

Designing NIKH: the NextGEM Innovation and Knowledge Hub to Access Next Generation Radio Frequency EMF Exposure and Health Data

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Abstract—While Europe faces dramatic changes and profound challenges, emerging technologies that emit Radio Frequency (RF) Electromagnetic Field (EMF) exposure, particularly in telecommunications, have raised public concerns about possible adverse effects to human health. To address these concerns, the NextGEM Project aims to provide a safe living environment in the face of rapid technological changes that necessitate a fast and reliable access to the relevant scientific knowledge. The creation of the NextGEM Knowledge and Innovation Hub (*NIKH*) is accordingly proposed for accessing the next generation EMF and Health data, thus offering a standardised way for the European citizens, regulatory authorities and the scientific community to access data on EMF and Health. This work presents the aspects of NextGEM with regards to the technological aspect as expressed through the development of the *NIKH* platform for data provisioning of the newly generated scientific knowledge, regarding novel EMF exposure frequencies, as well as for the connection with the relevant stakeholders.

Index Terms—Radiofrequency Electromagnetic Field (RF-EMF); Communication Engineering; Systems Telecommunications; Bioelectromagnetics; Public and Environmental Health; Health Risk Assessment

I. INTRODUCTION

Emerging technologies that use Radio Frequency (RF) Electromagnetic Field (EMFs), particularly in telecommunications, are vital for countering the changes and challenges that Europe and the rest of the world are facing. At the same time, human exposure to the EMFs continues to raise public concern about possible adverse effects to human health. There are also some citizen groups even perceiving the fifth generation (“5G New Radio”) of wireless networks as a greater threat to public health compared to previous generation systems. In this scope, the exposure standards issued by the International Commission for Non-Ionizing Radiation Protection (ICNIRP) [1] and the International Committee on Electromagnetic Safety of the Institution of Electrical and Electronic Engineers (ICES-IEEE)

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[2], [3], are set to regulate EMF human exposure. These international guidelines are based on comprehensive reviews of the relevant scientific literature and similar approaches, resulting in analogous values of the exposure level and action values for workers, and the basic restrictions and reference levels for the general population. In regards to occupational exposures, the European Union has mandated that member states implement the ICNIRP guidelines (directive 2013/35/EU) [4]. Due to the non-binding nature of the recommendation for the general public, the related policies vary across European countries. This divergence between countries is also reflected in an increased consideration of possible health effects of man-made non-ionizing EMF exposure that may potentially be exacerbated by aggregation of different types of telecommunication services and associated radio signals.

Horizon Europe funded project NextGEM [5] strives to increase the awareness of citizens regarding EMF exposure and potential health effects by creating the NextGEM Innovation and Knowledge Hub (*NIKH*) for EMF and Health. *NIKH* is intended to be a tool of choice for European regulatory authorities and the scientific community, relying both on a Scientific/Research as well as a Technological dimension:

- **NextGEM Scientific/Research dimension:** The assessment of causal exposure-outcome associations is based on an integrated appraisal of the evidence provided by various horizontal research activities, experimental studies in humans, small organisms, cell cultures and isolated biological systems, in addition to replication studies.
- **NextGEM Technological dimension:** *NIKH* can handle information on EMF measurements, research data and Risk Assessment (RA) presented through effective means of communication to stakeholders. Its functionality and results can be demonstrated using the NextGEM research output as a benchmark for the inclusion of existing data from previous research, or other EU projects.

This work presents the definition and overall design of *NIKH*, as capable of accessing the next generation of radio

frequency EMF and health data and aiming to satisfy the aforementioned challenges in the RF-EMF domain. The remainder of this paper is organized as follows. In Section II, an overview of the NextGEM overall concept is presented. Section III presents the ingestion of experimental data and scientific knowledge in *NIKH*, while Section IV describes the design and development stages of *NIKH*. Section V depicts the application tools and services. The connection with the EMF stakeholders is identified in Section VI. Finally, Section VII provides conclusions and future work.

