effects on health:
  - Decreased use of sunscreen with no change to other sun protective behaviors
  - Decreased use of sunscreen with suboptimal increases in other sun protective behaviors
  - Use of alternative sun protection products with UV filters that don’t meet FDA standards
- Scenarios likely to lead to no or minimal effects on health:
  - Decreased use of sunscreen with optimal practice of other sun protective behaviors
  - Obtaining sunscreens with restricted ingredients from elsewhere
  - Switching to alternate formulations
- Scenario likely to lead to positive effects on health:
  - Increased use of sunscreen

Recommendations

Recommendation 1: EPA should conduct an ecological risk assessment for all currently marketed UV filters and any new ones that become available.

There is an urgent need to conduct such an assessment, driven by the evidence of local exposures of aquatic organisms in U.S. aquatic ecosystems to UV filters, potentially including endangered species, and experimentally demonstrated potential for environmental impact, either alone or in context of other system stressors.

The results of the ERA should be shared with FDA for their considerations of the environment in their oversight of UV filters.

The following points are critical for conducting an ERA for UV filters:

- Nonstandard species and biological endpoints should be considered given the diversity of important ecological species potentially exposed to UV filters and the potential for adverse effects not captured in standard test protocols (e.g., corals and their unique endpoints related to bleaching).

- Cell-line tests and other New Approach Methods such as molecular/biochemical changes may be useful for elucidating toxic modes of action (e.g., narcosis, endocrine disruption) and potential for effects

- ERAs should not only consider UV filters individually, but also evaluate the potential for risks from co-occurring UV filters.

- ERAs should consider the environmental settings or exposure scenarios, specifically the potential for localized (in space and time) elevated UV-filter concentrations in the water column and/or sediment that provide habitat for a diverse or unique biological community.

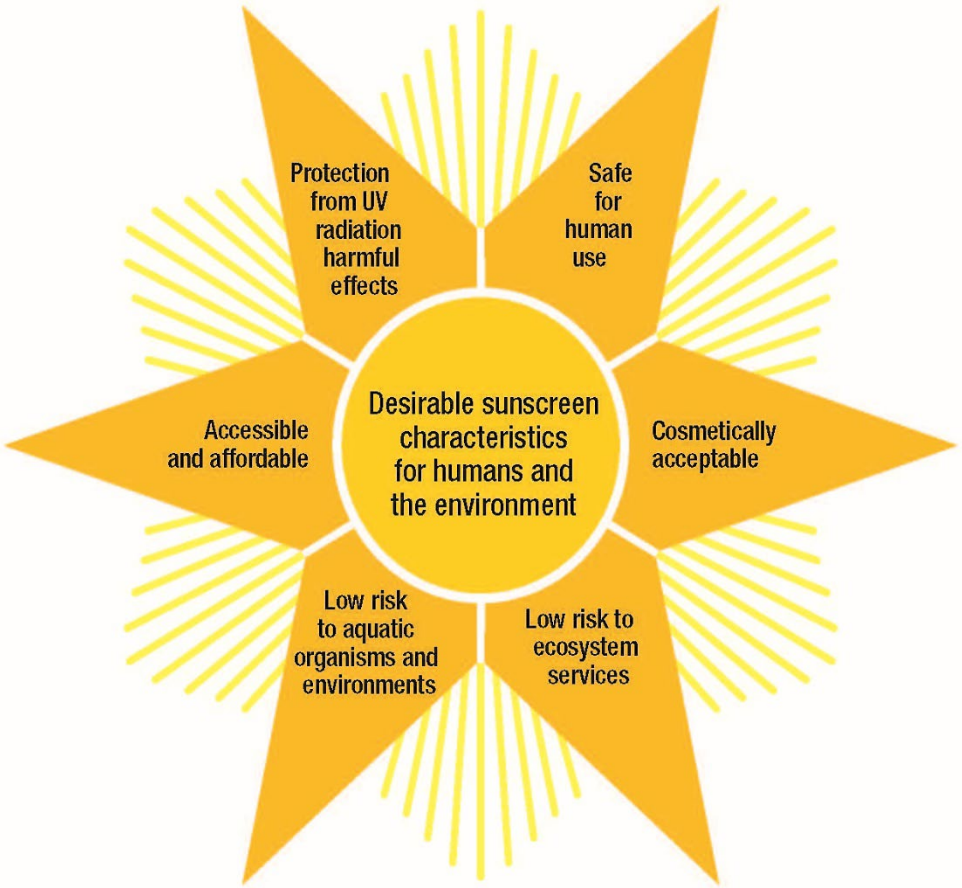
Recommendation 2: EPA, partner agencies (e.g., NOAA, FDA, NIH, CDC, NSF, DOI), and sunscreen formulators and UV filter manufacturers should conduct, fund or support, and share research and data on sources, fate processes, environmental concentrations, bioaccumulation studies, modes of action, and ecological and toxicity testing for UV filters alone and as part of sunscreen formulations. Additionally, epidemiological risk modeling and behavioral studies related to sunscreen usage should be conducted to better understand human health outcomes from changing availability and usage.

Future research should adhere to international or national standards where applicable.

This may include new national/international standards.

Public access and transparency in all data and research outcomes is critical.

Any policy and management actions taken will require consideration of their human and ecological outcomes and coordination across multiple agencies and organizations to develop creative solutions.



Thank You & Questions

The committee appreciates the contributions from all public meeting participants, EPA for support of the study, and National Academies staff.

Report is available for free download at nap.nationalacademies.org/26381

View communication products along with the report

RESOURCES AT A GLANCE

Report Highlights

Interactive Overview