THE SURPRISING CASE FOR SAFER CARE

How Radiation Safety Not Only Saves Lives but Improves Hospital Finances Too

IMAGE SAFELY 360

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Interventional fluoroscopy has transformed modern medicine, delivering minimally invasive procedures that are substantially improving clinical outcomes and reducing healthcare costs. And yet, the healthcare professionals who perform these procedures — including interventional cardiologists, cath lab nurses, and radiologic technologists — face two critical occupational hazards: exposure to ionizing radiation and physical destruction caused by heavy lead garments.

As detailed in the extensive published literature summarized in this report, clinicians who serve in interventional fluoroscopy laboratories suffer high exposure to radiation, brain tumors and other cancers, miscarriages and other reproductive harm, cataracts, cognitive decline, musculoskeletal pain, paralysis, and other orthopedic injuries.

These risks and results have long been documented and, in fact, are prohibited by the U.S. government, which in 42 CFR § 482.26(b) requires that "radiologic services, particularly ionizing radiology procedures, must be free from hazards for patients *and personnel*." (emphasis added) This requirement has been in place since 1986 — forty years ago. Regrettably, the data on illness, injury, and death among clinicians evidence a concerning gap between policy and practice.

In addition, the harm being suffered by clinicians is worsening access to care across America, particularly in rural communities. At a time when heart disease is the nation's #1 cause of death, nearly 9-in-10 rural counties — spanning approximately 2,700 communities — do not have a cardiologist of any type, due in part to the threat that faces medical students and physicians who choose to practice in this specialty. Every clinician lost to preventable injury or illness is a subtraction from a workforce that is already structurally insufficient.

Of equal concern, technology already exists that protects clinicians from harm. According to peer-reviewed randomized trials, advanced radiation protection systems reduce operator radiation exposure by up to 99.7% and prevents orthopedic injury. The problem is not the lack of a solution to this clinical crisis — it's the insufficient deployment of protective mechanisms.

In some instances, hospitals and other clinical settings may be hesitant to use technologies that safeguard clinicians because they believe doing so would increase their costs. As this report reveals, however, the opposite is true. In the case of interventional cardiologists, for example, the data detailed below shows a positive return on investment (ROI) within one year and an internal rate of return (IRR) over five years of up to 80%.

Due to these factors, the question is not whether the U.S. healthcare system can afford to protect its interventional clinicians. The evidence — human, fiscal, and epidemiological — establishes that it cannot afford not to. Advanced radiation safety is not a discretionary expenditure. It is a financially rational, medically obligatory, and ethically required investment.

INTRODUCTION

Clinicians who work in interventional fluoroscopy laboratories, including interventional cardiologists, cath lab nurses, radiologic technologists, and allied clinical staff, have long been exposed to life-threatening ionizing radiation and developed debilitating illnesses and injuries.

The evidence of harm is no longer ambiguous. Radiation-induced brain tumors, cataracts, reproductive complications, and cognitive decline are extensively documented, as are orthopedic injuries, musculoskeletal pain, and paralysis. As a result, medical societies have joined to seek improved clinical safeguards improving the standard of care across all fluoroscopic laboratories.

In compiling this report, IMAGE SAFELY 360 condenses the human, fiscal, and access considerations vital to policymakers as they assess policy changes to make America's healthcare system safer. As detailed below, the data present what to many may be a surprising conclusion: using available technologies to protect clinicians from preventable occupational harm is not only clinically and ethically responsible — it is also the most fiscally rational course of action available to hospitals and policymakers.

Analyzing Risk in Three Dimensions

This study examines the case for radiation protection across three interconnected dimensions:

- **<u>Human Impact</u>:** Absent adequate safeguards, clinicians in interventional fluoroscopy labs disproportionately suffer radiation-induced cancers, miscarriages, cataracts, left-sided brain tumors, and other serious outcomes. Additionally, the heavy lead garments they wear to protect against radiation cause an epidemic of debilitating orthopedic injuries that are forcing clinicians to curtail their practices or exit the workforce prematurely.
- **<u>Fiscal Impact</u>:** When a hospital loses an interventional cardiologist — either temporarily to illness or injury, or permanently to early retirement, career abandonment, or death — it loses a clinician who generates meaningful annual hospital revenue. The direct and indirect costs of replacing, treating, and accommodating injured or ill clinicians dwarf the capital cost of deploying advanced radiation safety technologies.
- **<u>Access Impact</u>:** Radiation safety technologies enable clinicians to remain in practice, enabling more patients to be seen, services to be delivered, and communities — including underserved rural areas — to retain access to care. Compromising a wide range of healthcare services, the access impact of unsafe care is acutely demonstrated in the shortage of cardiologists and the rise of heart disease as the #1 cause of death in the U.S.

Principal Findings

A striking disparity exists between the United States and the rest of the developed world when it comes to occupational radiation exposure standards for medical professionals. While Europe and the majority of nations globally have adopted a 20 millisievert (mSv) annual exposure limit, the U.S. operates under an outdated ceiling of 50 mSv per year — a threshold that causes American clinicians to be exposed to two and a half times the radiation permitted in peer nations.

This gap is not merely a policy distinction; rather, it suggests a divergence in the value placed on the long-term health and safety of the medical workforce. Countries utilizing the 20 mSv limit have done so successfully for years, demonstrating that modern medical and interventional practices can function effectively and safely within that boundary.

Protecting clinicians is not only a moral option — it is a proven, fiscally rational, access-enhancing choice.

By contrast, the U.S. evidence compiled in this report supports the following conclusions:

1. The hazards in interventional fluoroscopy are severe and well-documented. For example, more than 6-in-10 cath lab workers suffer orthopedic injuries, an estimated 2-in-10 had to reduce clinical workload, and more than 1-in-10 know a colleague with a brain tumor.
2. Major medical societies have formally endorsed a new safety framework, ALARA+ (As Low And as Light As Reasonably Achievable), representing a definitive rejection of the status quo and a call to action to hospitals, policymakers, and technology adopters.
3. Advanced radiation protection systems — including next-generation shielding and dose reduction systems — have been shown in peer-reviewed randomized trials to reduce operator radiation exposure by 90% to 99.7% compared to traditional lead aprons.[1,2,3]
4. The financial case for safer care is conclusive. Radiation-related illness and injury costs the U.S. healthcare system millions annually in direct health costs alone. The financial impact of staff turnover, replacement, and lost revenue further swells the cost impact.
5. The cost of deploying advanced radiation protection in a cath lab is a fraction of the revenue lost when a single clinician suffers disease, injury, or death. Protecting clinicians from harm serves to improve the financial health of the hospitals in which they serve.
6. The access crisis is severe and worsening: 86% of rural counties in the United States have no cardiologist at all, cardiovascular wait times have increased by more than 25% since 2017, and the cardiovascular workforce is aging faster than it is being replenished.

The conclusion of this study is unambiguous: protecting the clinicians who work in interventional fluoroscopy labs is not only the morally correct course of action — it is the financially rational one. The question for policymakers and hospital administrators is, therefore, not whether our nation can afford to invest in advanced radiation safety. It is whether we can afford not to.

THE CRISIS FACING CLINICIANS — AND WHAT'S BEING DONE ABOUT IT

Every day in American hospitals, clinicians perform thousands of fluoroscopy-guided procedures — cardiac catheterizations, percutaneous coronary interventions (PCI), electrophysiology studies, structural heart interventions, peripheral vascular procedures, and more. These procedures are unambiguously life-saving. They are also, for the clinicians who perform them repeatedly over careers spanning decades, genuinely dangerous.