II. NEXTGEM OVERALL CONCEPT

The NextGEM vision is to provide an integrated sensing and analytical system, bringing together domain experts and technological advances to investigate, assess and communicate potential biological effects and health hazards from exposure to RF-EMF, with emphasis on new-generation radio-communication networks such as 5G (Fig. 1). The NextGEM Project will achieve this by developing and validating an open framework, exploiting the advantages of new deployed technologies, based on the following pillars:

- Multi-location sensing and analysis of high frequency EMF exposure levels;
- Development and testing of novel experimental studies (*in vitro*, *in vivo*) to investigate possible biological and health effects of exposure to RF, standalone or in combination with other agents and multiple types of RF signals (different frequency bands, modulation and polarization);
- Application and further development of systematic review methods and risk assessment approaches, tailored to evaluate health hazards from multiple sources, conditions and settings of exposure to RF-EMF, and focused on selected relevant outcomes such as cancer and reproduction;
- A set of solutions and practical guidelines for assuring compliance with current international exposure standards for the general population, always minimizing exposure;
- A data-driven evidence-based decision support dashboard targeted to public authorities and regulators;
- Interactive public interface, i.e., citizen web platform/app aimed at increasing public awareness.

III. EXPERIMENTAL DATA AND SCIENTIFIC KNOWLEDGE

NextGEM will provide a vast amount of data that will contribute to the planning of scientific studies, risk assessment and communication purposes, always providing cross-referencing. The NextGEM workflow includes setting up the EMF data platform, integration of existing data from available public and reviewed sources, and integration of new EMF-relevant data generated within the project. The *NIKH* platform will collect, store and process data within NextGEM in addition to other projects and studies of existing or new scientific knowledge.

A. NextGEM's New Scientific Knowledge

NIKH will integrate the new scientific knowledge as produced during the implementation of NextGEM activities. This knowledge may include measurements and modelling of

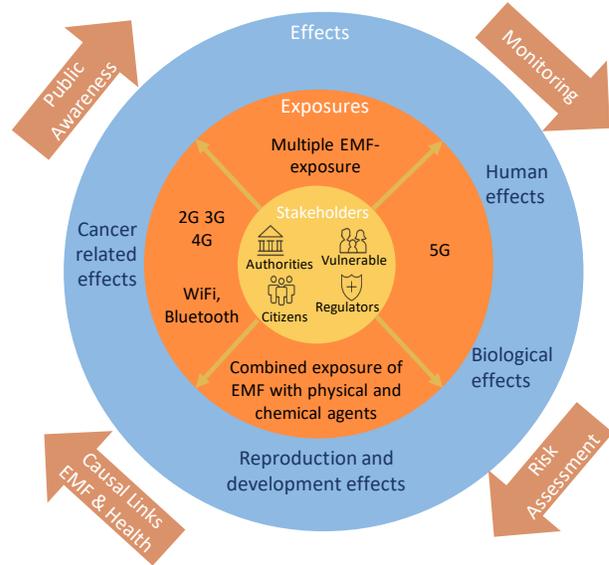


Fig. 1. NextGEM Approach

single and multiple RF sources, of changing EMF exposure patterns based on innovative monitoring technologies. More specifically, the platform will be able to store EMF data as taken from analysis modelling and from the results taken from experimental studies. The EMF environmental and personal exposure levels will be investigated and compared to assess the impact of new communication technologies in compliance to international safety standards. Numerical models of EMF generated by the application of 3G, 4G and 5G to mobile telephony will be integrated, such as the calculation of fields induced inside the human body, as produced by the designed tools to monitor the EMF distribution in living and working environments. This will allow the presentation of average personal exposure levels estimations and cumulative absorption of RF energy, for specific population segments such as children and workers. In addition, the results from sensors and wearable devices will be inserted to characterize 5G exposures.

Apart from the above, to access health effects and elucidate interaction mechanisms, results of different and combined EMF exposure patterns obtained by experimental and human studies on selected endpoints will be stored in *NIKH*. More specifically, the results of the experimental studies which include *in vitro* and *in vivo* studies and the controlled exposure studies on human volunteers will be integrated within *NIKH*. In addition, the undertaken repetitive and conclusive studies, for selected experimental conditions in independent laboratories and the exploration of the possibility to identify candidate biological exposure markers, will be used for the risk assessment of both heavy and light mobile phone users. Finally, the new knowledge gained from the different interrelated real-world use cases of NextGEM will be integrated in *NIKH* for validating the integrated NextGEM RA tool based on experiences from model validation in case studies.

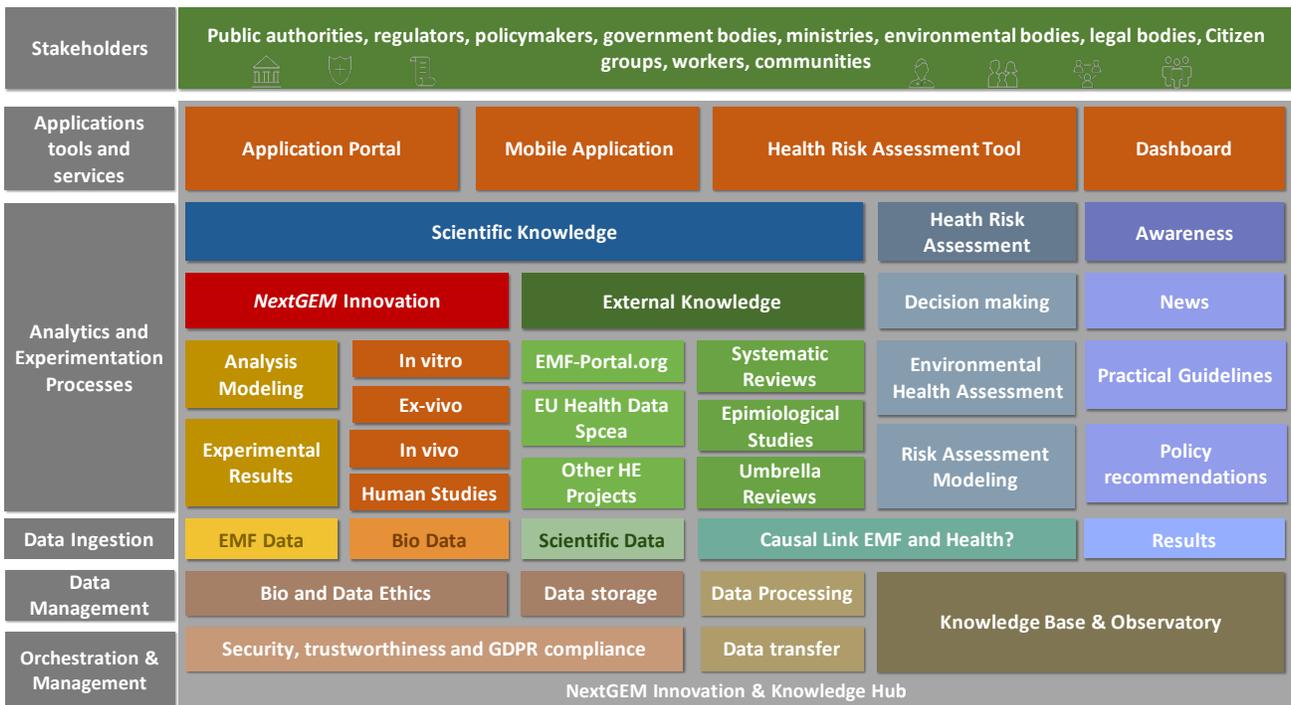


Fig. 2. Architectural Design of NextGEM Innovation & Knowledge Hub (NIKH)