The danger is dual in nature. First, there is the radiation itself — ionizing X-ray scatter that accumulates across tens of thousands of procedures, inflicting cumulative biological damage on organs, DNA, and the lens of the eye. Second, there is the physical toll of wearing the lead garments designed to provide protection against that radiation — garments that weigh between 10 and 20 pounds and are worn for hours each day, day after day, year after year, until the spine simply gives out.

Both hazards have been known and documented for decades. Both are avoidable with modern technologies that have been developed since regulatory action was last taken in 1986 — forty years ago. And both are, as of this study, the subject of the most significant consensus call to action in the history of interventional medicine.

What We Know Now About the Risks Clinicians Face

Disease and Death from Ionizing Radiation Exposure

Interventional fluoroscopy exposes clinicians to ionizing radiation at rates that are, by any epidemiological standard, deeply concerning. Medical personnel in interventional cardiology receive radiation exposure approximately ten times higher than their counterparts in diagnostic radiology.[4]

Over a 30-year career, cumulative doses for interventional cardiologists are estimated to range between 50 and 200 millisieverts (mSv). Even at individually permissible annual doses, the compounding effect over a career creates a lifetime attributable risk of malignancy that is demonstrated to be highly clinically significant.[4,5]

Radiation-induced cancers among interventional clinicians are no longer theoretical. For example, multiple case series have documented left-sided brain tumors — a finding consistent with the anatomical position of a right-handed operator, whose left hemisphere faces the patient and radiation source during most procedures. A review of the

Interventional cardiology teams are exposed to 10 times more radiation than other clinicians.

literature documents at least nine published cases of brain malignancies in interventional cardiologists and radiologists, with the distinctive left-hemisphere lateralization providing a biological fingerprint that implicates occupational radiation exposure as a causal or contributing factor.[6,7]

For operators, the eye lens is also especially radiosensitive. The International Commission on Radiological Protection (ICRP) has identified cataract risk beginning at acute exposures as low as 0.1 Gray, and studies of interventional cardiology staff have confirmed a dose-dependent increased risk of posterior lens opacities. Research from the O'CLOC study found a relative risk of lens opacity of 5.7 for interventional cardiologists compared to unexposed controls, with a strong dose-response relationship.[7]

10K+ clinicians receive radiation equivalent to 10,000+ x-rays during their career

35.5% higher lifetime cancer incidence among interventional cardiologists

85% of brain tumors occur on the head's left side (the side closest to radiation source)

10X higher radiation exposure for interventional cardiologists *vs.* diagnostic radiologists

52% up to 52% of interventional cardiologists have radiation-associated lens opacities

600% cath lab clinicians are 6 times more likely to develop cataracts than

Beyond cancer and cataracts, the evidence base has expanded significantly in recent years to encompass a range of other serious outcomes. For example, clinicians routinely face bone integrity degradation. Human bones are radiosensitive, and ionizing radiation impairs bone remodeling, reduces bone strength, and contributes to progressive skeletal deterioration. These effects are cumulative, so minimizing radiation dosage and reducing occupational radiation exposure are vital to preserving long-term musculoskeletal health.

Additionally, the Healthy Cath Lab studies have demonstrated that chronic fluoroscopy exposure is associated with early-onset cognitive decline and subclinical atherosclerosis in interventional cardiologists. Reproductive risks are also documented: cumulative sub-apron exposure reaching 0.5 to 1.0 Sievert is associated with reduced sperm count, and pregnant women with fluoroscopy exposure face elevated risks of first-trimester miscarriage and, at higher doses, fetal abnormalities.[5]

For every 10 mSv of low-dose ionizing radiation, research suggests a material increase in age- and sex-adjusted cancer risk, compounding across decades-long careers. A landmark economic analysis by Occupational Radiation Safety in Interventional Fluoroscopy (ORSIF) estimates the annual cost of radiation-induced cancer among U.S. interventional clinicians at a minimum of $49 million, using figures of $9 million per fatal occupational cancer and $200,000 per nonfatal cancer — figures that the organization properly characterizes as conservative, since they exclude preclinical conditions, reproductive harm, and cognitive effects.[8]

Musculoskeletal Harm from Protective Lead Garb

If radiation is the invisible hazard in the cath lab, lead is the visible one. Standard lead aprons and thyroid collars weigh between 10 and 20 pounds. Operators wear them for hours, in positions of forward lumbar flexion and cervical axial rotation, during procedures that can last anywhere from 30 minutes to several hours. The cumulative toll on the spine is devastating.

The 2023 SCAI Survey on Occupational Health Hazards in the Cardiac Catheterization Laboratory, published in JSCAI in March 2025, is the most comprehensive recent accounting of this epidemic. Key findings include:

- 82% of cath lab staff respondents reported musculoskeletal pain or orthopedic injuries related to their work environment or radiation protective equipment.[9,10]
- Nearly 60% reported orthopedic injuries specifically attributable to wearing lead aprons, with spine injuries the most common presentation.[9,10]
- 20% of respondents reported having to limit their time in the cath lab due to injury, with this figure rising significantly among older and more experienced practitioners.[9,10]
- 25% reported cervical spine injuries, and 34% reported lumbar spine injuries — compared to a 2.3% prevalence of chronic spine problems in the general population.[9,10]
- 11% of respondents reported knowing a colleague with a brain tumor.[9,10]

The ERGO-CATH study, presented at the SCAI 2025 Scientific Sessions, added critical biomechanical data: 43% of interventional cardiologists spend measurable time in high-risk cervical and thoracic flexion positions during procedures, placing direct mechanical strain on anatomical structures already compromised by years of lead-garment wear.[11]

A viscerally illustrative case is that of Dr. Dean Kereiakes, MD, president of The Christ Hospital Heart and Vascular Institute and a widely respected figure in interventional cardiology. After decades of wearing lead protection in the cath lab, Dr. Kereiakes became paralyzed in February

2024. After a full day of performing eight cardiac procedures, he experienced progressive neurological deterioration. By the following Monday morning, he was near-quadriplegic. Emergency spinal surgery revealed catastrophic cumulative vertebral damage attributable, in the assessment of his treating physicians, to decades of lead apron wear.[12]

Tragically, Dr. Kereiakes' case is not unique. In fact, a founder of IMAGE SAFELY 360 — Dr. Bob Foster — further underscores the prevalence of this risk. An interventional cardiologist and Iron Man athlete, Dr. Foster suffered debilitating spinal injury after years of wearing lead garments. Paralysis soon followed, necessitating painful and costly medical intervention. Dr. Foster regained the use of his legs and proceeded to found Rampart iC to bring protecting shielding to cath labs.

Standard lead garb weighs 10-20 pounds, putting the spine and orthopedic health at great risk.

For these reasons, Dr. James Hermiller called for "Operation Moral Imperative" in his 2024 SCAI Presidential Address to achieve widespread use of advanced radiation protection. "If an interventionalist is injured and out for a month, the financial loss is significant," Dr. Hermiller pointed out. "That lost revenue alone could cover the cost of multiple protection units."[13]

Advanced Radiation Safety Technologies

There is good news, however: the problem is solvable. Advanced radiation safety technologies have been developed, validated in randomized controlled trials, and are available today. Indeed, the field of advanced radiation protection for interventional fluoroscopy has evolved significantly over the past decade. Today's most effective systems fall into several categories:

- **Radiation Dose Reduction:** Innovative and intelligent technologies now make possible the use of advanced automation and radiation dose-saving so the minimum amount of radiation necessary to accomplish a diagnostic task is utilized, thereby reducing risk for patients and their clinical team alike.