B. Integrate External Knowledge with Existing Scientific Data

The stored data will be accessible from the NextGEM dashboard as soon as the primary obligations related to scientific publishing etc. are fulfilled. Moreover, *NIKH* will include the evidence based on reviews and meta-analyses of epidemiological studies in relation to RF exposure and cancer in humans. NextGEM will furthermore provide access to the collected data to non-NextGEM users, while also committing to long-term database management. Input may also include scientific results from other related projects such as from the EU EMF and Health Cluster (CLUE-H), the cluster of four Horizon Europe Projects (NextGEM, SEAWave, ETAIN and Goliat) that will assess exposure and risks of RF EMFs, including those of 5G. In addition, The NextGEM platform will provide a link to existing knowledge bases such as the EMF Portal [6] and ZENODO [7], to provide access to the latest published information and results. Finally, *NIKH* will ensure compliance and interconnection with the EU Health Data Space (EHDS) [8], for integrating additional health data from other data sources.

IV. DESIGN AND DEVELOPMENT STAGES OF NIKH

The implementation of *NIKH* is a practical realization and integration of a number of architectural components. It can be used to monitor, store, share and access EMF exposure, biological data and engineering solutions, maintain compliance with safety standards, minimize exposure levels in set environments and contexts, and increase citizens' awareness on EMF and Health. To enable validation and exploitation, a bench-marked,

open and extendable proof-of-concept reference platform is to be developed, to encompass *NIKH* features and to ignite the incremental evolution of *NIKH* into a central innovation and knowledge base for EMF data. The development of *NIKH* includes four different stages: i) design of the platform to store the innovations and research outputs produced within NextGEM, ii) inclusion of external scientific knowledge from previous research or through synergies with projects funded under other clusters and pillars in the knowledge base, iii) enabling security, trustworthiness and GDPR compliance, and iv) offering a link to other EMF stakeholders.

A. Platform Design for Collecting Research Outputs

NIKH platform will be the realization of an open-source framework, integrating detailed information and metadata for EMF and biological data, as well as usable solutions towards end-users. *NIKH* will be designed in a modular, micro-services architecture, composed of the cohesive building blocks required for the above-mentioned functionalities, as depicted in Fig. 2, and allowing flexibility and interoperability to embody diverse business processes and scenarios. The various services will cover different layers of the *NIKH* architecture; from the *Orchestration & Management* layer that will ensure optimized resource configuration, the *Data Ingestion & Management* layer for handling EMF and Biological raw data and results; to the *Analytics and Experimentation Processes* layer for translating data to insightful information and knowledge for relevant Stakeholders (provided through the tools on the *Applications tools and services* layer). Through interactions of these services, *NIKH* will be able to orchestrate the pro-

cesses for translating analytics and experimentation model descriptions, to deployed end-to-end data processing jobs that range from data management and analysis components, to end-user applications and services. It will offer template services embodying NextGEM’s logical structure based on diverse research scenarios and will manage execution planning (explicit and automatically decided), as well as the interactions between NextGEM components while ensuring seamless integration. In its essence, it will comprise the “glue” of the NextGEM system and will expose service interfaces for directly interacting with the diverse data and network management components that govern its optimized operation. *NIKH* will ensure proper resource allocation to establish end-to-end communication paths from end devices and data sources to end users and control mechanisms.

B. Knowledge Base and Observatory

The Knowledge Base will contain a large library of project activities and outputs including protocols, public deliverables, publications, guidelines, policy recommendations, and articles related to the project concept. This will provide public authorities and the science community with rich content information through cross-browser and multi-device compatibility. Throughout and beyond NextGEM’s life-cycle, users will have the ability to continuously enrich the content of the Knowledge Base, thus contributing to an expanding base and a one-stop information source for all actors in the electromagnetic exposure and health ecosystem. The different features of the application supporting citizen self-awareness on EMF exposure will be developed to support the required end-user functionality as well as to set up and deploy the application as a stand-alone module. A database can enable data storage and query capabilities to search and update the stored knowledge. Optionally, it is foreseen to integrate data from other databases and make accumulated data accessible to other researchers.