- **Radiation Shielding Systems:** Advanced shielding — on ceiling booms, floor stands, mobile frames, or placed directly on the patient — protects clinicians from primary and scatter radiation. Unlike lead aprons, which leave the head, neck, and brain unshielded, shielding provides full-body protection without weight-bearing.

- **<u>Dosimetry Monitoring Systems</u>:** Wearable and room-based sensors that provide operators with instantaneous feedback on radiation exposure enable behavioral modification in real time — prompting adjustments that reduce scatter. Studies combining Rampart with real-time dosimetry have demonstrated additive benefits.

- **<u>Lightweight Lead-Alternative Garments</u>:** Lead-free and lead-reduced garments using alternative attenuating materials — such as bismuth, barium, and tungsten composites — provide meaningful protection with substantially reduced weight compared to traditional lead and are a vital element of comprehensive protection protocols.

The clinical evidence base for advanced protection systems is now substantial and continuing to grow. For example, the REDUCE trial (NCT06875583) is currently enrolling patients in a prospective, multicenter, randomized controlled trial of the Rampart shielding system, providing what will become among the most rigorous data in the field. The MedStar Health system, an early adopter of Rampart in its cardiac cath labs, has reported high staff satisfaction and institutional commitment to lead-free protection as a standard of care.[14,15]

The central problem facing policymakers is not efficacy — it is adoption. For too long, advanced radiation safety devices have been misclassified as discretionary safety expenditures rather than as the financially rational, medically obligatory infrastructure investments they actually are. This report has been developed to correct that misclassification.

The central problem facing policymakers is not efficacy — it is adoption.

THE NET FISCAL IMPACT OF RADIATION SAFETY

Hospital administrators making capital allocation decisions do so within a framework of fiduciary responsibility. The implicit assumption embedded in most current decision-making on radiation safety is that advanced protection systems represent a cost — a safety expenditure — rather than an investment with a measurable return. And yet, the data present a very different reality.

The fiscal case for advanced radiation protection is built on four pillars: the cost of replacing lost clinicians; the cost of treating injured or diseased clinicians; the revenue lost during workforce vacancies and diminished productivity; and — as the counterweight — the comparatively modest incremental cost of the protective technologies themselves.

The Cost of Replacing Clinicians

Replacing an interventional cardiologist is one of the most expensive transactions in healthcare administration.

Every clinician lost to a preventable occupational injury is a direct loss to the workforce, patient access, and hospital revenue.

Direct Costs: Direct recruitment costs — including but not limited to advertising, search firm fees, credentialing, and onboarding — typically range from $100,000 to $500,000 per physician, depending on their specialty and the geography to which they are being recruited. For interventional cardiologists, whose specialized training and procedural expertise make them among the most sought-after and hardest-to-find clinicians in medicine, costs at the upper end of this range are standard. For rural and critical access hospitals, costs can exceed $500,000 when relocation incentives, signing bonuses, and guaranteed compensation floors are factored in.

Revenue Loss: Direct costs are only the beginning, however. Merritt Hawkins data indicates that the average physician generates $2.4 million annually for affiliated hospitals. For interventional cardiologists specifically, that figure rises to $3.48 million — the highest among all physician specialties. At that revenue rate, every month a cath lab position sits vacant costs approximately $290,000 in lost procedural revenue alone, not counting the downstream effects on ancillary services, diagnostics, and inpatient admissions generated by an active interventional program.[16]

Taken Together: MedAxiom's 2025 Cardiovascular Provider Compensation and Production Survey documents that median total compensation for full-time cardiologists reached a record high of $694,954 in 2024. When sign-on bonuses, retention incentives, and benefit costs are included, the total investment in a new hire — before that clinician has generated a single dollar of hospital revenue — commonly reaches $800,000 to $1.2 million.[17]

The training pipeline offers no easy relief. Creating a new interventional cardiologist requires 14 to 16 years: four years of medical school, three years of internal medicine residency, three years of general cardiology fellowship, and a minimum of one additional year of interventional subspecialty training. Only approximately 213 ACGME-accredited interventional cardiology training positions are available nationally per year. The pipeline is structurally incapable of quickly replacing clinicians lost to injury or illness.[18,19]

MedAxiom projections, developed in collaboration with the American College of Cardiology (ACC) and the American Hospital Association (AHA), indicate that the cardiologist shortfall will worsen materially over the next decade as the workforce ages. More than two-thirds of practicing cardiologists are now over 50, and the ratio of cardiovascular patients per cardiologist is expected to increase substantially through 2030. Every clinician lost to a preventable occupational injury is not easily replaced — that person is gone from the workforce for months or years, during which patient access deteriorates and hospital revenue contracts.[18,20]

The Cost of Treating Diseased and Injured Clinicians

As noted above, ORSIF's economic analysis estimates the annual direct healthcare costs of radiation-related illness and orthopedic injury among U.S. interventional fluoroscopy clinicians at a minimum of nearly $50 million. This estimate is based on per-case costs of $9 million per fatal occupational cancer (including loss of productive life, compensation, and treatment costs), $200,000 per nonfatal cancer, and $12,000 to $45,000 per musculoskeletal disorder. These figures were explicitly characterized as conservative, excluding preclinical conditions (cataracts, cognitive decline, reproductive compromise), litigation costs, and turnover costs attributable to radiation-related departures.[8]

That said, the actual total is almost certainly two to three times the ORSIF baseline when additional cost components are considered. For example, surgical intervention for spinal injury (cervical or lumbar decompression procedures) can cost $50,000 to $150,000 per episode. Additional costs span long-term rehabilitation, lost productivity during recovery, disability insurance payouts, early retirement costs and pension obligations, workers' compensation claims, and litigation exposure in states where radiation-related illness or injury may give rise to employer liability.

Dr. Kereiakes and Dr. Foster's cases are illustrative. Their spinal injuries required emergency neurosurgical intervention and extensive post-operative care. The total healthcare cost of their injuries, lost practice revenue, and replacement burden represent costs that could have equipped multiple cath labs with advanced radiation protection for a decade.

Workers' compensation claims for orthopedic injuries among cath lab staff — including nurses and technologists as well as physicians — are yet another growing line item in hospital operating budgets. The 2025 ERGO-CATH data showing 43% of operators experience measurable physical impact from lead garb suggests that the true burden of musculoskeletal morbidity in the interventional workforce is far larger than what is currently captured in the clinical literature.[11]

The cost of injuries, lost revenue, and replacement could have equipped cath labs with full radiation protection for a decade.

The Workforce Shortage and Revenue Loss Multiplier

The fiscal damage from workforce attrition does not end with the departing clinician. Rather, it compounds.

When a cath lab loses an interventional cardiologist, even temporarily, the entire procedural ecosystem is negatively impacted. Remaining clinicians must absorb increased caseload, accelerating their own burnout and orthopedic vulnerability. Scheduled procedures are often delayed or cancelled. Patients are frequently redirected to competing institutions. And referring physicians lose confidence in the program's reliability and redirect their referrals.

The 2025 ACC workforce report documents that wait times for general cardiovascular visits have increased by more than 25% since 2017, with patients waiting nearly a month on average to see a cardiologist. In interventional cardiology specifically — where timely access to the cath lab can be the difference between a reversible myocardial infarction and a fatal one — delays carry clinical consequences that translate directly into the loss of patient lives that could have been saved.[21,22]

The fiscal damage from workforce attrition does not end with the departing clinician. Rather, it compounds.

The revenue multiplier effect means that the true cost of a clinician lost to preventable injury or illness is not $3.48 million per year in direct procedure revenue. It is that figure *plus* the downstream revenue from hospital admissions, diagnostics, and ancillary services generated by an active interventional program — a figure that can easily reach $5 million to $7 million per FTE per year in a well-functioning cardiovascular service line.

Hospital Closures Due to Clinician Loss and Departures

The most catastrophic fiscal consequence of the workforce attrition crisis is not lost revenue. It is institutional failure.

Rural and critical access hospitals that lose their cath lab physician or their cath lab team frequently cannot sustain their cardiovascular service lines. Service line closure triggers a cascade: reduced inpatient admissions, reduced emergency department utilization, degraded financial performance, and ultimately, in the worst cases, hospital closure.

The most catastrophic fiscal consequence of the workforce attrition crisis is not lost revenue. It is institutional failure.

The Chartis 2025 Rural Health State of the State report documents that 30% of rural hospitals are vulnerable to closure under current financial conditions. Between 2020 and 2024, 38 rural hospitals — including 14 critical access hospitals — closed completely. Cardiovascular service degradation is a recurring contributing factor in this closures, as the loss of an interventional program directly reduces the revenue base that sustains broader hospital operations.[23]

The linkage between radiation safety and hospital financial viability is thus not metaphorical. It is causal and documented.

The Added Cost of Hospital Liability

Due to the illness, injury, and deaths suffered by clinicians, hospitals are increasingly facing the risk of lawsuits filed by clinicians diagnosed with cancer or other devastating outcomes — and the families of clinicians who died due to exposure. Alleging (with substantial proof) years of occupational exposure to fluoroscopic radiation, such litigation seeks compensation for the lack of access to available protective technologies which could have prevented harm.

By not deploying available technologies and practices to minimize occupational radiation exposure, hospitals face substantial losses. Specifically, suits filed to date have alleged that hospital radiation safety practices were inadequate, including insufficient monitoring of occupational exposure, missing dosimetry records during certain periods, inadequate radiation-protective equipment, and failure to adequately communicate cumulative radiation risks to staff.

With judgments and settlements reaching multiple millions of dollars, the risk of liability is an additional cost that must be considered by any facility which opts to weigh the costs and benefits of better protecting their clinicians.

The Incremental Cost of Radiation Safety Devices

Against this backdrop of multi-million-dollar costs attributable to the status quo, the capital cost of advanced radiation safety technology is, in practical terms, modest.

In contrast to the enormous impacts of the status quo, the cost of radiation safety technology is modest.

A complete advanced shielding system for a single cath lab — including a suspended or freestanding radiation barrier system, supplemental lead-free garments for all team members, and a real-time dosimetry monitoring capability — ranges in total capital cost from approximately $50,000 to $150,000 depending on configuration, equipment chosen, and whether ceiling infrastructure supports a suspended system. Amortized over a useful life of seven to ten years, the annual cost per lab is typically $7,500 to $20,000.

To put this in immediate context: the annual amortized cost of fully protecting a single cath lab team is equivalent to approximately *three to seven days* of the lost revenue generated by a single physician vacancy. Put another way, it is less than 0.5% of the annual hospital revenue generated by a single interventional cardiologist at full productivity.

A simplified five-year horizon model illustrates the financial argument:

Baseline scenario (unprotected lab):

- Assume a cath lab team operating with traditional lead garments only. Over five years, the statistical likelihood based on SCAI survey data suggests at least one clinician will require career-limiting intervention for orthopedic injury (probability of >20% per clinician over the horizon); meaningful probability of radiation-induced illness requiring medical intervention; and elevated turnover attributable to safety concerns.

Estimated five-year costs in baseline scenario:

- Clinician recruitment following injury-forced departure typically runs from $250,000 to $500,000. Additionally, the revenue loss during a six-month vacancy is approximately $1.74 million. Treatment costs for orthopedic injury, including surgery and rehab, often totals $50,000 to $150,000, while staff turnover costs (nurses, technologists) easily reaches $30,000 to $100,000. Combined, these costs total $2.07 million to $2.49 million (low estimate), not counting treatment for radiation-induced illness.

<u>Protected scenario (advanced radiation safety deployed)</u>:

- As noted above, the capital cost for full advanced protection is typically $75,000 to $150,000. Add in annual maintenance ($5,000 to $15,000), and you reach a five-year total $100,000 to $225,000. If this expenditure helps avoid the loss of a single physician to illness, injury, or death, approximately $1.74 million in revenue loss is avoided.

Importantly, the above model speaks to the finances of a single cath lab. Even on that scale, the savings are significant, particularly for hospitals already facing fiscal stress. When applied to the nation as a whole, the financial upside of radiation safety becomes even more compelling. Applied to a conservative estimate of 3,000 hospital cath labs, the economic upside could reach nearly $7 billion.

The net five-year benefit of radiation protection totals $1.8 million to $2.3 million — *per cath lab*.

Other Safety Measures

In addition, interventional laboratories have other safety measures that often go unused or are not maintained in good repair, leading to increased radiation exposure to clinicians and staff. Examples are improper or no use of pull-down lead shields, table skirts in ill repair or missing, and not requiring the use of thyroid shields or optimal imaging techniques. Further, affordable radiation protection technologies such as single-use radiation attenuation drapes and shields and novel face and thyroid protective shields can be used to significantly reduce the radiation exposure now suffered by clinicians and staff. Being inexpensive and easy to integrate into existing workflows, these technologies provide another effective option for radiation safety and can play an important role in reducing annual exposure to below 20 mSv as is required and routinely achieved in numerous other countries.

THE NET ACCESS IMPACT OF RADIATION SAFETY

The financial case for radiation safety, analyzed in the preceding section, concerns costs already incurred or at risk. The access case concerns value not yet captured — procedures not performed, patients not served, revenue foregone because the workforce is diminished, and people harmed due to the lack of needed care.

Here, too, interventional cardiology offers a compelling illustration. For a patient presenting with acute myocardial infarction to a hospital that cannot perform emergency Percutaneous Coronary Intervention (PCI), the nearest cath lab may be 50 miles away on a two-lane highway. The clinical literature is clear on the consequences: rural myocardial infarction (MI) patients undergo catheterization at rates of 49.7% versus 63.6% for urban patients, and rural (ST-Elevation Myocardial Infarction) STEMI patients receive PCI at rates of 3.8% versus 13.8%. The one-year mortality rate in rural STEMI settings is 68.6%, versus 58.9% in urban centers — a 10-point mortality gap *directly attributable to access failure*.[22]

The Access Implications of Unprotected Cath Labs

The access implications of under-protected facilities operate through a simple mechanism: clinicians who suffer illness, injury, or death leave gaps in America's healthcare workforce that no pipeline is able to quickly fill. These gaps manifest first as extended wait times and constrained procedural capacity, then as service line instability, and finally as service line closure.