C. Data Transfer and Processing

The data transfer and network provision guarantee between the distributed data location as stored in the NextGEM platform, including an information-sharing process in a scalable and reliable manner. More specifically, cloud environments will be the key importance to preserving users’ data collection, analysis, processing, and storage in the compute continuum. In close cooperation with the other components, *NIKH* can provide a robust solution and access control within NextGEM’s platform. Special attention is given to establishing the basis for guaranteeing a secure environment with respect to the legal/regulatory issues currently existing in Europe. In addition, the research and work on techniques and technologies to control access, contain the aim of sharing the exported NextGEM data and registries in a secure and private manner. Additionally, it will provide secure interfaces with EU Health Data Spaces. Standards, protocols, and Application Programming Interfaces (APIs) will enable the integration of different services and data needed for creating a unified platform prototype, acting as a critical mass to be extended and

evolve into the European Hub for EMF data and information services.

D. Security, Trustworthiness and GDPR Compliance

While embodying “security by design” principles for the trustworthy transfer of data across the platform layers, *NIKH* can tackle isolation requirements for multi-tenant data management services, privacy preservation and IP rights protection. To assure NextGEM operation from a cybersecurity perspective and provide evidence for its GDPR compliance, the Security Assurance Platform (SAP) [9] will be employed. SAP will thus be tailored within *NIKH* in a model-driven approach. *NIKH*’s real-time operational compliance to security, privacy and GDPR requirements will be provided in an evidence-based manner through the integration of SAP which will enable hybrid assessments based on vulnerability analysis, penetration testing and continuous monitoring of NextGEM assets. The establishment and operation of continuous security and privacy assurance checks for *NIKH* and its security and privacy control mechanisms, will ensure security and privacy conformity and will generate and maintain objective evidence for compliance with regulatory requirements (e.g. GDPR) and make the overall platform accountable and trustworthy. This will include distributed and trustworthy data management and compliance with ethics and legal aspects. Moreover, this assessment and monitoring of the NextGEM framework will have a GDPR compliance flavour by i) inspecting organisational and technical measures that are put in place to ensure compliance with GDPR requirements, ii) verifying their effectiveness, and iii) recording all information related to the handling of personal data, offering their accountability.

V. APPLICATION TOOLS AND SERVICES

The multi-modal environment of *NIKH* will provide the relevant application tools and services to ensure the needed interaction ability, not only for the novice but also for the most advanced user. *NIKH*’s approach minimises cognitive load, using consistency as a key, preferring clarity over complexity, and always maintaining control by the user. This includes the development of the relevant tools and services to the public authorities and the scientific community, including a dashboard/GUI to visualize stored data, the mobile app for citizens’ awareness, and finally the risk assessment tool for identifying potential causal links between EMF and health.

A. Application Portal and User Interface

A key User Interface (UI) feature is the adaptivity provided through a configurable NextGEM dashboard for the identified target groups including public authorities, industry players and the scientific community. For the design and implementation of *NIKH*’s Graphical User Interface (GUI), the requirements and technical specifications are followed to develop and produce the detailed low-level design of the front-end dashboard, and to be validated by the end-users. The appropriate type of UI components required are selected in the implementation

of the dashboard. A graphical web-based front-end dashboard will be developed to facilitate the visualisation of data from EMF measurements, analytical models and biological investigations, together with practical guidelines, tools and applications, thus supporting public authorities and regulators with scientific evidence to implement exposure directives and improving risk assessment, management and communication. The dashboard will rely on open standards to gather data, adhering to the Findable, Accessible, Interoperable, Reusable (FAIR) principles, from the NextGEM platform thus enabling the interfacing between the back-end system and the dashboard for easy and secure communication and data transfer. This can fulfil the need raised by various national and international organizations since EMF data will be publicly accessible by the NextGEM dashboard. The organizations in question may serve the general public or be connected to special interests such as trade unions, environmental organizations, trade and industry organizations, standard-setting bodies etc.