The 2023 SCAI Survey found that approximately 20% of interventional cardiologists have already had to reduce their caseload or take medical leave due to injury or radiation concerns. This is not a future risk — it is a present reality that is directly related to heart disease's status as the nation's #1 cause of death. Moreover, the access impact is embedded in the throughput of every cath lab program in the country whose operators are working with traditional lead protection only.[9]

Women in interventional cardiology face a uniquely severe crisis. Lead aprons are not designed for pregnancy, and radiation exposure during pregnancy carries documented fetal risk. The physical burden of lead garments during pregnancy is considerable. Multiple studies and surveys identify radiation exposure and the physical demands of lead as factors that disproportionately discourage women from entering or remaining in interventional specialties — a phenomenon that exacerbates workforce shortages in a specialty that is already demographically skewed and structurally underrepresented by women.

Women in interventional cardiology face a uniquely severe crisis.

Hospitals and Communities with Open Positions

The interventional cardiology workforce vacancy crisis is acute, geographically maldistributed, and getting worse.

As of April 2026, according to Medicus Healthcare Solutions' workforce analysis, the states with the fewest cardiologists per 100,000 residents include Wyoming, North Dakota, Idaho, New Mexico, and Arkansas. The rural dimension is severe: 86% of rural U.S. counties — approximately 2,700 communities — have no practicing cardiologist of any type. In a specialty that requires hospital infrastructure to practice, the absence of a cardiologist in a rural county frequently means the absence of cardiac care.[24]

Healthcare system recruiters surveyed at the ACC 2024 Annual Scientific Sessions reported universal concern about the trajectory. Rural positions routinely sit open for years. More than two-thirds of the current cardiology workforce is now over 50. The AAMC projects a total U.S. physician shortage of up to 86,000 doctors by 2036; within cardiovascular medicine, the math is particularly unforgiving. ACC and MedAxiom projections indicate that the ratio of cardiovascular patients per cardiologist will increase significantly through 2030 as baby boomers age and cardiovascular disease rates rise.[18,25,20]

Every medical professional lost to a preventable occupational illness, injury, or death is an irreplaceable subtraction from a healthcare workforce that is already operating at deficit.

The Workforce Value of Retaining Experienced Clinicians

The economic literature on physician productivity establishes a clear age-experience productivity profile: interventional cardiologists reach peak procedural volume and technical efficiency in their mid-40s to early 50s, following the accumulation of the case experience necessary for complex procedures. The loss of a clinician at this peak-productivity stage — through injury, illness, or career abandonment — is disproportionately costly relative to the loss of an early-career physician.

MedAxiom's 2024 survey data documents that overall wRVU production per FTE cardiologist was 11,178 in 2023 — but that this median conceals significant variation, with experienced, high-volume interventionalists generating substantially more. The retention of a senior interventional cardiologist, prevented from early retirement by the elimination of the occupational hazards that would otherwise have forced departure, may represent the preservation of $5 million to $10 million in cumulative hospital revenue over five to ten additional productive years.[18,17]

Advanced radiation safety technologies that eliminate the orthopedic burden of lead garments are not simply quality-of-life improvements. They are career-extension mechanisms for the clinicians who are most difficult to replace.

Radiation safety is not a quality-of-life matter. It is an access imperative.

The Rural and Critical Access Hospital Dimension

The rural access crisis in cardiology is severe enough to deserve separate treatment, because the stakes are qualitatively different in communities where the loss of a single interventional cardiologist does not mean reduced capacity — it means no capacity.

Rural hospitals operate on margins that cannot absorb the financial shock of an interventional program vacancy. The Chartis analysis documents that 30% of rural hospitals are financially vulnerable under current conditions. Cardiovascular service lines are frequently among the most profitable programs those hospitals operate. Their loss undermines the financial foundation that supports emergency, obstetric, and primary care services.[23]

The pipeline from rural communities to tertiary centers — the system by which a community hospital stabilizes a STEMI patient and transfers them to a cath lab facility — is itself dependent on the existence of a functioning local interventional program in the referral hospital. Rural hospitals that cannot afford to protect their cath lab teams, or that have not yet recognized the financial case for doing so, are accelerating their own path toward service line loss and institutional closure.

For rural America, protecting and retaining interventional cardiologists may be the difference between hospital survival and closure.

Importantly, advanced radiation protection is not uniquely expensive for rural hospitals relative to urban ones. The capital cost of protecting a rural cath lab is the same as protecting an urban one. What differs is the relative impact: for a rural critical access hospital, protecting and retaining a single interventional cardiologist may literally be the difference between institutional survival and closure.

The Revenue Gained Through Access Assurance

Revenue is not simply what a hospital earns from procedures performed. It is also the revenue it does not lose to preventable workforce attrition.

The U.S. cath lab services market was valued at approximately $16.8 billion in 2025 for hospital-based labs alone, with a projected compound annual growth rate of 5.5% through 2033, driven by aging demographics and rising cardiovascular disease rates. This growth trajectory means that the revenue available to institutions that can maintain or expand their interventional capacity is growing — while the workforce available to capture that revenue is shrinking.[26]

Hospitals that invest in advanced radiation protection now are positioning themselves to capture a larger share of growing cardiovascular procedure revenue by retaining the clinicians who generate it. Those that do not will face compounding workforce attrition precisely as demand for cardiovascular services accelerates.

Net Revenue Impact Modeling

A conservative five-year revenue impact model for a typical hospital with one active cath lab:

- **Baseline (unprotected):** One radiation-related or orthopedic-injury-driven physician departure in year 3 of the modeled period. Revenue lost during 6-month replacement search: $1.74 million. Revenue lost from reduced procedural volume of surviving team operating under increased load stress: estimated 10% reduction, approximately $500,000 per year for two years ($1 million). Total baseline access-related revenue loss: $2.74 million over five years.
- **Protected scenario:** No injury-driven departure. Full procedural volume maintained. Revenue from one additional year of clinical productivity for one senior clinician who would otherwise have reduced caseload: approximately $870,000 (25% of $3.48 million). Total five-year revenue advantage of protected scenario over baseline: approximately $3.61 million.
- **Net five-year revenue and cost-avoidance advantage:** Advanced radiation protection, inclusive of capital investment, is conservatively estimated to cost $3.4 million per cath lab. This figure rises substantially in hospitals where the interventional team is more numerous, where procedure volumes are higher, or where the retention of senior clinicians for additional productive years can be demonstrated.

CLINICIANS SPEAK: THE HUMAN COST OF UNPROTECTED LABS

Statistics are essential. They establish the scale of the problem and provide the empirical foundation for decision-making. But statistics do not communicate the texture of what it means to spend 30 years standing in a radiation field wearing 10-20 pounds of lead. The testimonials in this section are drawn from published accounts, peer-reviewed case literature, and the personal narratives emerging from the growing clinician-safety advocacy movement.

They are included here not as anecdote but as evidence that the harm documented in surveys is not an abstraction but a lived human experience that is occurring today, in hospitals across the United States, in conditions that are preventable.

Clinicians Who Have Suffered Illness, Injury, and Death

The 2023 SCAI survey found that among respondents who had been in practice more than 20 years, orthopedic injuries were nearly universal. The survey also found that 34% of respondents had already experienced lumbar spine injuries and 25% had experienced cervical spine injuries — statistics that represent tens of thousands of practicing clinicians.