The NextGEM Citizen Application will empower end-users, i.e. citizens, consumers, and communities to (i) easily and effectively receive practical guidelines for exposure prevention and reduction; (ii) coherently monitor in a simple way their exposure based on their location, and (iii) interact dynamically and efficiently with existing EMF exposure initiatives. This can enable effective behavioural changes towards appreciation of risk and protection in a logical manner. The application is to be designed and implemented in the form of an Open Geospatial Consortium (OGC) compliant web service, with front-end web-based Human Machine Interface (HMI) dashboard and APIs based on open standards. The application will be designed to pull processed data from the NextGEM platform and present it in a meaningful way to citizens and consumers. It will also use open APIs for interfacing relevant external data sources from libraries and online platforms to integrate existing initiatives and EMF monitoring tools (e.g. provided by regulatory bodies).

B. Human Risk Assessment Tool

A Risk Assessment (RA) tool will be developed for performing risk assessment of RF-EMF exposure and selected health outcomes, to support public authorities and regulators in assessing the risk of workers and the general public. The risk assessment for human health in complex multi-factorial exposure environments is based on i) hazard identification and characterization, ii) exposure assessment, and iii) risk characterization which combines the results of the hazard and exposure assessments. Necessary data for RA will be obtained from internal project activities on exposure assessment and hazard identification/characterization, complemented by available literature data. To create a successful RA tool, the following methodology will be used:

Step 1 Identification of requirements for human risk assessment models to accommodate different exposure and health situation scenarios. Further, output information criteria will be identified and output formats and modules, in a range

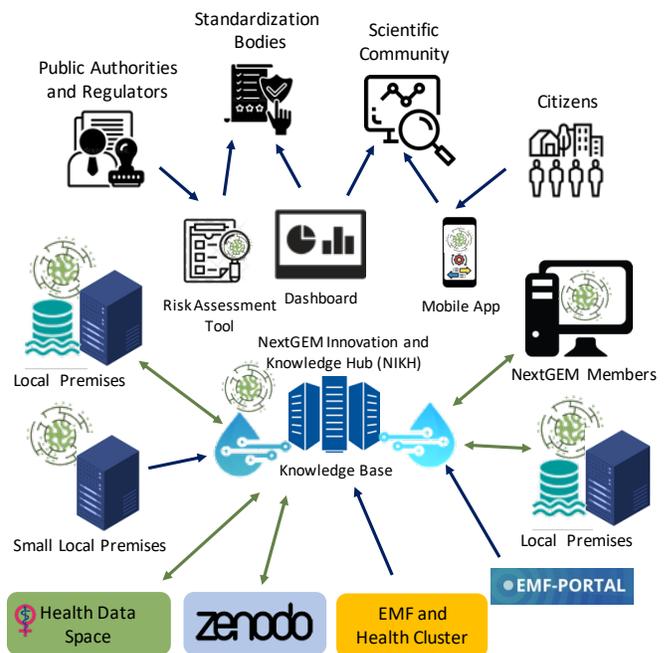


Fig. 3. NIKH Connection with EMF Stakeholders

of existing/novel control banding/risk management, predictive exposure and RA models, will be identified.

Step 2 Identification of existing hazard, exposure and RA models accommodating the required needs: Suitable existing human RA models will be identified and categorized depending on their best match regarding the model elements and output format required, including applicability to NextGEM case studies. The input parameters for the identified models will be specified and summarized. Results from NextGEM experiments including omics may feed back into the development of biological mechanism-based hazard models.

Step 3 Model refinement and establishment of integrated RA methods based on results from NextGEM and the user and stakeholder needs: This step will further refine the existing human RA models based on results from the previous step supporting stakeholder needs and opinions. The models will be validated in the NextGEM case studies.

Step 4 Development of a NextGEM RA tool based on experiences from model validation in case studies: Validated RA models will be developed into computational models and guidance documents suitable for the different stakeholders involved in the requirements identification.

The novel RA models and tools for different stakeholders will be integrated into the NIKH platform to proceed to a risk assessment for environmental health and decision-making.