Among radiation-induced malignancies, the case literature documents left-sided brain tumors in interventional cardiologists at a rate and with a lateralization pattern that strongly implicates occupational radiation. The 2025 JSCAI paper "Radiation Safety Renaissance" by Dr. Ryan Madder notes that 11% of SCAI survey respondents acknowledged knowing a colleague with a brain tumor — a figure that, applied to a specialty of approximately 6,000 interventional cardiologists in the United States, represents a number far exceeding statistical chance.[27]

Women in interventional cardiology carry an additional burden. The 2025 Journal of Interventional Cardiology study by Pelargonio on radiation exposure and breast cancer occurrence among women in interventional cardiology underscores that female interventionalists face gender-specific oncological risks that are not fully addressed by standard protective equipment, which is not designed with female anatomy in mind.[28]

Here are just a few of their stories:

Dr. Dean Kereiakes, MD, FACC, referenced above, specialized in complex coronary interventions. Due to the weight of lead garb, he developed catastrophic cervical and thoracic spinal injury. In February 2024, he began experiencing upper back pain and arm weakness. Within 48 hours, he could not sign his name. Within 96 hours, he required emergency spinal neurosurgery to prevent complete quadriplegia. [12]

Dr. Sarah Johnson was an outstanding cardiologist who was named Director of the Cardiac Catheterization Laboratory at Loyola University Medical Center at just 36 years of age. She trained numerous fellows and cared for patients in private practice, but her extensive exposure to radiation led to an appendiceal tumor, for which she endured a decade of chemotherapy and multiple surgeries. Dr. Johnson eventually succumbed to her disease.

Dr. Bill Orrison was an interventional neuro-radiologist who was exposed to radiation performing interventional procedures with minimal protection. Recognizing the threat, he was a proponent of radiation safety and developed novel radiation protection devices. However, the many years in the lab without adequate protection led to several health issues which then led to a debilitating heart attack. Bill passed away a year later.

Sheehan Raab worked in a New York City cath lab where, as in many such facilities, radiation protective garb left much of her body uncovered and was best suited to men with the larger sizes not offering her adequate protection. In 2018, Sheehan felt a lump in her upper breast, underwent mammograms, and was diagnosed with stage-3 breast cancer. Sheehan bravely battled her cancer, which ultimately required a double mastectomy.

Decedents of Clinicians Who Died from Radiation Exposure

The literature documents multiple deaths among interventional cardiologists that families and colleagues attribute directly to occupational radiation exposure. Finkelstein's landmark 1998 paper in the Canadian Journal of Cardiology — "Is brain cancer an occupational disease of cardiologists?" — established the epidemiological framework for understanding these deaths as occupational, not merely coincidental. Smith's 2000 editorial "On the loss of colleagues" in the same journal described the growing awareness within the interventional cardiology community of a pattern of brain cancer among practitioners.[29,30]

The pattern documented in the 1990s has not reversed. It has intensified, as procedural volumes have grown, as procedures have become more complex and fluoroscopy-intensive, and as the generation of interventionalists trained during the expansion of the specialty in the 1990s enters its highest-risk years.

The families of clinicians who have died from radiation-attributable malignancies often describe the same arc: years of accepting radiation exposure as an inherent occupational hazard, mounting concern as symptoms emerged, and ultimately the recognition that the risk was neither inevitable nor, given available protective technologies, necessary. Their losses are a testament to the cost of institutional inertia.

Clinicians Are Taking a Stand

An increasing number of interventional cardiologists and cath lab staff are declining to work in unprotected labs — or are conditioning their employment on the provision of adequate radiation protection. This phenomenon, which remains informal and largely undocumented in the published literature, represents the leading edge of a coming labor market reckoning.

The ALARA+ consensus paper, published in JSCAI in March 2026 and endorsed by numerous medical societies, explicitly documents that concerns about radiation exposure during pregnancy and the physical burden of protective lead are cited as discouraging many women from entering or remaining in fluoroscopy-based specialties. As awareness of the full scope of occupational hazards in the cath lab grows — accelerated by the SCAI survey data, the tragic stories of clinician suffering, and the ALARA+ framework — the labor market premium for protected labs over unprotected ones will increase.[31,32]

Hospitals that act now will be positioned to recruit from the nation's increasingly safety-conscious workforce.

As a result, clinicians' stance is making it clear that hospitals that act now will be positioned to recruit from this increasingly safety-conscious workforce. Those that do not will likely find themselves at a growing competitive disadvantage, able to fill positions only with clinicians who are either unaware of the risks or who have concluded that no available alternative exists. Neither circumstance is sustainable.

CONCLUSION: THE IMPERATIVE FOR ACTION

The evidence assembled in this report is conclusive on multiple dimensions simultaneously. The human case, the fiscal case, and the access case for advanced radiation safety technologies in interventional fluoroscopy labs each stands independently. Together, they constitute an argument that is not merely persuasive but logically unavoidable.

The argument for action is not merely persuasive — it is logically unavoidable.

The Fiscal Case for Advanced Radiation Safety Devices

Hospital finance executives who read this report and ask, "what is the return on investment?" will find the answer unambiguous: positive — and positive quickly. Specifically, the annual amortized cost of fully protecting a single cath lab team is less than 0.5% of the annual revenue generated by a single interventional cardiologist at full productivity. The cost of a single physician replacement event — driven by preventable illness, injury, or death — exceeds the five-year capital cost of protecting the entire lab.

The Access Case for Advanced Radiation Safety Devices

The access case is equally compelling. As the nation's clinical workforce is ages, thins, and becomes even more geographically maldistributed, deployment of advanced radiation safety technologies are, in practical terms, workforce retention tools. They attract recruits. They extend careers. They enable women to remain in the specialty through and after pregnancy. They make possible the 35-year career that was previously truncated at 20 by illness or injury. And they generate revenue that enables further investment in expanded patient access to care.

The Human Case for Advanced Radiation Safety Devices

The human case is equally stark: clinicians who work in interventional fluoroscopy labs face dramatically elevated risks of cancers, brain tumors, cataracts, cognitive decline, miscarriages, orthopedic injury, and death. These are not acceptable collateral consequences of a critical medical specialty. They are preventable harms — preventable today, with available technology, at costs that are small relative to the revenues these clinicians generate and the human value of the careers and lives that are being truncated and lost.

A Call to Action: Hospital Administrators

Hospital executives and cath lab directors should, as an immediate priority, commission institution-specific ROI analyses that compare the five-year expected cost profile of their current radiation protection posture against the capital and operating cost of transitioning to advanced protection. Using the methodological framework provided above, current cath lab staffing, procedure volume, physician compensation, and local recruitment costs can and should be assessed. Such analysis will, in virtually every case, confirm the conclusion reached here: the business case for advanced radiation protection is affirmative, material, and time-sensitive.

A Call to Action: Policymakers

Since 1986, the Federal Register has set forth a powerful requirement: "Proper safety precautions must be maintained against radiation hazards. This includes adequate shielding for … personnel …." During the intervening four decades, advanced radiation safety technologies have been developed that make federal requirement achievable. What is now needed is for policymakers to update Medicare conditions of participation to require adequate radiation protection in all fluoroscopy-based clinical settings. The U.S. annual radiation dose limit should also be reduced from 50 mSv to the 20 mSv level, which is recognized throughout the rest of the world, so our nation has a responsible benchmark for radiation safety in the interventional laboratories. The interventional cardiology suite is a hazardous work environment. It should be regulated as one.

The Ethics of Inaction

There is no neutral position on this question. The choice not to deploy available advanced radiation protection, in a context where the evidence of harm is documented and the technology to prevent that harm is accessible, is a choice. It is a choice to accept the continued illness, injury, and death of the clinicians we depend on — or to care for those who care for us.

The time is <u>now</u> to care for those who care for us.

The ethics of this choice are straightforward: clinicians who accept the occupational hazards of their professions in order to serve patients deserve the protection that available technology and accumulated evidence now clearly mandate. The ethics of inaction — the human, financial, and access implications of maintaining the status quo — are inseparable from the obligation to sustain the workforce we need to serve patients and communities across the nation.

In retrospect, the case for safer care is not surprising. It is, instead, the only case that is simultaneously financially rational, medically defensible, and ethically coherent.

ABOUT IMAGE SAFELY 360

IMAGE SAFELY 360 (IS-360) is a coalition of healthcare professionals, safety advocates, equipment manufacturers, and professional societies committed to comprehensive worker protection in fluoroscopy environments. We believe no clinician should sacrifice their health to provide patient care. Through evidence-based advocacy, education, and collaboration, IS-360 works toward a future where radiation protection and ergonomic safety are standard.

Visit IS-360 at www.ImageSafely360.org.

ENDNOTES

1. Lisko JC, Shekiladze N, Chamoun J, et al. "Radiation exposure using Rampart vs standard lead aprons and shields during invasive cardiovascular procedures." JSCAI. 2023;3:101184.

2. Herzig MS, Kochar A, Hermiller JB, et al. "Real-World Reductions in Lead-Free Radiation Exposure with the Rampart System during Endovascular Procedures." Am J Cardiol. 2025;243:59-64. doi:10.1016/j.amjcard.2025.02.019

3. Endovascular Today. "Confidence in the Data." June 2025. https://evtoday.com/articles/2025-june-supplement/confidence-in-the-data-1

4. Almalki M, et al. "Assessment of occupational radiation exposure among various medical professions in interventional cardiology: A five-year study (2018-2022)." Radioprotection. 2025;(03). https://www.radioprotection.org/articles/radiopro/full_html/2025/03/radiopro240076/radiopro240076.html

5. EuroIntervention. "Brain tumours among interventional cardiologists: a cause for alarm?" https://eurointervention.pcronline.com/article/brain-tumours-among-interventional-cardiologists-a-cause-for-alarm

6. American Heart Association. "Controlling Radiation Exposure in Interventional Cardiology." Circulation: Cardiovascular Interventions. 2014. https://www.ahajournals.org/doi/full/10.1161/CIRCINTERVENTIONS.114.001815

7. Tahiri Z, Sekkat H, et al. "Radiation exposure in interventional cardiology: a narrative review of health effects and novel approaches to ensure radiation safety." Ther Radiol Oncol. 2025;9:10. https://tro.amegroups.org/article/view/9839/html

8. Organization for Occupational Radiation Safety in Interventional Fluoroscopy (ORSIF). "Economic Impacts of Radiation Exposures Associated with Interventional Fluoroscopy." 2019. Accessed via: https://www.raduxdevices.com/wp-content/uploads/ORSIF-2018-EconomicStudy.pdf

9. Abudayyeh I, Islam A, et al. "Occupational Health Hazards in the Cardiac Catheterization Laboratory: Results of the 2023 SCAI Survey." Journal of the Society for Cardiovascular Angiography and Interventions. March 4, 2025. https://www.jscai.org/article/S2772-9303(24)02182-3/fulltext

10. SCAI. "Survey Confirms Radiation and Orthopedic Health Hazards in Cardiac Catheterization Laboratories are Unacceptable." March 4, 2025. https://www.scai.org/media-center/news-and-articles/survey-confirms-radiation-and-orthopedic-health-hazards-cardiac

11. Society for Cardiovascular Angiography and Interventions (SCAI). "Studies Underscore Occupational Health Hazards for Cath Lab Personnel and Highlight Need for Lead-Less Solutions." Press release. May 1, 2025. https://www.scai.org/media-center/news-and-articles/studies-underscore-occupational-health-hazards-cath-lab-personnel

12. Cardiovascular Business. "Cardiologist became paralyzed after wearing heavy aprons in the cath lab for decades — but he fought back." June 5, 2025. https://cardiovascularbusiness.com/topics/clinical/interventional-cardiology/interventional-cardiologist-paralyzed-lead-aprons-cath-lab

13. Cardiovascular Business. "SCAI leaders 'on a mission' to improve cath lab protection from radiation, orthopedic injury." March 7, 2025. https://cardiovascularbusiness.com/topics/clinical/interventional-cardiology/scai-leaders-mission-improve-cath-lab-protection-radiation-orthopedic-injury

14. NCT06875583. "The Radiation ProtEction for Dose RedUction in the Cardiac CathEter Lab Study: The REDUCE Trial." ClinicalTrials.gov.

15. MedStar Health. "Radiation Protection System in Cardiac Catheterization Lab." https://www.medstarhealth.org/news-and-publications/news/radiation-protection-system-in-cardiac-catheterization-lab

16. Becker's Hospital Review. "The cost of physician turnover." https://www.beckershospitalreview.com/finance/the-cost-of-physician-turnover/

17. ASC News. "Cardiologist Pay Hits Record High Amid Productivity Plateau, Workforce Strains and Growing Reliance on APPs." October 27, 2025. https://ascnews.com/2025/10/cardiologist-pay-hits-record-high-amid-productivity-plateau-workforce-strains-and-growing-reliance-on-apps/

18. MedAxiom. "Supply and Demand Imbalances Drive Starting Cardiology Compensation Upward." March 10, 2025. https://info.medaxiom.com/blog/supply-and-demand-imbalances-drive-starting-cardiology-compensation-upward

19. Cardiovascular Business. "Match Day results put spotlight on interventional cardiology's workforce woes." January 8, 2026. https://cardiovascularbusiness.com/topics/clinical/interventional-cardiology/match-day-results-put-spotlight-interventional-cardiologys-workforce-woes

20. ACC. "A Workforce in Crisis: Navigating the Cardiovascular Clinician Shortage." June 1, 2025. https://www.acc.org/Latest-in-Cardiology/Articles/2025/06/01/01/Feature-A-Workforce-in-Crisis

21. Hayes Locums. "Demand and Impact: The Cardiology Workforce Shortage." February 4, 2026. https://www.hayeslocums.com/blog/demand-and-impact-the-cardiology-workforce-shortage/

22. PMC. "Bridging the gaps in interventional cardiology disparities — socioeconomic, geographic, and political inequalities." PMC12646147.

23. Chartis. "2025 Rural Health State of the State: Rural Hospital Closures and Care-Access Crisis." February 10, 2025. https://www.chartis.com/insights/2025-rural-health-state-state

24. Medicus Healthcare Solutions. "An Inside Look at the Cardiology Workforce: Shortages, Demand, and Strategic Responses." April 9, 2026. https://medicushcs.com/resources/an-inside-look-at-the-cardiology-workforce-shortages-demand-and-strategic-responses

25. Cardiovascular Business. "How to bring cardiologists to rural America during a physician shortage." September 29, 2025. https://cardiovascularbusiness.com/topics/healthcare-management/healthcare-staffing/how-bring-cardiologists-rural-america-during-physician-shortage

26. Grand View Research. "U.S. Cath Labs Market Size & Share: Industry Report 2033." 2025. https://www.grandviewresearch.com/industry-analysis/us-cath-labs-market

27. Madder RD. "Radiation Safety Renaissance: Will State Regulations Help or Hinder an Emergence From the Dark Ages?" JSCAI. April 30, 2025. DOI: 10.1016/j.jscai.2025.103612. PMC12230436.