VI. CONNECTION WITH THE EMF STAKEHOLDERS

NextGEM will ensure engagement and awareness with relevant stakeholders to share information about the health impact of exposure to EMF. The acceleration of adoption and application can be done through NIKH and associated tools. These tools will aim to share scientific results and

practical guidelines with external stakeholders to provide them with updates and policy recommendations about potential health risks in real-life scenarios with existing or future EMF exposures. The research directives and innovative approaches can be expressed through the *NIKH* and associated tools, utilizing their capabilities and features, to empower relevant stakeholders to enhance the produced knowledge (Fig. 3). This knowledge and results can be used for public awareness under a set of planning activities, and provide contributions with impact for standardisation bodies.

A. Scientific Community

The research results from the experimental laboratory studies (*in vitro*, *ex vivo*, *in vivo*) and human studies on EMF exposure and supportive horizontal activities, will be made available via the *NIKH* platform. More importantly, the accessibility of such evidence will enable trained personnel, scientists and engineers to continually monitor scientific studies and public health data. *NIKH* can offer the scientific results to develop models for human health risk assessment in different exposure and health scenarios, for identifying existing hazards and exposures, accommodating the required needs based on results from NextGEM activities and stakeholders.

B. Public Authorities and Regulators

Public authorities and regulators need readily available consistent and/or credible scientific evidence of possible health problems caused by exposure to the EMF field (e.g. emitted by cell phones and other sources). The *NIKH* platform can be used as a tool to enhance authority operations and regulation implementation across Europe. All NextGEM open-access publications and contributions of reusable data sets accessible via *NIKH*, can be used as scientific evidence for enforcing the relevant directives and providing abundant evidence to support the regulatory authorities' determination. The public authorities can improve their risk assessment, management and communication through access to FAIR data and robust evidence via *NIKH*, on EMF exposure. In this manner, public authorities and regulators can act proportionately and consistently in dealing with risks to the general public, by basing decisions on accumulated high-quality evidence.

C. Citizen Awareness and Risk Communication

To enable citizen awareness about the new technology advancements and potential health effects, *NIKH* will promote safety and well-being focusing on the scientific evidence of the impact of EMF exposures to public health, and risk-preventing behaviours discarding any unclear or false messages on causal links and potential health effects. The risk communication strategy facilitated by *NIKH* and the NextGEM Citizen Application will effectively engage and inform a large proportion of concerned citizens who are not fully aware of EU/international regulations and standards, and who distrust regulatory authorities and telecom providers. Consequently, it can play a critical role in an effective perception of risks, and can support citizen needs during stressful conditions, caused by a lack of knowledge and self-awareness.

D. Standardization Bodies and International Organizations

The innovative outcomes in terms of both EMF and health will be undertaken towards the standardization bodies and international organizations. *NIKH* aims to promote EMF and health-related outcomes of experimental studies to renowned SDOs and related fora, for the development of quality criteria and standards (CEN, ISO, CENELEC, ITU) international guidelines (ICNIRP), to establish links with EU Committees (SCHEER [10]) and international organizations (WHO, IEEE), and to update EU recommendations/directives with respect to the new RF-exposure scenarios. In the case of 6G, NextGEM outcomes will offer the unique opportunity to establish a discussion with the regulators and standardization bodies before the official deployment of this next-generation technology.

VII. CONCLUSIONS AND FUTURE WORK

The need for assessing the EMF exposure and potential health effects requires the scientific evidence to be accessible to the scientific community and the public. In this work, the design of *NIKH* platform is described as an innovation hub for storage and exchange of relevant knowledge about the next generation of radio frequency EMF to ensure a safe living environment. The next steps of this work include the validation of the designed architecture to exploit the NextGEM outcomes within the EMF relevant stakeholders, standardization bodies and related entities across the EU. Finally, the identification of new opportunities for the extension of *NIKH* capabilities to support the inclusion of the results of other projects and initiatives, will be pursued.

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