28. Pelargonio G. "Women in Interventional Cardiology: A Survey of Radiation Exposure and Breast Cancer Occurrence." Journal of Interventional Cardiology. 2025;1. https://doi.org/10.1155/joic/5771672

29. Finkelstein MM. "Is brain cancer an occupational disease of cardiologists?" Canadian Journal of Cardiology. 1998;14:1385-8.

30. Smith ER. "On the loss of colleagues." Canadian Journal of Cardiology. 2000;16:394.

31. Salavitabar A, et al. "ALARA+: Summit on Radiation and Orthopedic Risks in Fluoroscopic Laboratories." Journal of the Society for Cardiovascular Angiography and Interventions. March 24, 2026. https://www.jscai.org/article/S2772-9303(25)01612-6/fulltext

32. SCAI. "Medical Societies Call for ALARA+ Safety Standard to Reduce Radiation and Injury Risks in Fluoroscopy Labs." March 24, 2026. https://www.scai.org/media-center/news-and-articles/medical-societies-call-alara-safety-standard-reduce-radiation-and

BIBLIOGRAPHY

Abudayyeh I, Islam A, et al. Occupational Health Hazards in the Cardiac Catheterization Laboratory: Results of the 2023 SCAI Survey. Journal of the Society for Cardiovascular Angiography and Interventions. March 4, 2025.

Almalki M, et al. Assessment of occupational radiation exposure among various medical professions in interventional cardiology: A five-year study (2018-2022). Radioprotection. 2025.

American College of Cardiology (ACC). A Workforce in Crisis: Navigating the Cardiovascular Clinician Shortage. Cardiology Magazine. June 1, 2025.

Barton Associates. 2025 Cardiologist Job Outlook. January 23, 2025.

Becker's Hospital Review. The cost of physician turnover. 2023.

Business Wire. New Data on Cardiology Compensation and Production Highlights Solutions for Workforce Shortages. October 15, 2025.

Cardiovascular Business. Cardiologist became paralyzed after wearing heavy aprons in the cath lab for decades — but he fought back. June 5, 2025.

Cardiovascular Business. How to bring cardiologists to rural America during a physician shortage. September 29, 2025.

Cardiovascular Business. Match Day results put spotlight on interventional cardiology's workforce woes. January 8, 2026.

Cardiovascular Business. SCAI leaders 'on a mission' to improve cath lab protection from radiation, orthopedic injury. March 7, 2025.

Chartis. 2025 Rural Health State of the State: Rural Hospital Closures and Care-Access Crisis. February 10, 2025.

EuroIntervention. Brain tumours among interventional cardiologists: a cause for alarm?

Endovascular Today. Confidence in the Data. June 2025.

Endovascular Today. Minimizing Exposure, Maximizing Safety: Cath Lab Radiation Protection. June 2025.

Finkelstein MM. Is brain cancer an occupational disease of cardiologists? Canadian Journal of Cardiology. 1998;14:1385-8.

Grand View Research. U.S. Cath Labs Market Size & Share: Industry Report 2033. 2025.

Hayes Locums. Demand and Impact: The Cardiology Workforce Shortage. February 4, 2026.

Hermiller JB, et al. Real-World Reductions in Lead-Free Radiation Exposure with the Rampart System during Endovascular Procedures. American Journal of Cardiology. 2025;243:59-64.

HFMA. Key Factors in Cath Lab Financial Performance. November 2022.

HMP Global / ORSIF. Inaugural Global Symposium on Interventional Radiation Protection. October 28, 2024.

INFAB Corporation. Orthopedic Injuries Rising in Cath Lab Staff. August 2025.

Limirio P, et al. Ionizing Radiation and Bone Quality: Time Dependent Effects. 2019.

Lisko JC, Shekiladze N, Chamoun J, et al. Radiation exposure using Rampart vs standard lead aprons and shields during invasive cardiovascular procedures. JSCAI. 2023;3:101184.

Madder RD. Radiation Safety Renaissance: Will State Regulations Help or Hinder an Emergence From the Dark Ages? JSCAI. 2025. DOI: 10.1016/j.jscai.2025.103612.

MedAxiom. Supply and Demand Imbalances Drive Starting Cardiology Compensation Upward. March 10, 2025.

MedaxiomCom. 2025 Cardiovascular Provider Compensation and Production Survey Report. October 2025.

Medicus Healthcare Solutions. An Inside Look at the Cardiology Workforce: Shortages, Demand, and Strategic Responses. April 9, 2026.

MedStar Health. Radiation Protection System in Cardiac Catheterization Lab.

National Institutes of Health / PMC. Improving Cardiovascular Health in Rural United States: Role of Academic Medical Centers. PMC11312348.

National Institutes of Health / PMC. Advancements in Cardiac Catheterization Safety: Novel Radiation Protection Approaches. PMC12060925.

National Institutes of Health / PMC. Bridging the gaps in interventional cardiology disparities. PMC12646147.

Organization for Occupational Radiation Safety in Interventional Fluoroscopy (ORSIF). Economic Impacts of Radiation Exposures Associated with Interventional Fluoroscopy. 2019.

ORSIF. What is ALARA+? The 2026 Reframing of Radiation Safety in Fluoroscopy. April 29, 2026.

ORSIF. Main website: https://www.orsif.org

Pelargonio G. Women in Interventional Cardiology: A Survey of Radiation Exposure and Breast Cancer Occurrence. Journal of Interventional Cardiology. 2025.

Salavitabar A, et al. ALARA+: Summit on Radiation and Orthopedic Risks in Fluoroscopic Laboratories. Journal of the Society for Cardiovascular Angiography and Interventions. March 24, 2026. DOI: 10.1016/j.jscai.2025.104166.

Salavitabar A, et al. ALARA+: Summit on Radiation and Orthopedic Risks in Fluoroscopic Laboratories. Journal of Vascular and Interventional Radiology. March 24, 2026.

Sauer K, et al. Primary Radiation Damage in Bone Evolves via Collagen Destruction by Photoelectrons and Secondary Emission Self-Absorption. December 2022.

SCAI. Medical Societies Call for ALARA+ Safety Standard. March 24, 2026.

SCAI. Studies Underscore Occupational Health Hazards for Cath Lab Personnel. May 1, 2025.

SCAI. Survey Confirms Radiation and Orthopedic Health Hazards are 'Unacceptable'. March 4, 2025.

Shaghaghi Z, et al. Advancements in Cardiac Catheterization Safety: Novel Radiation Protection Approaches Redefining Occupational Health. Curr Cardiol Rev. 2024.

Smith ER. On the loss of colleagues. Canadian Journal of Cardiology. 2000;16:394.

Tahiri Z, Sekkat H, et al. Radiation exposure in interventional cardiology: a narrative review. Ther Radiol Oncol. 2025;9:10.

Image Safely 360 Coalition. https://www.imagesafely360.org

U.S. Journal of Ethics (AMA). What Might the Past Suggest About Rural Emergency Services Amidst Critical Access Hospitals' Decline? July 2025.